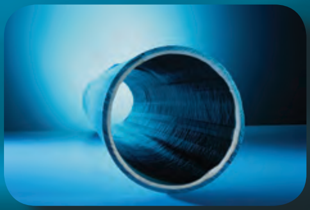
Polynt Composites













Composites Applications Guide

Technical Services

PCAC

PCAC (Polynt Composites Application Center) provides complete composites training on current and emerging composites materials and processing technologies. PCAC training events are free of charge and include publically offered courses and private customer-specific courses. At each event, attendees receive a unique training experience through instruction from a full team of Polynt Composites USA personnel, as well as specialists from other composites industry suppliers. Events consist of Tech-Talk classroom sessions and Demo-Zone workshops for hands-on training.

Polynt Composites Application Center

GEL COAT
APPLICATION AND REPAIR
AUGUST 12-13, 2015

POLYNT COMPOSITES APPLICATION CENTER
821 EAST 16TH AVENUE
NORTH KANSAS CITY, MO 64116

Wednesday ⇨ August 12, 2015

7:30 - 8:00 a.m. Arrive at Polynt Composites Application Center (PCAC) ⇨ Breakfast served on site
8:00 a.m. Welcome to Polynt Composites ➡ Meet the Team ➡ Review the Agenda
8:15 a.m. Chemistry of Polynt Composites Products and Peroxide Basics
9:00 a.m. Break
9:15 a.m. How can I tell if my Polynt Composites products are good? ➡ Hands-on Quality Control
10:00 a.m. Spray Equipment Type Overview
10:15 a.m. Proper Setup of Gel Coat Spray Equipment
11:00 a.m. "Good technique = good results" ➡ Applying Gel Coat
12:00 p.m. Lunch served on site
1:00 p.m. Gel Coat Application Workshop
3:00 p.m. Polynt Composites Gel Coat Product Line Overview
3:30 p.m. Equipment Maintenance and Cleanup ➡ Polynt Composites ➡ Thermoclean Products
4:00 p.m. Gel Coat Application Troubleshooting
4:30 p.m. Wrap-up and review
5:30 p.m. Group dinner

John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
Kelly Potter, Polynt Composites
John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
John Sawayda, Polynt Composites
John Sawayda, Polynt Composites
John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
Don Williams, MVP
John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
Tom Gay, Polynt Composites
John Sawayda, Polynt Composites
TBD

Thursday ⇨ August 13, 2015

8:00 - 8:30 a.m. Welcome back to Polynt Composites Application Center (PCAC) ⇨ Breakfast served on site
8:30 a.m. Gel Coat Patching Basics
9:00 a.m. Gel Coat Patching Workshop
11:30 a.m. Lunch served on site
12:30 p.m. Wrap-up and review
1:00 p.m. ➡ Tour of Polynt Composites Research Facility
Thanks for attending Polynt's Gel Coat Application and Repair School!

John Sawayda, Polynt Composites
Tom Gay, Polynt Composites
John Sawayda, Polynt Composites
Tom Gay, Polynt Composites

Find the full Polynt Composites Application Center schedule and the Polynt Composites Application Guide (Cook Book) online at www.ccpcompositesus.com

Got questions?

Call one of our experts ...

Our Technical Service personnel constantly monitor the dedicated email address and phone number to rapidly respond to your questions related to and including the following:

- Product application
- Product problems
- Product testing or requests for data
- Product recommendations
- PCAC schools
- Project status

Our goal is to respond within 2-4 hours of your inquiry.

Contact Us

Phone: 800-821-3590, ext. 6245
816-391-6245

Email: TechService@polynt.com

Educational Videos

We have several educational videos to complement our classroom training sessions:

- How to Set Up a Good Spray Fan Pattern
- How to Spray Gel Coat
- Troubleshooting Dimples in Gel Coat
- How to Build a Mold Using OptiPLUS®
- How to Repair Gel Coat

Stay tuned for more videos in 2015 and 2016!

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Carpentersville, Illinois

Chatham, Virginia

Centralia, Washington

Ennis, Texas

Forest Park, Georgia

Houston, Texas

Lynwood, California

Marshall, Texas

North Kansas City, Missouri

Orlando, Florida

Sandusky, Ohio

U.S. Sales & Marketing

Polynt Composites USA’s Sales & Marketing Departments are located at its headquarters in Carpentersville, Illinois. Regular business hours are Monday through Friday 7:30am-4:30pm CST.

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Fax: 800-538-7329 / 816-391-6215
International Orders: 816-391-6260

Email: CustServ@polynt.com

U.S. Technical Service

Our technical service hours are Monday through Friday, 7:30am-4:30pm CST.

Tel: 800-821-3590, ext. 6245

Email: TechService@polynt.com

Polynt Composites Canada

www.ccpcomposites.ca

Polynt Composites USA has four locations across Canada with our head office located in Brampton, Ontario. Our warehouses maintain inventories of all the materials necessary for composites manufacturing. We offer distribution across Canada, so please contact your nearest branch for service.

Canadian Distribution Branches

Cape Sable Island, Nova Scotia	902-745-2855
Brampton, Ontario	905-495-0606
Winnipeg, Manitoba	204-668-4900
Drummondville, Quebec	819-477-4516

PREFACE

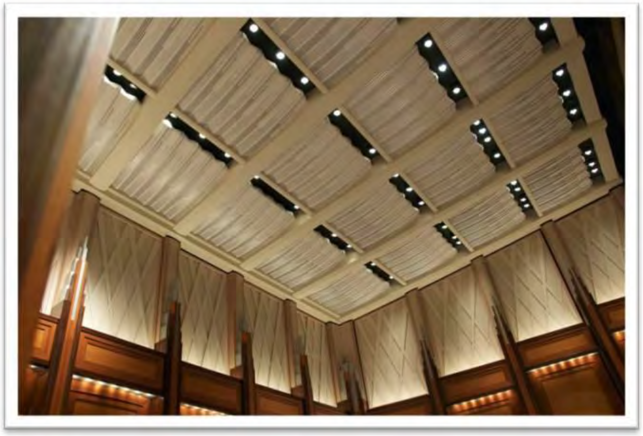
About Polynt's Composites Applications Guide

The Applications Guide, also known as the "Cookbook," is an indispensable resource guide for the latest in composites technology. This book includes hands-on practical experience and expert advice from Polynt Composites' skilled scientists and engineers. It serves as a valuable "how to" guide for composites builders when making decisions about product selection, ideal application techniques, processes, equipment, safety, industry standards and environmental regulations.

The Applications Guide has changed significantly since the first edition was published in 1969. Over the years we've continued to add content to keep you informed about the latest composites technology. We've moved from a printed 'Cookbook' to a modernized, 'live' and interactive web design. Our new format is more user-friendly, provides better search capability, and includes more graphics and visual aids. The 'live' web format allows us to continually refresh the content to keep you up to speed on the latest changes in our industry. We hope this guide will serve not only as a tool in support of the products you make, but as an important element in our ongoing business relationship.

A Word to Our Valued Customers

As your partner in the composites industry, Polynt Composites is committed to your success. Customer satisfaction and product quality are the highest priorities at Polynt Composites. It is our goal to more than meet the expectations of our customers. Our commitment goes well beyond the research, development and manufacture of the most innovative and highest quality products on the market. Polynt Composites is also dedicated to customer education to help you get the most out of our products over their full life cycle from production selection, purchase, application and field service. Along with the information in this guide, Polynt Composites offers additional educational resources, including 'hands-on' educational sessions through Polynt Composites Application Center (PCAC), complemented with 'how to' videos, and onsite training and troubleshooting from our expert technical service staff.



As always, we welcome your comments and suggestions.

New in This Edition

We have updated the following sections or chapters:

Chapter 2 – FRP Composites: Flame Retardant FRP Composites	• Added demonstration pictures of flame retardant material
Chapter 4 – Open Molding-Field Service: Swimming Pool Recommendations	• Moved from Chapter 8 to Chapter 4 • Added Polycor® 960SW and Shimmer® 946SW gel coat information; also Shimmer patching procedure
Chapter 8 – Open Molding-Field Service: Patching	• General revision • Added references to videos
Chapter 12 – Tooling: Building a Mold	• Added references to video • Added pictures from video
Chapter 14 – IMEDGE® Products	• Added IMEDGE® HPC610

About This Document

This document contains the following features to help users navigate:

- Bookmarks (matching the structure of the Table of Contents)
- Links within the Table of Contents (to each respective chapter or section)
- Links within the chapter and section Overview blocks (to each respective section)
- Links from chapter and section references within the text (to the respective chapter or section)

To use these features, simply select the bookmark or link to move to the desired chapter or section within the document.

Recently Released Videos

Recently released on the Polynt Composites website:

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1. Health, Safety and the Environment

Overview

- **Introduction**
- **Regulations**
- **Safety**
- **Fire Hazards**
- **General Hazards of Materials Health Hazards**
- **Electrical Hazards**
- **Equipment Hazards**
- **HSE Information**

1.1. Introduction

Health, safety, and the environment are of prime importance to all manufacturers, especially those handling hazardous materials and chemicals. This has become a very complex issue with numerous federal, state and local regulations. Each user of a chemical product, such as polyester resin and gel coat, must comply with federal, state and local laws that regulate production, employee exposure, emissions, and shipping of hazardous materials and waste.

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The following information is of a general nature only. Compliance requirements must be determined by the user of the product. Information concerning the hazards of these products can be found in the Safety Data Sheet (SDS) and label for each product. These documents must be read. Polyester resins and gel coats can be handled safely when proper precautions are taken to protect workers, facilities, and the environment.

Polynt products are intended for industrial users only. Sales to private individuals and home consumers is not recommended nor endorsed. Polynt does not sell products (nor recommend that they be sold) to private individuals for repairing their boats, tubs/showers, lawn furniture, swimming pools, spas or saunas, farm implements or equipment, automobiles, etc. There are plastic supply firms and automotive retail outlets that have products available for fiberglass repair.

Information concerning health and safety regulations can be obtained from OSHA, EPA, state and local government offices or their websites. At the end of this chapter is a list of references, including websites, where more detailed information can be obtained.

1.2. Regulations

1.2.1. Federal Regulations

The OSHA Hazard Communication Standard, 29 CFR 1910.1200, requires employers to evaluate chemicals used in their workplaces to determine if they are hazardous and to transmit information on hazardous chemicals to employees by means of a comprehensive training and in-plant hazard communication program.

OSHA establishes permissible exposure limits (PELs) for certain chemicals, such as styrene, which has an industry voluntary standard for permissible exposure of 50 ppm, and an OSHA PEL of 100 ppm.

SARA TITLE III (EPA, 40 CFR 355) requires emergency planning, chemicals inventory reporting, and toxic chemical release reporting.

The Resource Conservation Recovery Act (RCRA) includes ‘cradle-to-the-grave’ regulations, governing the generation of storage, treatment, and disposal of hazardous waste.

The Clean Air Act Amendments of 1990 (CAAA) regulate emissions of hazardous air pollutants (HAP) and volatile organic compounds (VOCs). Under the Clean Air Act, two National Emissions Standards for Hazardous Air Pollutants (NESHAP) have been promulgated that limit the HAP emissions from FRP processes. These NESHAPs govern reinforced plastic composite production and boat manufacturing. The NESHAPs establish HAP emissions standards based on the Maximum Achievable Control Technology (MACT).

The Department of Transportation regulates shipment of hazardous materials and wastes.

1.2.2. State Regulations

State and/or local regulations must be at least as stringent as the federal requirements.

California regulations place limits on VOC emissions of resins and gel coats by limiting monomer content and requiring specific application methods.

California also requires the label or data sheet to state the amount of any VOCs in that product.

California Proposition #65 prohibits releases of certain chemicals into drinking water and requires 'clear and reasonable' warning to persons potentially exposed to carcinogens and reproductive toxins.

Other states, such as New Jersey and Pennsylvania, have regulations concerning hazardous materials.

Federal, state and local regulations are constantly changing. Publications and trade organizations, such as the ACMA or NMMA, are good sources for tracking regulatory information.

1.3. Safety

Polynt Composites encourages its customers to develop a Safety Management System. Safety is the responsibility of every employee. Fire losses and worker illnesses and injuries have occurred where good work practices were not established or enforced.

The Safety Management System should designate the person(s) responsible for the written safety programs (Hazard Communication, Personal Protective Equipment, Lock-out/Tagout, Confined Space Entry, Exposure Control, Disaster Control, etc.) and employee training. Supervisors and employees should be aware of hazards (see SDS), necessary precautions, and incident reporting responsibilities.

Periodic safety inspections are recommended. Safety Data Sheets (SDS) and other safety data for all hazardous materials found in the workplace must be kept on-site. All employees, supervisors, and workers should be aware of proper handling and cleanup directions when handling any hazardous material.

Polynt strongly recommends that its customers establish an Emergency Action Plan or Emergency Response Plan for each facility.

1.4. Fire Hazards

A fire is dangerous, destructive, and costly. It can start from a simple cause or a complicated one. Knowing how fires start is the foundation to knowing how to prevent one.

To sustain a fire, there must be:

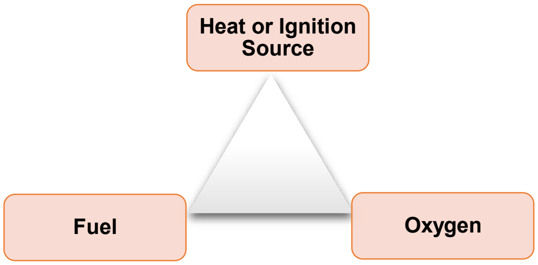


Figure 1-1. Requirements to sustain a fire.

If you remove any of these factors, a fire cannot occur.

1.4.1. Fuel

Quantities of a fuel source are required for a fire. Resins or gel coats, in the liquid state, are flammable fuel sources. Resins or gel coats can also be combustible fuel sources when cured, or as a dust. Most cleanup solvents, catalysts, and waxes are fuel sources. Composites plants have the usual fuel sources of paper, rags, wood, cardboard boxes, trash, etc. All fuel sources must be carefully controlled and minimized.

Resins and gel coats are found in four states in a plant:

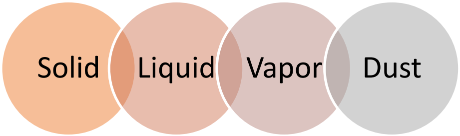


Figure 1-2. Four states of resins and gel coats.

Vapors and dust are typically the most dangerous. Excess vapors and dusts must be avoided. Keep containers closed or covered when not in use. Controlled dust should be reduced and not allowed to accumulate.

Vapors are created from spraying, heating from curing parts, evaporation, etc. Vapors from resin and gel coat are heavier than air (sink to the floor) and may collect in low spots. Vapors and dust can normally be removed from a plant by effective mechanical ventilation.

NOTE: Check for federal, state, and local codes on exhausting and/or discharging any materials directly into outside air. These regulations must be followed.

Flammable liquid resin and gel coat are also dangerous. It is essential to keep uncatalyzed resin and gel coat in closed containers when not in use, and stored in a separate area away from the work area until needed. Do not store in direct sunlight or where excess heat is present. Wipe up or remove all spills or overspray as soon as possible.

Liquid catalysts (peroxides) must be handled according to the manufacturer's recommendations. Organic peroxides can be explosive and are the most dangerous fuels in a plant because they provide oxygen and fuel to a fire. They should be kept in their original containers, out of direct sunlight, not exposed to heat, free from contamination, and closed when not in use.

Catalysts are oxidizing materials which will react, at times, explosively, with reducing agents, such as cobalt accelerators, metals, and strong acid. A catalyst should never be diluted with acetone. If a diluted catalyst is necessary, use catalysts obtained from a catalyst manufacturer or those diluents recommended by the catalyst's manufacturer.

Catalyst must always be kept or used in containers which will not react with the catalyst. See the catalyst manufacturer's SDS for specific recommendations. Overspray and catalyst mist must be minimized. Overspray must be wiped up and removed immediately according to the manufacturer's recommendations.

Special care must be taken with catalyzed resin or gel coat (e.g., oversprays and gun flushings, as these mixtures have the individual hazards of all the combined materials of resins or gel coats, catalyst, solvent, etc.). In addition, the chemical reaction between the resin or gel coat and catalyst produces heat which can possibly cause ignition of solvents, unmixed or high concentrations of catalyst, and other flammable materials. The amount of heat generated will depend on the amount of catalyst, the degree of mixing, the temperature, the mass, and the reactivity.

Catalyzed resin or gel coat must not be allowed to accumulate. Gelled masses and sanding dust should be removed at once or temporarily immersed in water until they can be removed.

Plant solid waste must be handled carefully. Trimmings, overspray and trash have thin ragged sections which can be ignited. Trash should not be allowed to accumulate. The cured parts are harder to ignite, but will burn.

Likewise, any finely divided solid material may present a fire or explosion hazard when dispersed and ignited in air if the following conditions are met:

- The dust is combustible.
- A cloud is formed exceeding the minimum explosive concentration.
- A source of ignition is present. Dusts should be minimized and not allowed to accumulate.

Wax mold release agents are also fuel sources. Care and caution must be used with these materials and the materials used in their application and removal. See the manufacturer's SDS for instructions for handling, use, and storage.

1.4.2. Oxygen

Oxygen is necessary for any fire. There are two main sources of oxygen: air and chemically combined oxygen in the material itself. All volatile materials must be within certain ratios with air or oxygen to burn or explode. With polyesters (resins or gel coats), good mechanical ventilation can dilute the fuel below its explosive limit.

Peroxides are a special case. Peroxides contain chemically combined oxygen which can be easily liberated for combustion by heat, chemical reaction, decomposition, contamination, etc. Since peroxides are also fuels, all that is required for starting a fire is heat or a source of ignition.

Because of this, peroxides require additional care to be used safely. Storage should be separate from other flammable or combustible materials. Close containers when not in use. Spills, gun flushings, and oversprays should be removed immediately. See the manufacturer's SDS for recommendations.

1.4.3. Heat

Heat or a source of ignition is necessary for a fire. This can be a match, cigarette, flame, hot filament, exotherming resin or gel coat, heater, pilot light, spark (metal or hard surface or static), arcing of an electric motor or wires, etc.

Dusts and vapors require a smaller ignition source than liquids or cured parts to start a fire.

To avoid these hazards, ignition sources must be removed from spray areas, working and storage areas.

One source of heat that must not be overlooked is from the chemical reaction of resin or gel coat and/or peroxides. Polyesters produce heat when they gel and cure. The amount of heat produced depends on the amount of catalyst and its degree of mixing, the temperature, the mass, the resin to filler ratio, and the reactivity.

Trimmings, overspray, flushed material from spray guns, and dust from sanding and grinding should be removed at once or temporarily dispersed in water until they can be removed.

A good safety program works to remove, control, or minimize all three elements.

The following results indicate that closed cup flash points are lower than open cup flash points. This data also shows that the addition of acetone to a gel coat significantly lowers the flash point.

Table 1-1. Closed cup flash points.

Flash Point	
Material	**Flash Point (approx.)**
Acetone	0°F
Methyl Ethyl Ketone	20°F
Ethyl Acetate	24°F
Styrene	88°F
Polyester Gel Coats	79 to 88°F
Methyl Methacrylate	51°F

Polynt does not recommend the addition of acetone or any other solvent to resins or gel coats.

The following extinguishing agents may be used on resin or gel coat fires:

- Foam
- Dry chemical
- Water fog
- Carbon dioxide

If electrical equipment is involved, the use of foam or water should be avoided.

NOTE: Direct streams of water may spread a fire involving solvents or monomers due to incompatibilities and density differences. The burning material often floats on water.

By properly handling catalysts and accelerators, controlling vapors, and keeping the shop safely clean, much can be done to reduce the risk of fire. With these factors controlled, a composites operation is relatively safe.

1.5. General Hazards of Materials

1.5.1. Catalysts (Initiators)

Read the SDS for all catalyst products. The catalysts required for curing resins and gel coats are usually organic peroxides, such as methyl ethyl ketone peroxide (MEKP) and benzoyl peroxide. By their nature, organic peroxides are usually highly flammable and may decompose explosively.

Initiators are tested for heat sensitivity, shock sensitivity, burning rate, flash point, storage stability, and reaction to blasting caps to determine their relative hazards.

Obtain the manufacturer's SDS and product information to learn more about how to safely dispose of unwanted or old initiators.

According to NFPA 43B, incompatible materials (such as accelerators) and flammable liquids should not be stored within 25 feet of organic peroxides. The effective separation distance should be maintained by floor slope, drains, dikes, a two-hour fire wall, or a detached storage building to prevent flammable liquid leaks from entering the organic peroxide storage area.

Only closed containers should be permitted in the storage areas. No more than a one-day inventory quantity of initiator should be brought from storage into the work area.

Initiators should never be added or allowed to contact accelerator which has not been added and well-mixed with large, diluting quantities of resin or gel coat. The best procedure is to first mix accelerator into the resin until a homogenous mix is obtained, then add the initiator. See manufacturer's handling precautions.

A very small amount of peroxide initiator can make drastic changes in the physical properties of a resin or gel coat. Polynt emphasizes the importance of following the proper procedures in handling the commercial forms of these products. Failure to do so can lead not only to poor performance of the initiator but also, in some instances, to a violent polymerization or decomposition.

Storage conditions and contamination are potential sources of risk in handling peroxide initiators:

A. **Heat**— Do not expose organic peroxides to any form of heat, such as direct sunlight, steam pipes, radiators, open flames, or sparks. Heat may cause organic peroxides to decompose violently, and they will burn if ignited. Never exceed the peroxide manufacturer's recommended storage temperature or conditions.

B. **Metals**—Do not let organic peroxides come in contact with easily oxidized metals such as copper, brass, and mild or galvanized steel. If replacement parts must be installed on peroxide handling equipment, use the same materials of construction as specified by the manufacturer of the equipment.

Metal contamination, such as dust from grinding, can produce serious consequences. For example, the installation of a brass relief valve on a catalyst pressure pot or a brass connector in a catalyst line could cause the peroxide that comes in contact with the brass to decompose. Under such confined conditions, the decomposing peroxide could develop enough pressure to burst the pressure pot or the initiator line.

C. **Promoters and Accelerators**— never mix organic peroxides directly with promoters or accelerators. Such mixtures can be explosive. In addition, never contaminate initiators with resin or resin overspray because the resin may contain enough promoter to decompose the peroxide. A small amount of promoter goes a long way. Promoters are not consumed; they just continue to decompose the peroxide. The peroxide decomposition produces heat. This heat speeds up the action of the promoter, which then produces more heat. The cycle can continue until the point is reached where the remaining peroxide decomposes violently.

D. **Solvents or Diluents**—If a solvent is used to clean organic peroxide handling equipment, be sure to dry off the solvent before using. Some solvents, such as acetone, can react with peroxides to form unstable peroxides of their own. Small amounts of these unstable 'solvent peroxides' can cause the explosive decomposition of commercial peroxides.

If it is necessary to dilute an organic peroxide, be sure to consult with the peroxide manufacturer for compatible solvents. Never use contaminated solvents. Never use reclaimed solvents unless they have been tested by the peroxide manufacturer. For greatest safety, obtain the manufacturer's diluted organic peroxides.

Always store an organic peroxide in its original container. If it is necessary to transfer or measure out some peroxide, use clean polyethylene, polypropylene, Teflon®, or stainless steel containers, funnels, etc.

E. **Other**—Other types of contaminants to be avoided when working with organic peroxides are dirt, resin or gel coat sanding dust, acids, bases, and styrene. Further information on the proper handling of peroxides is available on request from catalyst manufacturers.

Basic guidelines regarding organic peroxides

A. Read the SDS (Safety Data Sheet).

B. No smoking around peroxides (or any polyester or associated materials).

C. Organic peroxides and promoter (for example, MEKP and cobalt) should NEVER be mixed directly with each other—a violent reaction will occur!

D. Organic peroxides should always be stored separately from promoters. Consult local insurance inspection bureau and fire authorities for guidance.

E. Organic peroxides should not be allowed to 'sit around.' Take only as much as will be used during each shift. If the peroxide is transferred into another container, use a container made of a suitable material such as polyethylene.

F. Always wear eye protection. Rubber gloves and face shields are also recommended.

G. Organic peroxides should not be stored in a refrigerator that also contains food or water, nor should they be poured into or stored in containers that could be mistaken for other items, such as a soda pop bottle, baby bottle, etc.

H. Dilution of organic peroxides by the end user is not recommended.

I. Although the flash point of some organic peroxides is higher than other chemicals usually found in the typical composites operation, it is misleading to think that peroxides are 'safer' with regard to fire. While it will take a hotter temperature to get them to burn, they will decompose and auto-ignite sooner than the other chemicals. The decomposition temperature is 145°-170°F.

J. Do not expose organic peroxides to any form of heat such as direct sunlight, steam pipes, radiators, open flames, or sparks.

K. Do not let organic peroxides come in contact with easily oxidized metals such as copper, brass, and mild or galvanized steel.

L. Most organic peroxide suppliers have safety programs available (including videos or CDs). Contact the supplier to request a product stewardship visit.

M. Always store organic peroxides at or below the recommended temperature as specified by the manufacturer.

N. 'Red' organic peroxides are believed by some to be less stable than clear. Rotate inventory of red organic peroxides frequently.

These safety considerations are not all inclusive. The organic peroxides supplier should be contacted for specific safety recommendations.

1.5.2. Accelerators

Read the SDS. Some of the accelerators commonly used are extremely hazardous. Diethylanaline (DEA) and dimethylanaline (DMA) are particularly hazardous since even small splashes may be absorbed through the skin, resulting in contact dermatitis. Headache, nausea, breathing irregularities, or fainting may occur soon after breathing vapors of these materials. If excessive quantities are inhaled, even more severe reactions, including poisoning or death, may occur.

1.5.3. Styrene and Solvents

Read the SDS. Some monomers and clean up solvents used may have health effects. Physiological health problems may occur from overexposure. For specific information regarding the health hazards of specific products, consult the manufacturer's SDS.

The accumulation of styrene and solvent vapors provides one of the conditions for an explosion or flash fire. A static charge or simple spark ignition source is all that is needed. Vapors should be immediately removed by a good ventilation system.

California Air Quality Management District rules require that the maximum loss of volatile organic compounds (VOCs) for all VOC-containing products packaged in quarts or larger be reported. This includes Polynt's gel coat and resin product lines.

As a result, a series of tests were performed according to the Standard Method for Static Volatile Emissions on catalyzed polyester resins and gel coats. The maximum quantity of VOCs not consumed during polymerization was found to be 40 grams per liter (or 230 grams per meter considering surface area exposed to air) for all catalyzed Polynt resins and gel coats measured in a gallon can lid. For all uncatalyzed Polynt resins and gel coats, the maximum VOC content is 600 grams/liter.

Copies of this VOC content information should be retained and available for compliance inspections.

Depending on the application equipment, the temperature, and gel time, gel coats may lose 20 to 25 percent of the pounds sprayed, or up to 65 percent of the monomer(s) present.

Styrene, a typical monomer, can be lost from gel coats in two ways. When gel coat is atomized, styrene evaporates as the gel coat travels from the end of the gun to the mold. The loss of styrene at this point is controlled by temperature, method of atomization, spray distance, and the degree of breakup (atomization).

The second loss occurs as the gel coat cures on the mold. During this time period, the loss is governed by the evaporation rate of styrene. Once the surface film is gelled, the evaporation rate drops off dramatically. This loss of styrene is influenced by the gel time, temperature, film thickness, surface area, mold configuration, and air movement.

Styrene monomer is flammable and forms explosive mixtures with air.

- The lower explosive limit is 1.1% (by volume).
- The upper limit is 6.1% (by volume).

When styrene vapor is present in concentrations between these limits, any source of ignition can cause an explosion.

Table 1-2. Styrene ignition temperatures.

Styrene Ignition Temperatures	
Flash point is the lowest temperature at which a substance gives off enough vapors to form a flammable or ignitable mixture with air near the surface of the substance being tested.	Flash point of styrene is 31°C (87.8°F)
Fire point is the lowest temperature at which a liquid in an open container will give off enough vapors to continue to burn when ignited. Fire points are generally slightly above flash points.	Fire point of styrene is 34°C (93.2°F).
Auto-ignition temperature is the lowest temperature required to initiate or cause self-sustained combustion in the absence of a spark or a flame.	Auto-ignition temperature of styrene is 490°C (914°F).

Adequate ventilation (especially the use of fume hoods) is recommended. Open flames, local hot spots, friction, and static electricity must be avoided.

1.5.4. Disposal of Cured Unsaturated Polyester

Discarded solid plastic materials from a manufacturing process utilizing unsaturated resins or gel coats cured with organic peroxides, like methyl ethyl ketone peroxide, constitute an industrial solid waste. As required by 40 CFR 262.11 (and corresponding applicable state regulations), the generator of this waste is required to determine if it is a hazardous waste.

This process involves determining if the solid waste is classified as a listed hazardous waste, either as a discarded commercial product (40 CFR 261.33), as a specific source waste (40 CFR 261.32), or as a nonspecific source waste (40 CFR 261.31). The generator must then determine whether the waste meets the characteristics of hazardous waste defined in 40 CFR 261, Subpart C.

These defined characteristics are shown in Table 3.

Table 1-3. Defined characteristics of hazardous waste.

Defined Characteristics of Hazardous Waste			
Ignitability	Corrosivity	Reactivity	Toxicity

Since the waste is not a liquid with a flash point of less than 140°F, a non-liquid which may ignite spontaneously or by friction, an ignitable compressed gas, or an oxidizer, it does not exhibit the characteristics of ‘ignitability.’ Likewise, the waste does not exhibit the characteristics of ‘corrosivity’ (aqueous pH less than two or greater than 12.5 or corrodes steel), or of ‘reactivity’ (i.e., normally unstable, violently water reactive, or capable of generating toxic gases, vapors or fumes in contact with water). Depending on the level of methyl ethyl ketone peroxide used, the solid waste may be classified as hazardous because of toxicity. Methyl ethyl ketone is listed in Table 1 of 20 CFR 261.24.

All generators of solid wastes of this nature should retain a written determination in their records with documented data or generator knowledge on waste profiles for all wastes which they generate. This is required by federal and state regulations.

1.6. Health Hazards

Read the SDS for health hazard warning information for all materials used in the workplace. Most materials used in a manufacturing facility may be hazardous if not properly or carefully handled. Each chemical should be considered separately, and looked at in reference to other chemicals with which it can come in contact or react with to produce new chemicals. Chemicals may enter the body through several routes of entry, including inhalation, ingestion, absorption, or injection. Consult the SDS (Safety Data Sheet) to determine acceptable exposure levels and emergency response procedures.

Both the OSHA Hazard Communication Standard and certain state regulations require that manufacturers place precaution labels on containers of manufactured products, and provide the SDS to each customer that lists the acute (immediate) and chronic (delayed) hazards of their products.

Contact with hazardous materials must be minimized. Resins, gel coats, solvents, initiators, etc., should not come in contact with the body. Where contact is unavoidable, protective equipment (clothing, gloves, etc.) should be used and all spills cleaned up at once.

Safety glasses or goggles must be worn at all times in all working areas.

If the possibility of vapor or dust is present, adequate ventilation is necessary. NIOSH-approved ‘hood-type’ supplied air respirators are recommended for applications with high vapor or dust levels.

NOTE: Air supplied to the hood must be absolutely clean and separate; no exhaust vapors or compressor oil. All dusts should be removed by adequate ventilation and with an adequate face mask being worn. Do not use air to blow dust off a person. Remove by washing with cool water.

Pigments used by some gel coat suppliers may contain lead and hexavalent chromium compounds. OSHA regulations require workplaces with lead-containing materials to monitor worker exposure. Because of the number of recognized health hazards associated with the use of lead and heavy metal pigments, Polynt does not use lead or heavy metal pigments in its resin or gel coat products.

Two types of lead/chromium pigments used by some gel coat suppliers are described as:

Chrome Yellow

- Classified as Light and Primrose.
- Contains Lead Chromate.

- Lead is a reproductive toxin and affects various body systems and organs adversely.
- Hexavalent Chromate is considered a respiratory carcinogen.

Moly Orange

- Bright Orange and Scarlet shades.
- Is a compound of Lead Chromate, Lead Molybdate and Lead Sulfate.
- Has the same lead and chromate hazards as chrome yellow.

Many states have regulations to control the use and waste disposal of mixtures containing lead and hexavalent chromate. The OSHA Occupational Exposure to Lead Standard, 29 CFR 1910.1025, defines requirements of workplaces with employees who may be exposed to lead. **Compliance procedures required by this standard include:**

A. Make an initial determination of employee exposure by monitoring the work space in which lead may be present.

B. Employee exposure is that exposure which would occur if the employee were not using a respirator.

C. Notify employees within five days of the receipt of monitoring results that represent that employee's exposure.

D. If monitoring results show employee exposure to be at or above the action level of 30 micrograms of lead per cubic meter, additional monitoring is required.

E. If monitoring results show employees are exposed to lead above the permissible exposure level of 50 micrograms per cubic meter, periodic monitoring, medical surveillance, engineering controls, employee notification, and respirators may be required.

If the decision is made to monitor for lead or chromium, qualified industrial hygiene consultants for monitoring and testing services may be obtained by contacting:

American Industrial Hygiene Association

2700 Prosperity Ave., Suite #250

Fairfax, VA 22031

Ph: 703-849-8888

Fax: 703-207-3561

www.aiha.org

1.7. Electrical Hazards

The two main hazards from electrical equipment are sparks and shock. All equipment, power lines, lights and connectors should be explosion-proof and effectively grounded.

All possible sources of static discharge should be eliminated through adequate grounding or other measures. This includes spray guns, holding tanks, transfer lines, etc.

1.8. Equipment Hazards

A composites operation may use many power tools. All tools which have exposed turning parts should have guards to prevent hands and clothing from being caught in them. All persons should be properly trained in the use of power tools. Spray guns should be grounded, worn fittings and hoses replaced.

NOTE: Airless spray equipment develops enough pressure to force material through the skin. Safeguards must be taken to prevent this. Any person who sprays, regardless of equipment type, must be adequately trained and be made aware of how to protect himself and others from these hazards.

Before starting repairs on spray equipment or any equipment with moving parts or internal pressure, turn off and disconnect all power sources and bleed off all internal pressures. Care must be taken with chopper guns because cutting blades and glass roving cut anything with which they come in contact.

Well-run housekeeping and order programs that include trash removal, spill cleanup, and regular equipment and building maintenance will reduce fire and health hazards in the workplace. Such programs save money, promote efficiency, and increase job satisfaction.

1.9. Health, Safety and Environmental (HSE) Information

The references listed below are given as a guide only. This is not meant as a recommendation or endorsement of any of these references or services. They are listed as a sample of the type of information that is available.

There are many sources of information and guidance on health, safety, and environmental matters, for example:

- Company insurance carrier
- Local Fire Marshal
- Suppliers (product stewardship)

Other sources of information are:

Regulations/Compliance

United States Environmental Protection Agency (EPA)

www.epa.gov

United States Department of Transportation (DOT)

www.dot.gov

Occupational Safety and Health Administration (OSHA)

www.osha.gov

American Composites Manufacturing Association
1010 Glebe Road, Ste 450
Arlington, VA 22201
Ph: 703-525-0511
Fax: 703-525-0743
www.acma.org

National Marine Manufacturer's Association (NMMA)
200 E. Randolph Drive, Ste 5100
Chicago, IL 60601
Ph: 312-946-6200
www.nmma.org

Fire Safety

National Fire Protection Association (NFPA)

www.nfpa.org

No. 13 — Sprinkler Systems

No. 30 — Flammable and Combustible Liquids Code

No. 68 — Explosion Venting Guide

No. 69 — Explosion Prevention System

No. 70 — Electric Code

No. 77 — Static Electricity

No. 91 — Blower and Exhaust System

No. 654 — Prevention of Dust Explosions in the Plastics Industry

Chemical Health Hazards

National Toxicology Program (NTP)

National Institutes of Health

www.nih.gov

Styrene Information Research Center (SIRC)

www.styrene.org

International Agency for Research on Cancer (IARC)

World Health Organization

www.iarc.fr

Compliance Guides

J. J. Keller and Associates, Inc.

Ph: 800-327-6868

Labelmaster

Ph: 800-621-5808

Thompson Publishing Co.

Ph: 800-677-3789

Business & Legal Reports, Inc.

Ph: 800-727-5257

www.blr.com

Summit Training Source, Inc.

Ph: 800-842-0466

2. FRP COMPOSITES

Overview

- **Introduction**
- **General Chemistry of FRP Composites Resins**
- **General Properties of FRP Composites**
- **Fabrication of FRP Composites**

2.1. Introduction

Composite materials, commonly called composites, are engineered materials comprised of two or more distinct constituents, or physically and chemically distinct phases. The two main components of a composite are the matrix (continuous phase) and reinforcement (reinforcing phase).

2.1.1. Matrix—envelops and holds reinforcements in place. It functions to protect reinforcements from the environment and inflicted forces, as well as shape the composite. The degree of environmental protection depends on the matrix properties. When a force is imposed on a composite, the matrix transfers the load from the surface of a part, into and between reinforcement materials, diffusing force throughout the part.

Table 2-1. Examples of matrix and reinforcement types

Matrix	Reinforcement
•Polymer •Mud •Pitch •Plastic •Carbon •Glass •Cement •Rubber •Ceramic •Metal •Silicone carbide	•Glass fiber--whiskers (short), chopped, continuous) •Aggregate (clay, gravel, sand) •Silica •Carbon fiber •Aramid fiber •Rebar (steel bar) •Cellulose fiber •Steel mesh •Steel wire

2.1.2. Reinforcement—enhances mechanical and physical properties of the matrix. The reinforcement can take many forms (Table 1). Fiber reinforcements can be unidirectional, multidirectional or randomly oriented.

Since fibers can be oriented in a specific direction, it allows you the ability to construct a part with maximum strength oriented in a desired direction.

2.1.3. Composite—the resulting material has a unique set of attributes and properties that is more useful than the individual constituents. The combination of matrix and reinforcement produces some of the strongest, lightweight and versatile materials.

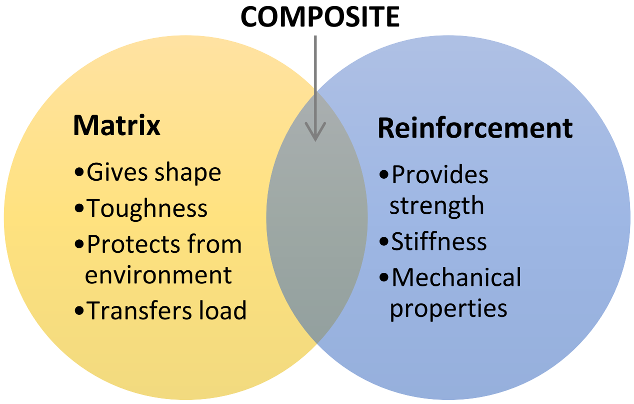


Figure 2-1. Attributes and properties of a composite.

When combined together, the matrix and reinforcement form a wide variety of composites.

Matrix	Reinforcement	Composite
Epoxy resin	Glass fiber	Bridge repair
Dental polymer	Silica	Dental filling
Polyethylene	Recycled wood fiber	Wood-plastic composite (WPC)
Thermoset resin	Glass fiber	Boat hull, deck

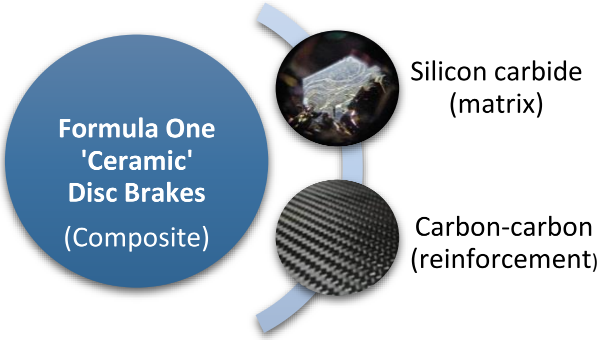


Figure 2-2. A combination of silicon carbide and carbon-carbon fiber make ‘ceramic’ disc brakes for sports cars.

2.1.4. Composite versus Conventional

Composite materials are different from conventional materials in many ways. Conventional materials, such as aluminum, have set properties and characteristics. Composites offer versatility in product design and performance. Composites can be created to have an array of desired properties, such as strength, elasticity, flame retardant, corrosion resistant, and more. An additional benefit is that they can be shaped into a wide range of sizes and complexity, from small intricate parts to large ones. Composites achieve their properties and characteristics only after being successfully processed in the manufacturing facility. Therefore, the material shelf life, storage conditions, and processing temperatures have to be properly managed and controlled.

2.1.5. FRP

Greater than 90% of modern composites use polymeric matrices, commonly referred to as plastic, or resin. Fiber-reinforced plastic (FRP) or fiber-reinforced polymers, are composites made by combining a polymeric matrix and reinforcing fiber, such as glass.

Figure 2-3. Composite industry applications

- Nose cones, radomes, nacelles, fuselage, propeller, spacecraft heat shields, naval submarines, stealth and fighter aircraft

Aircraft / Military

- Windblades, wind turbines

Alternative Energy

- Parts for buses, cars, subways, ferries, military–body panels, cabs, spoilers, trucks, military Humvee (all composite)

Automotive / Transportation

- Repair and /or replacement of bridges, decks, columns buildings, roads

Civil Infrastructure

- Materials for buildings, homes, architectural: wall panels, roofing swimming pools, showers, bathtubs, sinks, panels, facades, theme parks

Construction

- Canoes, kayaks, trailers, bicycle frames, racing car bodies, statues

Consumer

- Parts with chemical resistance: tanks, pipes, pressure vessels, stacks, hoppers, plant scrubbers, ductwork

Corrosion Resistance

- Parts for insulators, housings, utility boxes, panels, antennae

Electrical

- Consumer and commercial boats, ships, naval craft: molds, decks, hulls, naval submarines

Marine

The major subcategory of FRP is Glass Fiber Reinforced Plastic (GFRP or GRP). All three terms are sometimes used interchangeably. This book focuses on glass fiber reinforced composites.

2.1.6. Glass Fiber

Glass fiber reinforced plastics are used extensively throughout the world. These are generally considered commodity-type composite materials. Applications cover a wide range, from consumer, such as canoes, to construction, such as wall panels (Table 2). Almost anything can be molded using FRP.

Glass fibers are composed of a mixture of inorganic metal oxides. The principle constituent is silicone dioxide with smaller amounts of aluminum oxide, calcium oxide, magnesium oxide, boron oxide, and zirconium oxide. Exact composition determines the end-use performance.

There are several commercially available glass types with the most common being E glass, followed by A glass, C and then S glass. Quartz fiber is essentially pure silicone dioxide and features one of the lowest dielectric constants of commercial materials.

2.1.7. Polymer Matrix

Polymers are classified by three types: thermoset, thermoplastic and rubber. Common thermoset polymers are polyesters, vinyl esters, epoxies, polyimides and phenols. They are synthesized in the laboratory using compounds derived from petrochemicals. Thermosetting polymers are resins which undergo a chemical crosslinking reaction during cure, creating a rigid network. Once the polymer resin is crosslinked, it cannot be reshaped when heated. This is in contrast to thermoplastic polymers, such as PET (polyethylene terephthalate, e.g. plastic bottles), which are linear polymers, that can't be crosslinked, but can be heated and reshaped many times.

When a thermoset resin is combined with glass fiber reinforcement, it makes lightweight and durable products Properties of the end-use product depend on the polymer chemical structure and reactivity. For example, unsaturated polyesters (UPRs) can be cost effective and offer good weathering resistance, whereas vinyl esters offer high mechanical properties, heat resistance and toughness.

2.1.8. Molding FRP

FRP parts are molded to the shape design by using a cure tool and a molding protocol. Most cure tools are called molds, although not all molds are curing tools (exception—fiber preforming mold). A cure tool can consist of several elements. At its very minimum, a cure tool consists of a mold skin which mirrors the cured part about its external surface. Larger molds incorporate bracing to reinforce local areas and framing to distribute the mold weight onto concentrated load points such as casters, which also provide for mobility.

2.2. General Chemistry of FRP Composites Resins

Overview

- **Introduction**
- **Synthesis of Polyester and Vinyl Ester Polymers**
- **Types of Polyester and Vinyl Ester Resins**
- **Curing Mechanism**
- **Peroxide Initiators**
- **Accelerators**
- **Suggested References**

2.2.1. Introduction

Thermoset polyester and thermoset vinyl ester polymers are the key ingredients for most Polynt resins and gel coats, and are the basis for RTM, marble, casting, laminating, pultrusion, and molding resins.

These versatile resins are used in a broad spectrum of applications, including:

- Building and construction
- Corrugated and flat paneling
- Reinforcements for acrylic sheet
- Shower stalls, tubs and marble vanities
- Interior and exterior auto body panels
- Polymer concrete and mine bolts
- Electrical components
- Boat and other marine laminates
- Corrosion-resistant tanks and components

Polyester and vinyl ester resins can be formulated from rigid to flexible (or anywhere in between) and can be corrosion and water resistant. The resins are used unfilled, filled, reinforced, or pigmented. Fabricators can cure polyester resins at temperatures that range from ambient up to 400°F (204°C).

When armed with the knowledge of how polyester and vinyl ester resins are made, and how they cure, the fabricator will more readily understand some of the important factors that affect them. This will support good use techniques with fewer problems. Knowledge and experience provide the foundation for efficient production methods and high-quality parts.

This section of the Applications Guide offers a brief description of the chemistry of thermoset polyester and thermoset vinyl ester resins. It is a guide to how these resins are made and how they cure. Further information is available in the references listed at the end of this chapter.

2.2.2. Synthesis of Polyester and Vinyl Ester Polymers

The building blocks for the synthesis of polyester and vinyl ester polymers come from the petrochemical industry with their ultimate source being oil and/or natural gas. Polyesters are comprised of three main types of compounds: dicarboxylic acids (meaning two acid groups per compound), glycols (meaning two alcohol groups per compound), and monomers/diluents. For vinyl esters, the building blocks are primarily di-epoxides, monocarboxylic acids, and monomers/diluents.

To make polyester, the dicarboxylic acids and glycols react together under heat to form a long chain compound called a polymer. Because the acids and glycols react together to form an ester in what is called an esterification reaction, the resulting polymer is called polyester (literally ‘many esters’). Some of the dicarboxylic acids are unsaturated (having carbon-carbon double bonds) and for this reason the polyester is said to be an unsaturated polyester. To form the polymer, the acids and glycols are ‘cooked’ together in a kettle. Cooking times can vary from 14 to 24 hours at temperatures up to 430°F (221°C). The progress of the cooking process, or ‘cook,’ is followed by measuring the reduction in acidity and the increase in viscosity. Water is a by-product of the esterification reaction and boils out of the reaction kettle as it is formed.

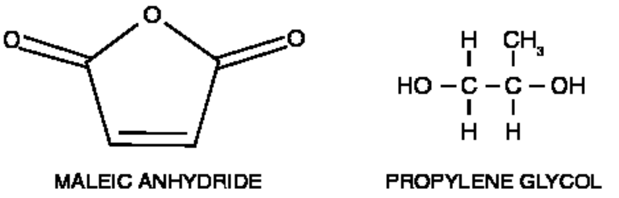
Vinyl esters are also unsaturated esters that are formed via an addition reaction between diepoxides and unsaturated monocarboxylic acids. Since the unsaturated function in vinyl esters typically comes from methacrylic acid or acrylic acid, rather than maleic acid as is the case with unsaturated polyesters, these polymers only have unsaturated groups at the ends of each polymer chain. The ‘cooks’ for vinyl esters are typically eight to 14 hours at temperatures up to about 240°F (116°C). The processing parameters for vinyl esters are very similar to those of unsaturated polyesters; however, no water is eliminated as this is an addition rather than a condensation reaction.

Both polyesters and vinyl ester polymers in their pure forms are generally hard solids; similar to chunks of glass.

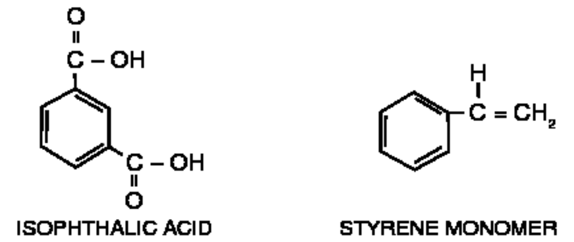
To make these polymers readily usable by the fabricator, they are dissolved in a monomer, usually styrene, which also has an unsaturated group needed for the curing process we will discuss later. When the fabricator adds a peroxide initiator, the unsaturated portion of the monomer reacts with the unsaturated portion of the polymer to form cross-links. The resulting material is a hard solid that will not soften, or melt, even when heated to very high temperatures. For this reason, the resin is said to be a thermoset resin (thermoplastic resins can be remelted, and/or resoftened and then shaped into other articles).

2.2.3. Types of Polyester and Vinyl Ester Resins

The properties of a polyester resin depend on the types and amounts of the dicarboxylic acids, glycols used in cooking the polyester polymer, and the monomer the polyester is diluted in. The most common unsaturated acid is maleic anhydride. Saturated acids such as phthalic anhydride, isophthalic acid, and adipic acid may also be included to impart different properties. Glycols include ethylene glycol, diethylene glycol, propylene glycol, dipropylene glycol, and neopentyl glycol. Styrene is the most common monomer but other monomers that can be used are vinyl toluene, alpha-methyl styrene, and methyl methacrylate. The structures of some of these components are shown in Figure 2-3.



MALEIC ANHYDRIDE PROPYLENE GLYCOL



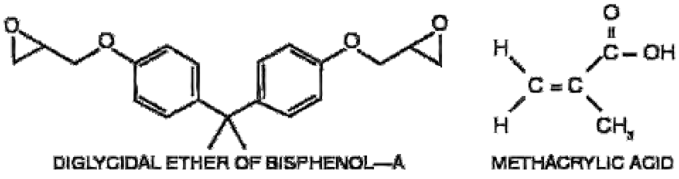
ISOPHTHALIC ACID STYRENE MONOMER

Figure 2-4. Structures of various acids, glycol, and monomer.

Each of these components contributes to the final properties of the resin. Isophthalic acid and neopentyl glycol increase moisture, chemical, and corrosion resistance. To improve resistance to weathering; neopentyl glycol, methyl methacrylate, and stabilizing additives that protect against ultraviolet rays of the sun are used. Adding adipic acid and reducing the amount of unsaturated acid results in a softer resin with increased flexibility. In contrast, to increase rigidity, higher amounts of unsaturated acid are used, sometimes with higher-functionality monomers such as divinylbenzene. These materials result in greater hardness and rigidity by increasing the number, and density, of chemical bonds in the resin as it cures. To alter the flammability characteristics of a resin, acids such as chlorendic anhydride and tetrabromophthalic anhydride are used.

Another building block, generally used in laminating resins, is dicyclopentadiene (DCPD). DCPD replaces some of the glycols and contributes to a faster tack-free time, lower apparent shrinkage, and a smoother surface on cure. DCPD containing resins are primarily used in structural applications which require an excellent cosmetic appearance and reduced fiber print-through.

As with unsaturated polyesters, the properties of vinyl ester resins are very dependent on the choice of the polymer's building blocks. The most common vinyl ester resins employ the diglycidyl ether of bisphenol-A as the diepoxide and methacrylic acid as the unsaturated monoacid. The choices of monomers for vinyl esters are very similar to that of unsaturated polyesters (meaning styrene and methyl methacrylate). The structures of the building blocks for vinyl esters are shown below:



DIGLYCIDAL ETHER OF BISPHENOL—A METHACRYLIC ACID

Figure 2-5. Used in most common vinyl ester resins.

Modifications may include using a novalac epoxy (a multi-functional epoxy), maleic acid, specialized diepoxides, and other mono-functional acids in addition to the basic ingredients mentioned above. The modifications can impart increased strength, increased flexibility, or modified cure behaviors depending on the choices made. Vinyl esters are selected for applications where mechanical strength and/or chemical or water resistance demands are greater than can typically be obtained by conventional unsaturated polyester resins.

In addition to the unsaturated polyester and vinyl ester resins, Polynt markets resin systems that are a combination of both polyester and polyurethane; these are the Polynt XYCON® hybrids. The properties of the hybrids reflect both the polyester and urethane chemistries. The XYCON® hybrids exhibit excellent toughness, crack resistance, fatigue resistance, lower shrinkage, adhesion, water resistance, and speed of cure. They are used as a barrier coat in marine applications to reduce fiber print-through and increased blister resistance. In addition, the hybrids can be formulated for use in structural applications.

2.2.4. Curing Mechanism

As previously noted, after the polyester or vinyl ester polymer is cooked, it is dissolved in monomer (usually styrene) so it is a readily pourable liquid that can be easily used by the fabricator. The ratio of polyester polymer to monomer ranges from about 75:25 to 50:50 parts by weight. Inhibitors are added to the solution to prevent the monomer and the unsaturated acid in the polymer from reacting prematurely.

Both the gel and cure of a polyester or vinyl ester solution takes place by a free radical reaction. In this procedure, peroxide is added to the polymer solution by the fabricator. The peroxide decomposes (splits apart) into two highly energized free radicals that react with the unsaturated portions of the polymer and monomer. The presence of the free radicals, together with the unsaturated functionalities of the polymer and monomer, results in the formation of new chemical bonds that ‘cross-links’ the resin system.

Once cross-linking starts, movement of the polymer in the solution is highly restricted. After only a small fraction of the unsaturated groups have reacted, the solution is gelled. Eventually, the polymer chains are cross-linked by the monomer into one solid, infusible mass that will not soften or melt on exposure to heat. Typically in laminating and casting applications, 80 to 90% of the unsaturated groups will have reacted by the time the part is demolded. The parts will reach 95 to 97% cure in two to four months if kept above 70°F (21°C). Curing is accompanied by the development of large amounts of heat, commonly referred to as exotherm. The heat is the result of the new chemical bonds being formed and this heat also makes the curing reactions proceed even faster.

Inhibitors react very quickly with free radicals and are used to protect the polymer solutions against premature cross-linking until the appropriate peroxide initiator is added by the fabricator. Free radicals can form naturally in the resin, and will form faster if the polymer solution is exposed to heat and/or sunlight, or is contaminated with metals or other materials. For this reason, it is important to store polyester resins in a cool, dark place as recommended on Polynt’s technical data sheets.

Factors that affect the curing reaction are:

- **Temperature of the Resin**—The time to gel and cure the resin will be reduced in half with each increase in temperature of 18°F (10°C). Conversely, the time to gel and cure the resin will double with each 18°F (10°C) decrease in temperature. If the temperature gets too low, the polyester may never cure properly.
- **Mass**—The amount of resin, and its shape, will affect the rate of cure. A thick casting will cure faster than a thin laminate because the casting will generate more heat and will hold the exothermic heat better than the laminate. Very thin laminates may require a source of external heat to cure properly.
- **Peroxide Initiator**—The type and amount of peroxide is based on the resin and the curing conditions. Polynt data sheets specify types and amounts of peroxides. Peroxide initiators are discussed in this section.
- **Accelerators**—These additives increase the rates of reaction between the free radicals and the unsaturated groups. Polynt adds accelerators (also called promoters) to its resins. Accelerators are discussed in this section.

2.2.5. Peroxide Initiators

The function of the peroxide is to initiate the cross-linking reactions in the resin. The cross-linking will first cause the solution to gel and then cause the gel to completely cure. When peroxide is added to a resin, heat and/or the accelerators in the resin decompose the peroxide into free radicals. The free radicals first consume the inhibitor present in the resin and then react with the unsaturated portions of the polyester polymer and the monomer. The reaction product between an unsaturated compound and a free radical results in a second free radical which then reacts with another unsaturated group. This forms a third radical, etc., etc., and cycle continues until the cross-links are formed. The whole process stops when the free radicals are no longer mobile enough to contact other unsaturated groups. This lack of mobility occurs when the viscosity of the curing system becomes very high. The remaining groups slowly cross-link as the part ages or when it is heated in a postcure step by the fabricator.

Some of the peroxides used to cure polyester and vinyl ester solutions are very unstable at room temperature and must be stored under refrigeration. Because peroxides and accelerators react explosively, they should never be mixed directly together. For this reason, resins for use at room temperature generally come preaccelerated (or prepromoted). If additional accelerator or promoter is needed, it should be mixed thoroughly into the resin before the peroxide is added. The precautions listed on the Safety Data Sheet for each peroxide should be strictly observed.

Curing of polyester and vinyl ester resins can be divided into two groups: room temperature (65 to 95°F (18 to 35°C)) and elevated temperature. Curing at elevated temperatures generally takes place in heated tools or molds at temperatures from 180 to 320°F (82 to 160°C). Peroxides for use at these temperatures include t-butyl perbenzoate, t-butyl peroctoate, benzoyl peroxide, peroxyketals, and other specialty peroxides. Accelerators are not generally needed to activate these peroxides. Heat is enough to decompose these peroxides into free radicals.

Room temperature cure is generally used in casting and laminating applications. Methyl ethyl ketone peroxide (MEKP), cumene hydroperoxides (CHP), 2,4-pentanedione peroxide (2,4-P), or combinations of these peroxides are generally used. To make these peroxides usable, they are diluted with various plasticizers until an active oxygen content of 4 to 9% is achieved. Accelerators added to the resins help to convert these peroxides into the free radicals necessary for the gel and cure process.

MEKP is made from methyl ethyl ketone and hydrogen peroxide. These two reagents react to form several different peroxides. The MEKP supplied by most manufacturers is a mixture of peroxides and residual hydrogen peroxide. The exact composition of each commercial MEKP depends on the manufacturing process. Thus MEKPs from different manufacturers react differently and should be checked before switching from one to another. There are also small amounts of water and hydrogen peroxide in MEKP. These can also change the reactivity of the MEKP.

Some of the factors governing peroxide usage are:

- **Amount**—An adequate amount of peroxide must be used to start the process and bring it to final cure. Resins and peroxide are formulated so that 0.75 to 3% solution is enough to generate the free radicals needed. If too much peroxide is used, too many polymer chains will start growing. Too many chains started results in short polymer chains, and the cured resin will have poor physical properties. If too little peroxide is used, the gel time will be very long and the growing polymer chains may die out before all the unsaturated groups are reacted. The resin may never cure properly even if postcured. It will tend to be physically weak and possibly rubbery.
- **Heat**—Enough heat must be supplied to properly cure the resin. It can come from an external source such as an oven, heat lamps, or a heated mold. The heat can also come from the exotherm of the resin itself. If the exotherm is stronger, such as in a thick casting, the part will get hotter and cure faster. If the part is a thin laminate then the exotherm will be weaker and the heat will be easily dissipated because of the large surface area-to-volume ratio of the part. The result of this will be a slower cure.
- **Shop conditions** are very important. If temperatures are below 60°F (15°C), cure will be greatly extended. However, if the temperature is 90°F (32°C) or above, then the gel and cure will be faster. Cutting back on the peroxide may result in enough working time, but there may not be enough free radicals to properly cure the resin.

2.2.6. Accelerators

Resins formulated for cure at room temperature contain accelerators (also called promoters). Accelerators increase the breakdown rate of the peroxide into free radicals. The amount of both accelerator and peroxide must be such that the fabricator has enough working time to form the part and, at the same time, enough speed of cure to make the process economically practical. Polynt adds accelerators to its gel coats and resins (i.e., pre-promotes them). Gel coat and resin data sheets contain information on the type and amount of peroxide initiator to use. Polynt’s resins are tailored to meet fabricators’ needs; i.e., fast gel and cure, fast gel with slower cure for longer trim time, longer gel with fast cure, etc.

Accelerators used in Polynt products are generally metal salts (sometimes called metal soaps) and amines. They include cobalt, calcium and potassium salts, and amines such as dimethyl aniline and diethyl aniline.

Some of these accelerators are described as follows:

- **Cobalt**—Solutions of cobalt generally contain from 6 to 12% metal. They impart a pink to red color to the resin depending on the amount used. Cobalt acts on most peroxides to form free radicals. Cobalt also affects perbenzoate and peroctoate initiators that are used at intermediate temperatures of 140 to 180°F (60 to 82°C). Cobalt does not act as an accelerator for benzoyl peroxide.

- **Amines**—Amines generally color polyester resins yellow to brown depending on the amount of amine used. They also can cause accelerated yellowing of cured parts. Dimethyl aniline (DMA) and diethyl aniline (DEA) do not act directly on MEKP or on 2,4-P (2,4-pentanedione peroxide). They increase the ability of cobalt to convert these peroxides into free radicals. They are very effective in shortening the cure time and hardness development of MEKP-initiated resins.

2.2.7. Suggested References

Books

- ❖ “Plastics Engineering Handbook of The Society of The Plastics Industry”, M. Berins, 845 pages, Springer; 5th edition (January 15, 1991), ISBN-10: 0412991810, ISBN-13: 978-0412991813
- ❖ “Modern Plastics Handbook”, Charles A. Harper, 1298 pages, McGraw-Hill Professional; 1 edition (March 24, 2000), ISBN-10: 0070267146, ISBN-13: 978-0070267145
- ❖ “Reinforced Plastics Handbook”, Third Edition, Donald V Rosato, 1082 pages, Elsevier Science; 3 edition (January 25, 2005), ISBN-10: 1856174506, ISBN-13: 978-1856174503

Annual Conference Proceedings

- ❖ American Composites Manufacturing Association (ACMA), www.acmanet.org
- ❖ “Composites Institute's, International Conference Proceedings”, SPI/CI, 528 pages, CRC Press (May 12, 1999), ISBN-10: 1566768004, ISBN-13: 978-1566768009
- ❖ JEC Americas Composites Show & Conferences, www.jeccomposites.com
- ❖ Society for the Advancement of Material and Process Engineering (SAMPE), www.sampe.org
- ❖ “Society of the Plastics Industry, Inc.” (SPI), www.plasticsindustry.org/
- ❖ The International Boatbuilders’ Exhibition & Conference (IBEX), www.ibexshow.com

Periodicals

- ❖ “Composites Manufacturing” (ACMA’s official publication), www.acmanet.org/cm-magazine
- ❖ “Composites World”, www.compositesworld.com/
- ❖ “MasterCast Connection” (the International Cast Polymer Association [ICPA] publication) www.mastercast.biz, www.icpa-hq.org
- ❖ “Plastics Today—Modern Plastics and Injection Molding”, www.plasticstoday.com
- ❖ “Professional Boat Builder”, www.proboat.com
- ❖ “UBM Canon Communications LLC”, http://ubmcanon.com

2.3. General Properties of FRP Composites

Overview

- **Introduction**
- **Mechanical Properties**
- **Specific Gravity**
- **Hardness**
- **Thermal Performance**
- **Chemical Resistance**
- **Electrical Properties**
- **Optical Properties**
- **Weathering Properties**
- **Polyester Shrinkage**
- **Technical Data Sheets**

2.3.1. Introduction

Fiber Reinforced Plastics (FRP) or Glass Reinforced Plastics (GRP) are a combination of polymer matrix resin and glass reinforcing fibers. Individually, the chemical and physical properties of resin matrices or glass fiber reinforcements are limited. However, when combined to form composites, exceptional properties can be achieved.

Overall properties of FRPs are determined by:

- Polymer resin matrix
- Glass to resin ratio
- Fillers
- Reinforcement (type, orientation)
- Additives
- Environment
- Manufacturing process

Composites have many advantages over other materials. They provide high strength, thermal resistance, fire retardant/resistance properties, hardness, environmental resistance, electrical insulation, low density, and can be molded into different shapes and sizes. Since FRPs are such adaptable materials, they are used in a broad range of applications, such as:

- **Construction**—bathtubs, shower stalls and floors, hot tubs, spas, vanities and sinks, pipes, building panels, portable buildings, floor grating, doors, satellite dishes, architectural façades and cladding.
- **Marine**—ski boats, fishing boats, sail boats, yachts, personal water craft, canoes, kayaks, docks, navigation markers.
- **Corrosion**—tanks, processing vessels, pipes, fans, pollution control equipment, scrubbers.
- **Transportation**—automobile body panels and structural components, truck hoods and caps, trailer sidewalls, RV sidewalls, train seating, airplane/train interiors.
- **Consumer**—swimming pools, sporting goods, hobby castings, decorative art.
- **Electrical**—appliance housings, circuit boards, insulating boards.

This section offers a brief outline of the properties that make FRP such a useful material.

2.3.2. Mechanical Properties

Mechanical properties characterize the strength, stiffness, toughness, and other load-bearing capabilities of materials. Mechanical properties are determined by testing the material when subjected to different forces. Typical tests for characterizing mechanical properties of FRPs include tensile (pulling), flexure (bending), compression, shear (tearing) and impact. Each test measures the effects of applying a force (Figure 2-5).

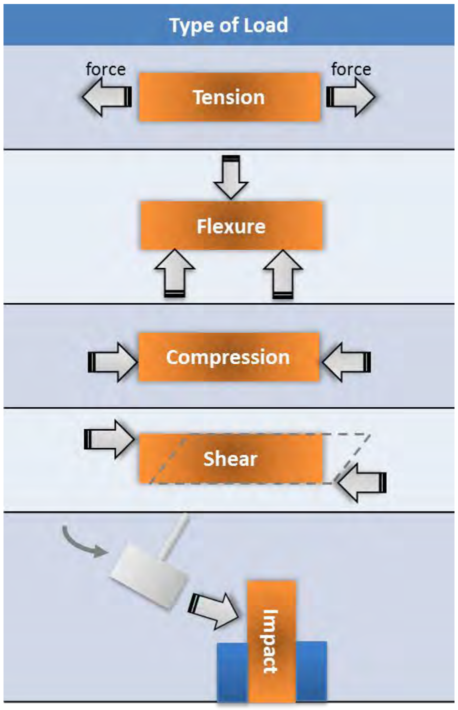


Figure 2-6. Assessing these types of forces is important to composite performance.

Composite Properties

The properties of a composite are a combination of the properties of the individual components. Cured, neat or unreinforced unsaturated polyester resins or vinyl ester resins are glasslike in nature and most are relatively brittle. Adding reinforcing fiber to the matrix dramatically increases strength and stiffness. The matrix holds fibers together, aids in load transfer between the fibers and provides compression and impact properties.

Reinforcement

The type of polymer matrix and reinforcement affects the properties of a composite. Common types of glass used in FRP composites are E-glass, S-glass C-glass and quartz, depending on the application (Table 2-3). The letter designation is taken from a distinctive property. E-glass is the most common due to its low cost.

Fiberglass is manufactured into different forms, fiber orientation and weight. Common glass fibers used in FRP composites include chopped strand mat (random short fibers held together with binder), roving fiber bundles, unidirectional cloth, veil, woven roving (plain weave, twill, satin, basket) as shown in Figure 2-6.

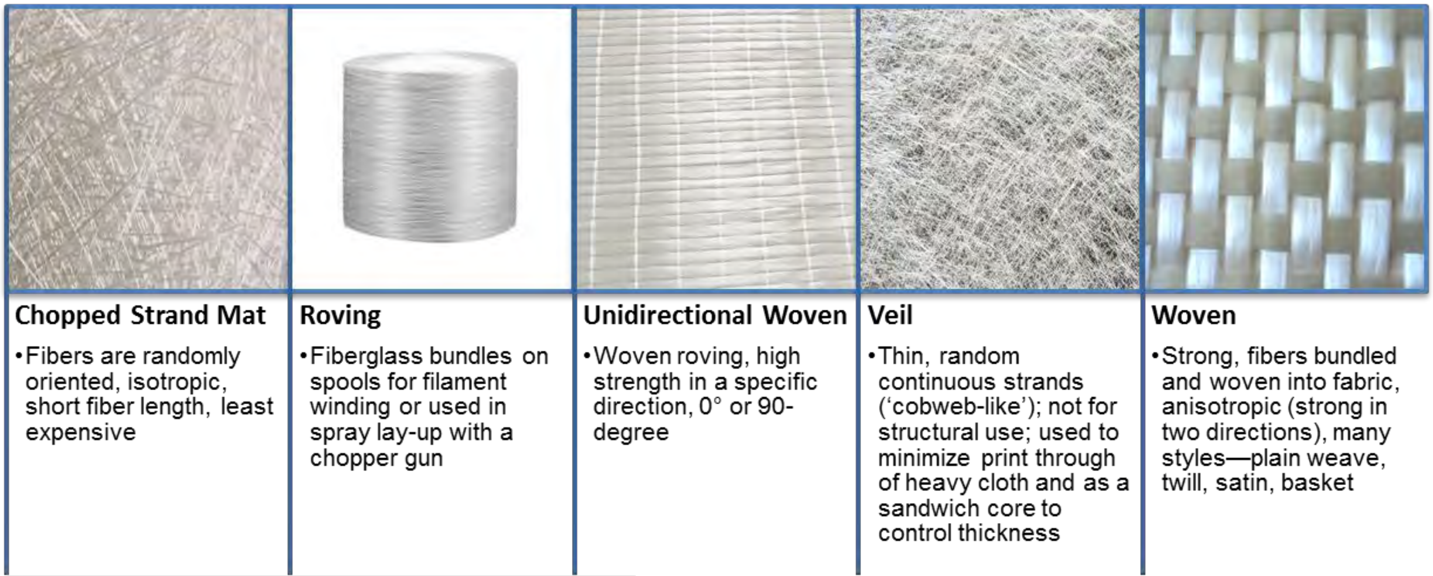
Table 2-2. Glass types used in FRP composites

Glass Type	Uses(3)	Application
C	High chemical resistance(1); Corrosion resistant; Higher elastic modulus and performance in high temps. vs. E-glass(3)	Advanced composites
E	Electrical applications; High dielectric strength; Resists attack by water; Alkali-free (<2%)	General use, Marine, Architecture, Automotive
R	European high strength (like S-glass)	Europe
S	Strong(2), >35% better tensile vs. E-glass; Retains mechanical properties at elevated temperature; Good corrosion resistance	Aerospace, Engineering
T	High strength; Used in Japan (like S-glass)	Japan
Quartz	Durable; Low density; High strength, stiffness and ≈ 2Xs elongation to break (vs. E-glass); Better electromagnetic properties vs. glass.	Thermal barriers, Radomes

(1)Resistant to acidic environments that destroy E-glass, i.e. loses much less of its weight when exposed to acid vs. E-glass; not as resistant to basic solution. (sodium carbonate) vs. E- and S-glass; boron-free glass.

(2)Tensile strength: E-glass=3445 MPa, S-2 glass=4890 MPa; Compressive strength: E-glass=1080 MPa, S-2 glass=1600 MPa; S-glass has much more silica oxide, aluminum oxide and magnesium oxide vs. E-glass; 40-70% stronger than E-glass.

(3)Source: CompositesWorld, "The Fiber", 2009



Chopped Strand Mat
- Fibers are randomly oriented, isotropic, short fiber length, least expensive

Roving
- Fiberglass bundles on spools for filament winding or used in spray lay-up with a chopper gun

Unidirectional Woven
- Woven roving, high strength in a specific direction, 0° or 90-degree

Veil
- Thin, random continuous strands ('cobweb-like'); not for structural use; used to minimize print through of heavy cloth and as a sandwich core to control thickness

Woven
- Strong, fibers bundled and woven into fabric, anisotropic (strong in two directions), many styles—plain weave, twill, satin, basket

Figure 2-7. Common glass fiber reinforcement types.

Anisotropy

A material is anisotropic when the properties of the material vary with orientation. By using reinforcing fibers, FRP composites can be anisotropic; composites can be engineered to have high mechanical properties in a given direction based on the chosen orientation of the reinforcing fibers. The highest mechanical properties are along the length of the fiber and weakest perpendicular to the fiber orientation. When fibers are oriented in the direction of known stresses, the strength of the reinforcement is used more efficiently, giving better performance. For instance, less roving reinforcement is needed to withstand a load when oriented parallel to a tensile load, than if a mat with random fibers were used. The mat may be more efficient in an application where the loads are more random. Other structural materials, such as steel or aluminum, are isotropic; the properties of those materials are the same in all directions. The advantage to using composites versus common metals is the end product uses less material and is lighter weight.

Another way to illustrate the anisotropy and design flexibility of composites is to look at properties of various product forms. A rod made of parallel glass roving strands can have a tensile strength of 150,000 psi, whereas a spray up laminate (made of randomly oriented, chopped glass fibers) may have a tensile strength of 15,000 psi. But a laminate made from a combination of mat and woven fibers has tensile and flexural strengths from 30,000 to 50,000 psi (Figure 2-7).

The high strength-to-weight ratio of composites makes them attractive for applications where strong, lightweight materials are essential to the efficiency and design of a product.

Impact

Another difference between composites and other construction materials such as steel and aluminum is how they react to impact. When a steel or aluminum panel is impacted at low forces, no change occurs. Impacts at higher forces may cause a dent. If an impact force is high enough, the impact may rupture the panel. FRP panels, when impacted, will show no change at low forces, cracking at higher forces, and rupture if the force is high enough. FRP has no yield point so it does not dent. IZOD Impact testing is used to compare various types or grades of plastics and constructions. It measures a material's resistance to impact from a swinging pendulum.

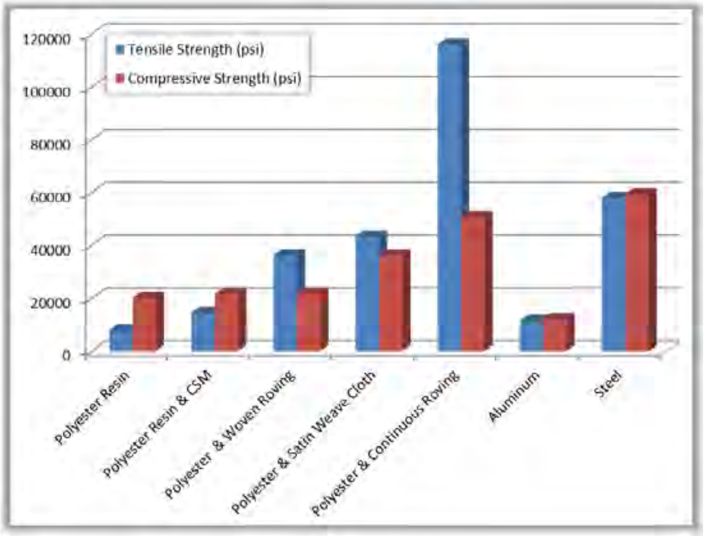


Figure 2-8. A comparison of tensile and compressive strength in polyester composites of different fiberglass types.

Footnote: *Polyester resin (unreinforced); Polyester CSM Laminate 30% glass; Polyester Woven Roving Laminate 45%; Polyester Satin Weave Cloth Laminate 55% glass; Polyester Continuous Roving Laminate 70% glass. Source: East Coast Fibreglass Suppl. Ltd., 2010.*

Adhesion

When a composite is under load, adhesion between the resin and reinforcement becomes crucial. The resin matrix helps distribute the load throughout the composite, to prevent cracking or coming apart from reinforcement fibers or inner core materials Adhesion between the resin matrix and reinforcing fibers depends on the sizing, the material coating the fiber. Sizing enhances bonding of the polymer to the fiber. The fiber sizing needs to be coordinated with the resin type.

Fillers

Mineral fillers are often used in FRP applications for:

Wear resistance	• **Silica, sand**
Chemical resistance	• **Barium sulfate**
Increased viscosity	• **ATH, clays**
Flame retardance	• **ATH**
Reduced cost	• **Calcium carbonate**

Figure 2-9. Uses of mineral fillers in FRP applications.

Fillers increase the stiffness of FRP but decrease strength.

Temperature

Temperature affects mechanical properties. Like most materials, FRPs become more brittle in colder temperatures and more flexible in warmer temperatures. See the paragraphs below on Thermal Performance for additional information.

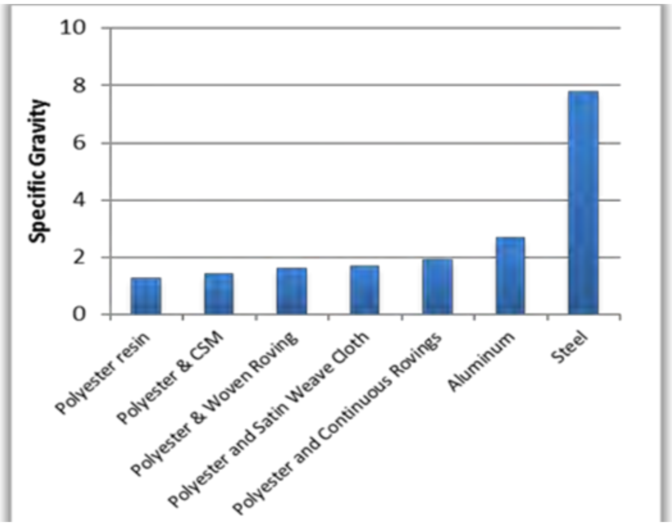


Figure 2-10. This graph shows that the specific gravity of polyester resin and polyester-reinforced composites is lower than aluminum and steel.

2.3.3. Specific Gravity

Specific gravity is the ratio of the density (mass/volume) of a substance to the density of a reference, such as water. For example, a typical polyester resin (unreinforced) is 1.3 times as heavy as an equal volume of water (resin is 1.3 g/ml, H_2O is 1.0 g/ml), so the specific gravity of the polyester resin is 1.3 (resin density/H_2O density). The specific gravity or relative density of unfilled FRP is low in relation to other structural materials (Figure 2-9). For typical resin-to-glass ratios, the specific gravity of FRP is approximately 1.7. In contrast, the specific gravity of aluminum is approximately 2.8 and steel is approximately 8.0.

The low specific gravity coupled with the design flexibility of mechanical properties results in an extremely high strength-to-weight ratio for FRP. Strength-to-weight ratio is a significant factor in weight sensitive applications such as aerospace and transportation.

The use of fillers in FRP affects the specific gravity. Most commonly used fillers (calcium carbonate, calcium sulfate, alumina trihydrate) and clays increase the specific gravity. However, lightweight fillers, such as hollow glass microspheres, can lower the specific gravity of FRP.

2.3.4. Hardness

The hardness of FRP is indicative of the type of resin matrix and/or degree of cure. The hardness of a resin matrix increases as it cures. When the resin reaches its maximum hardness value, it is completely cured and its properties are fully developed.

Hardness can be measured using a variety of tools called impressors. The most common are Shore Durometer (D) (ASTM D2240), Barcol 935 and Barcol 934 (ASTM D2583). Impressors are simple handheld devices that use a needle and spring assembly with a gauge to register the resistance to penetration of the needle point versus a reference. Barcol and Shore D hardness values range from 0 to 100. The higher the Shore D or Barcol reading, the harder the material is. Each impressor type has its own scale. Readings from one impressor are not equal to readings from a different type of impressor. Shore D and Barcol 935 impressors are used for softer FRPs or during the early stages of cure. The Barcol 934 impressor is used for advanced cure stages as well as fully cured materials.

The hardness property for cured resins depends on resin type. More rigid resins have higher Barcol readings, while resilient and flexible resins have lower readings. For typical FRP, hardness is measured with a Barcol 934 impressor. A Barcol 934 reading of 35 to 45 typically indicates the resin matrix has cured.

Hardness of gel coat films of typical thicknesses cannot be measured using these types of impressors. The needle fully penetrates the film and will read the hardness of the substrate beneath.

2.3.5. Thermal Performance

FRP is used in a number of elevated temperature applications, including the transportation, structural, corrosion and electronic industries. The thermal performance of the FRP is largely determined by the polymer matrix, both the type of resin matrix and the cure process. In general, isophthalic and most vinyl ester resins have excellent thermal performance that is superior to orthophthalic resins. Thermal properties of FRP can vary based on cure temperature. If a resin matrix is cured at a low temperature, it will have lower thermal performance than a resin matrix cured or post cured at elevated temperature. All resins have an ultimate level of thermal performance. Curing the polymer above the temperature at which the maximum thermal performance is reached will not result in any additional increase in performance.

The limitation on use of FRP in structural applications at elevated temperatures is loss of modulus or stiffness. This loss of stiffness is typically gradual at lower temperatures until the resin matrix polymer reaches a point where it transitions from a glassy to a rubbery state. This transition is called the glass transition temperature, T_g. The T_g depends on the degree of cure and polymer matrix. The more stable the molecule, the higher the T_g. When temperatures are above the T_g, the resin becomes more flexible, loses stiffness (modulus), and decreases the strength of the composite. Typically composites are not used in structural or load-carrying applications if the part sees extended exposure above the T_g of the resin. However, composites are used above their T_g in non-structural electrical or corrosion applications. Even for non-structural applications, the T_g or thermal performance of the polymer can be an important factor. A part that has been exposed to temperatures above its T_g can have diminished cosmetic appeal due to distortion, print, and other factors. Depending on the type of polymer matrix used, this can occur in dark-colored parts that are exposed to sunlight.

Glass Transition Temperature (T_g)

T_g can be measured by various methods. Two common methods are Differential Scanning Calorimetery (DSC) and Dynamic Mechanical Analysis (DMA).

- **Differential Scanning Calorimetery (DSC)**-Detects heat changes in the polymer matrix associated with transitions in material as a function of temperature and time. When the polymer resin absorbs enough energy as heat, a phase change to T_g occurs. DSC measures T_g by detecting this energy absorption.
- **Dynamic Mechanical Analysis (DMA)**-A small deformation is applied to a sample in a cyclic manner. It measures the stiffness (modulus) and damping (tan delta) of the material as a function of temperature or time. The T_g is seen as a large drop in the modulus or stiffness versus temperature.

In both DSC and DMA, the transition of the polymer from glassy to rubbery occurs over a range of temperatures. The T_g can be defined as the onset, midpoint or end of the transition. The most applicable measure depends upon how the data will be used. However, for T_g results to be comparable, they must all be defined using the same criteria.

Heat Distortion Temperature (HDT)

Another way to measure thermal performance is the Heat Distortion/Deflection Temperature (HDT), or Deflection Temperature Under Load (DTUL). It is the temperature at which a specimen deflects a given distance, under flexural load (edgewise position). The deflection temperature depends on the resin and on the existence of reinforcing materials. HDT can be run on neat resins or composites. HDT cannot be determined for most reinforced laminates since they do not reach the required deflection at a temperature within the safe operation range for the test equipment. HDT is used to determine short-term heat resistance. It distinguishes between materials that are able to sustain light loads at high temperatures and those that lose rigidity over a narrow temperature range. It is a useful measure of the relative service temperature for a material when used in load-bearing parts.

While T_g and HDT are indicators of FRP usage temperatures, another consideration is the effect of long-term elevated temperature exposure. Long-term elevated temperature exposure can cause the polymer resin matrix to oxidize, making the resin matrix increasingly brittle. This a concern in any application involving long-term elevated temperature exposure, but particularly in electrical applications where impact resistance or flexibility are required in addition to insulating properties. The long-term elevated temperature performance of FRP is evaluated by thermal aging studies. In these studies, FRP samples are exposed to a range of elevated temperatures for varying intervals. Critical properties are then tested. These results indicate whether the FRP sample is appropriate for use at the temperature and for the duration required for the application.

Two additional properties that are important for characterization of FRP thermal performance are the coefficient of thermal expansion (CTE) and thermal conductivity (k, λ, or κ).

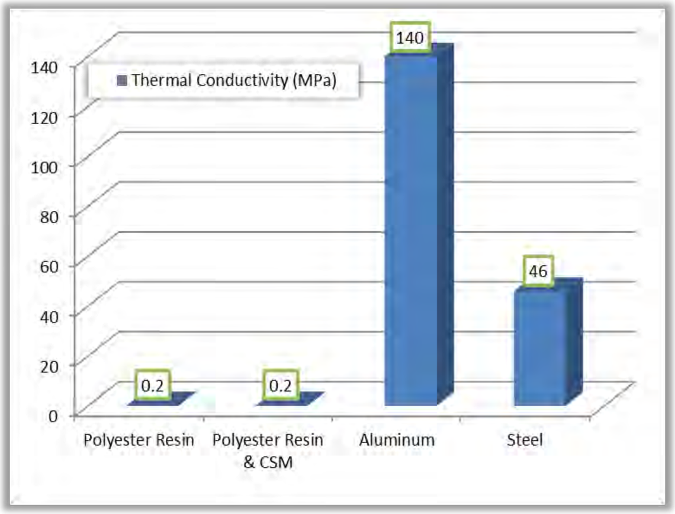
Coefficient of Thermal Expansion (CTE) (α)

CTE is the response (dimensional stability) of a material to changes in temperature. Solid materials typically expand in response to heating and contract on cooling. The CTE can be measured for linear (solids), area, and volumetric (liquids, solids) thermal expansion. CTE varies depending on temperature, filler, and reinforcement (content and orientation). Addition of filler or reinforcement generally reduces CTE. The CTE of composites is different in-plane versus through the thickness (perpendicular to reinforcement). In-plane numbers can also vary depending on the orientation of the fiber reinforcement.

An understanding of CTE is needed by parts designers to ensure that a part will fit in its assembly over the application temperature range. CTE is also an important consideration when dissimilar materials are used in the same part or mated together in assembly. Stresses created by differing expansion and contraction rates should be minimized. Mold designers need CTE information to ensure that parts built on the molds will have the required dimensions.

Thermal Conductivity (*k*, *λ*, or *κ*)

Thermal conductivity is a measure of how rapidly heat is transferred into or out of a material. It is also affected by temperature, filler and reinforcement (content, orientation). Thermal conductivity behaves differently when the temperature is above or below the resin matrix T_g. Thermal conductivity of FRP is low compared to metallic materials, making FRP suitable for insulating applications (Figure 2-10). The relatively low thermal conductivity of FRP also makes the surface pleasing to the touch in hot or cold ambient conditions.



NOTE: Polyester resin (unreinforced); Polyester resin & CSM Laminate, 30% glass

Figure 2-11. Thermal conductivity of polyester resin (neat) and reinforced is low, versus metals, aluminum and steel.

2.3.6. Chemical Resistance

FRP components are used in many applications requiring chemical resistance. These include tanks, processing vessels, swimming pools, pipes, fans, pollution control equipment, and scrubbers. The chemical resistance of FRP components is influenced by both the resin matrix and the reinforcement. Vinyl ester resins typically resist chemical degradation better than isophthalics, followed by orthophthalic based resins.

FRP components produced with isophthalic and vinyl esters have good chemical resistance to weak caustics, strong acids, and non-polar solvents. Strong caustics, polar solvents such as ketones (acetone), and those having chlorine (carbon tetrachloride and chloroform) rapidly attack FRP. These chemicals either react chemically with the polymers or swell the layers of the polymers to the point where they mechanically break (blisters). Glass fiber reinforcement generally does not improve corrosion resistance and, in some cases, reduces the performance. This is especially true in strong caustic environments because these chemicals can attack and dissolve the glass. Surfacing materials such as veils are available to enhance FRP part corrosion resistance.

The suitability of an FRP component for use in a specific corrosion application depends on the type of chemical to which the component will be exposed, the exposure temperature, and the exposure duration. Resin matrix suppliers provide a corrosion guide with specific recommendations based on these factors for their products. Typically, testing material sample coupons in the actual environment and conditions is the best method for choosing which resin will have the best long-term performance.

2.3.7. Electrical Properties

Many FRP composites have excellent electrical insulating (non-conductive) properties. They provide physical protection and visual concealment of electrical hardware, such as antennas, without signal interference. These composites are electrically transparent to radio frequencies (RF), meaning they allow radio signals to be transmitted and received. This property serves an important purpose in the marine, aerospace, communications and electronics industries. Composites can be manufactured into a variety of structures, such as radomes and cell towers.

Most thermoset polymers and glass fiber reinforcements are inherently non-conductive (insulating). They resist the flow of current, making them electrically insulating and transparent to the RF range of the electromagnetic spectrum (EM). An electrically insulating material allows an RF signal to be transmitted or received, with minimal absorption or reflection. Alternatively, highly conductive materials, such as metals, are non-insulating and absorb RF signals.

Electrical insulation and RF transparency are influenced by the following:

- Polymer matrix
- Glass (type)
- Moisture
- Fillers (type, size, dispersion & amount)
- Temperature
- Defects
- Impurities
- Manufacturing process

Electrical insulating properties are represented by a dielectric constant (κ) (ASTM D150), dielectric strength (ASTM D149), and conductivity (σ) (ASTM D257) (Table 2-4).

Table 2-3. Electrical properties of polyester matrix, reinforced, compared to metals.

Material(1)	Dielectric Constant κ (3)	Electrical Resistivity ρ (Ω-m)	Electrical Conductivity σ (S/m)
Polyester resin	2.8-4.5	--	--
Polyester resin (cast—flexible)	4.4-8.1	--	--
Polyester Resin (cast—rigid)	3.3-4.3	10^{10}-10^{12}	10^{-12}-10^{-14}
Fiberglass reinforced polyester	3.8-7.3	10^{10}-10^{13}	10^{-12}-10^{-15}
Glass	3.7-10	--	
Aluminum(2)	N/A	2.8×10^{-8}	3.5×10^{7}
Silver(2)	N/A	1.6×10^{-8}	6.3×10^{7}

Sources: (1)Naidu, M. S., Kamaraju, V., *High Voltage Engineering 4th Ed.*, Breakdown in Solid Dielectrics, (2009), Tata McGraw-Hill Publishing Co., p. 117; also "*Dielectric Constants of Materials*" (2013), Clipper controls; (2)Serway, Raymond A. (1998). *Principles of Physics*, 2nd Ed., Saunders College Publishing Co., p. 602; (3)Dielectric constant measured at 50 Hz.

Dielectric Constant (κ)

The dielectric constant is the ratio of the electrical permittivity of a substance to the permittivity of free space. When an electric field is applied to an insulator, electrical charges do not flow well through the material. Insulating materials are often called dielectrics. Dielectrics have values in the range of 1-100. Typical thermoset polymers have low κ. Typical FRP composites are dielectrics, with low dielectric constants (κ = 2.7 to 4.5), making them good materials for housing electrical equipment. Exact values vary depending on the physical and chemical properties of the polymer matrix and its surrounding environment.

Dielectric Strength

Dielectric Strength (Volts/mil or kV/cm) is the maximum working voltage a material can withstand, before breaking down. At dielectric breakdown, a material loses insulating properties and becomes conductive. It is affected by the thickness of the material. FRP composites generally have high dielectric strengths (300-500 V/mil). The dielectric strength of a FRP will decrease if there are contaminants or defects, such as air bubbles or delamination, in the composite.

Electrical Permittivity and Conductivity (σ)

The measure of how strongly a material opposes electric current is electrical resistivity (ρ). Low resistivity means electric charges move easily (metals). The inverse of electrical resistivity is electrical conductivity (σ, Siemens/m). Conductivity of good electrical insulators is $\approx 10^{-16}$ S/m, semiconductors $\approx 10^{-4}$ to 10^{6} S/m, and common metals $\approx 10^{8}$ S/m. Conductivity is affected by changes in temperature. If the temperature is great enough, an insulator may become conductive.

RF transparent resins are typically polyester, vinyl ester, epoxy, ABS, polyimide and cyanate ester based polymers. They can be combined with different types of fiberglass reinforcements (E, C, D, and S-glass). Commonly used composite fillers, such as calcium carbonate, ATH, silica or kaolin clays are typically insulating. Exposure to moisture increases conductivity and reflection or absorption of signal energy. Glass fibers generally have low moisture absorption. However, composite manufacturing and environment can affect water absorption. Many electrical applications also require elevated temperature performance so the same types of resins used in thermal applications are used in electrical applications, i.e. isophthalics, vinyl esters, and dicyclopentadiene (DCPD) resins. FRP can be made electrically conductive by using conductive polymers ("doped", highly conjugated), special fillers (carbon black, metal fibers), and specific reinforcements (metal coated veils, metal coated fabrics), etc.

Specific radio frequencies are used for many applications such as GPS, marine radar, etc. Radio frequencies are measured in hertz (Hz) and range from low frequency radio waves (kHz) to high frequency microwave bands (L, S, C and X, in GHz). Examples of approximate values and their applications are shown in Table 2-5 and Figure 2-11. Approximate values are listed since each application operates in a range of specific frequencies.

Table 2-4. Radio frequency applications.

Use	Frequency[1]	Wave Band
Navigation, AM Radio	10-1000 kHz	LF, MF
Aviation communications, Shortwave Radio, RFID tag	1-10 MHz	HF
FM radio, TV broadcasts, aircraft	10-100 MHz	VHF
GPS, cell phones, wireless LAN, two-way radios	100-1000 MHz	UHF
Radar, cell phones, commercial wireless LAN	1-10 GHz	SHF
High-speed satellite microwave transmission, radar gun	10-100 GHz	EHF

F=frequency; L=low; M=medium; H=high, VH=very high; UHF=ultra-high; SHF=super high; EHF=extremely high.

Antennas are used as transmitters or receivers of radio frequencies. They are designed to tune to specific frequencies, depending on their end use. Antennas come in different shapes and sizes. The design flexibility of composites allows FRP enclosures to be molded to accommodate their shape as well as house other common equipment, like cables and wiring. Some common uses include cell tower enclosures, transmission stations, RF transparent buildings, antenna supports, or they can be molded into customizable and complex shapes, such as radomes.

Radomes come in different shapes and sizes. They are cone-shaped (e.g. aircraft nosecone), geodesic, planar or specialized shapes (e.g. marine arch). They have applications in aerospace, marine and satellite communications. Depending on the need, radomes can store more than one type of antenna. For example, marine radar arches typically house radar electronics and marine radio antennas. Marine radio antennas operating in the VHF band can be used to monitor weather by the National Oceanic Atmospheric Administration (NOAA), to communicate with other boats and to call for assistance. Please note that in order to address proper antenna performance, always consult the antenna manufacturer's installation and instruction guidelines.

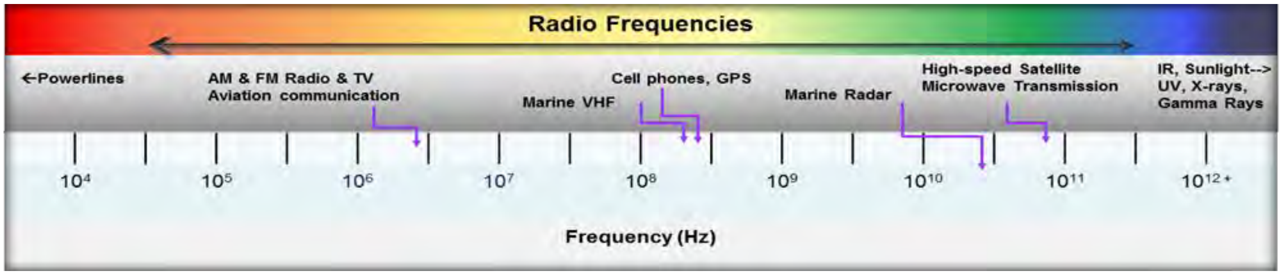


Figure 2-12. Radio frequencies.

2.3.8. Weathering Properties

The outdoor weathering properties of FRP are generally good. However, there is a certain susceptibility to ultraviolet rays which requires that ultraviolet absorber be specified for translucent laminates. Normally, UV absorbers are not required for gel coat because the pigments and fillers act as absorbers.

In addition, all exposed laminates should either have a gel coat or a glass surfacing mat specified for the exposed surfaces to prevent fiber 'blooming' or surface exposure of the fibers. For more information on weathering, see the 'Field Service' chapter of this book.

2.3.9. Polyester Shrinkage

All FRP resin matrices shrink to varying degrees during cure. Reinforcements and fillers are inert and do not shrink. Shrinkage is an important consideration for mold building and must be accounted for to ensure that parts will have the correct dimensions. For more information on shrinkage and mold building, see the 'Polyester Tooling' chapter. Since resin can shrink when it cures in the mold, after it exotherms and after demolding, the part is slightly smaller than the mold. Shrinkage of the resin matrix can also affect part cosmetics. Shrinkage of the resin matrix around fiber reinforcement can result in fiber print on the surface of the part. Shrinkage can also lead to part distortion. For more information on shrinkage and part cosmetics, see 'Field Service' section on Cosmetics.

The level of shrinkage of the overall part depends on:

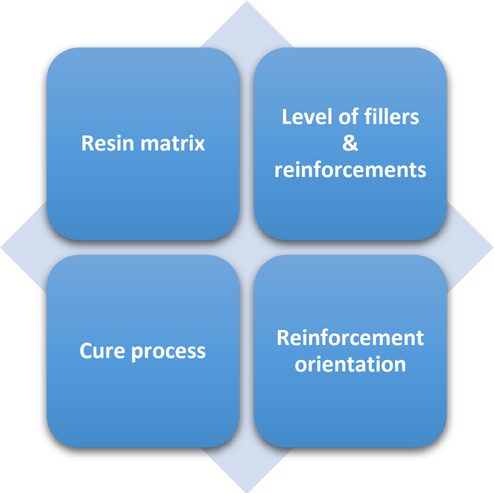


Figure 2-13. Level of shrinkage of overall part.

FRP resin matrices shrink approximately 6 to 9% by volume. Flexible resins generally shrink less than rigid resins. DCPD resins, although typically brittle, shrink less than orthophthalic, isophthalic or vinyl ester resins. Some specialized resins, mainly used in tooling applications, have a low profile additive that reduces or eliminates shrinkage. The shrinkage of FRP resin matrices also depends on the cure process and, specifically, the cure temperature. A resin cured in ambient conditions will not shrink as much as a resin cured at elevated temperature. The addition of filler and reinforcement to a resin matrix will reduce shrinkage. For reinforcement, the shrinkage is less parallel to the reinforcement than perpendicular to the reinforcement.

2.3.10. Technical Data Sheets

Resin, glass, filler, and other suppliers to the FRP industry provide technical data sheets (TDS) for their products. These data sheets typically include product properties 'as supplied' and when used to fabricate an FRP part. FRP part manufacturers often use these data sheets to compare properties of one manufacturer's product to another and for material selection. Caution must be exercised when comparing properties between different manufacturer's data sheets. Subtle differences in testing procedures can have a significant effect on properties.

In general, most manufacturers report the properties of products measured using industry standard test methods such as those published by the American Society for Testing and Materials (ASTM). These methods specify specimen preparation and testing procedures. However, within the test method guidelines variations are allowed in the construction of the samples. For example, the ASTM methods for testing resin castings and FRP laminates do not specify curing conditions that can significantly affect the resin casting and laminate properties.

Polynt participated in a double-blind, round-robin study where liquid samples of five competitors' resins were provided to one another. Each company made castings and laminates based on their own protocols for following the ASTM methods. Then, each company measured physical properties and reported results. In general, relative performance differences between the materials were discernible by all laboratories involved. In addition, in comparison of results for any given material, it was observed that some laboratories tend to report higher physical properties than others.

Therefore, comparing physical properties as listed on data sheets can lead to incorrect assumptions that one material is better than another. It is advisable to prepare and run side-by-side samples on the same piece of equipment in the same laboratory. This will narrow the number of variances and yield numbers that can be compared. In general, data sheets should only be used as general guidelines for suitability of a material for a given application, and to compare materials manufactured by a single supplier.

2.4. Flame Retardant FRP Composites

Overview

- **Introduction**
- **Fire Formation and Propagation**
- **Flammability of FRP Composites**
- **Flame Retardant Types**
- **Flame Retardant Mechanisms**
- **Industry Fire Safety Standards**
- **Environmental Impact**
- **Polynt Fire Retardant Resins and Gel Coats**

2.4.1. Introduction

Flame retardants (FR) represent a large group of organic and inorganic chemicals(1) that are added to combustible materials to make them more resistant to ignition and burning, when exposed to a heat source (e.g. flame). There is a growing demand for fire safe FRP composites since they are continually replacing other materials (e.g. metal) for industrial manufacturing. Comparatively, composites can have attractive qualities such as: effective flame retardant end-product, good corrosion resistance and mechanical properties, lightweight, less maintenance, can make large and complex parts, provide superior cosmetic properties and are cost effective.

Since some components of FRP composites are inherently flammable, flame retardant (FR) or fire resistant materials are used to provide fire safety to manufactured products. A flame retardant material is designed to resist burning and withstand heat, whereas fire resistant materials are designed not to burn at all. In this section, the main focus is flame retardants.

The main markets using flame retardant composites include:

- Transportation—buses, trains, subways, ferries
- Aerospace/Military—plane interiors, cargo bins
- Architectural—panels (interior and exterior), building materials, facades, theme parks
- Industrial—ductwork, smoke stacks

Flame retardants are based on different chemicals, for example: halogen, phosphorous, nitrogen, inorganic and intumescent agent, or combinations thereof.

Favorable qualities for a flame retardant material include:

Favorable Qualities
Fire resistance
High operating temperature
Heat insulation
Low smoke toxicity
Low smoke generation
Easy application
Low cost
Chemical and physical compatibility (polymer and FR)
Mechanical strength
Minimal environmental impact
Thermal stability
Corrosion resistance
Easy manufacturing process
Hydrolytic stability
Long product lifetime
High decomposition temperature of polymer

This section describes fire formation and propagation, FRP flammability, types of flame retardants, how FRs work, common fire safety industry standards, environmental impact, and examples of effective flame retardant resins and gel coats.

2.4.2. Fire Formation and Propagation

Three components required for fire formation are heat, fuel and oxygen (Figure 2-13). If any of the three key components of the fire cycle are eliminated, the process is interrupted or stopped.

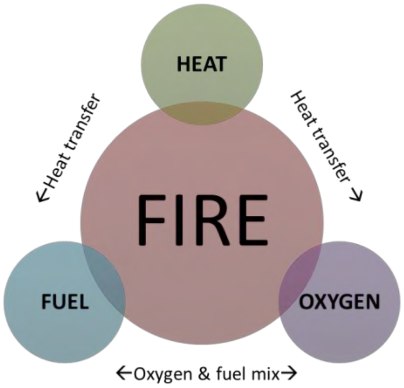


Figure 2-14. The fire cycle includes heat, fuel and oxygen (Source: H.W. Emmons: Heat Transfer (1973), p. 145)

A fire starts by ignition (Figure 2-14) from a heat source (e.g. small flame, electrical malfunction, short circuit). Heat chemically decomposes the fuel by pyrolysis, producing char and flammable gases. Flammable gases released by pyrolysis react with oxygen in heat producing combustion reactions. If sufficient heat is present, the combustion cycle is repeated. Heat generated from these reactions causes the fuel to keep burning in a feedback loop. Without a fire retardant, combustion continues until all flammable material is burned. Fire-retardants target one or more of these steps.

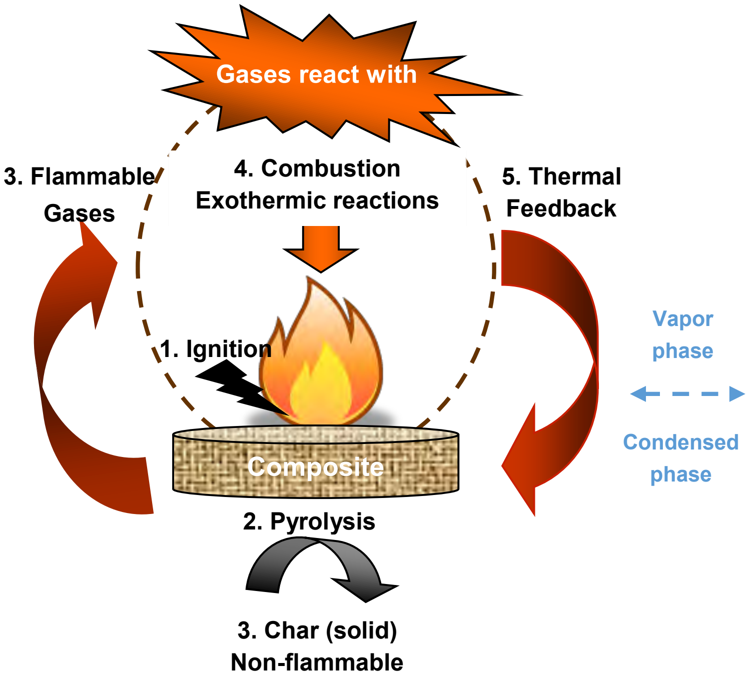


Figure 2-15. The combustion cycle—flammable gases react with oxygen and release heat (exothermic). Heat from these reactions promotes a feedback loop, as long as sufficient heat, oxygen and fuel are present.

2.4.3. Flammability of FRP Composites

Typical thermoset resins, like unsaturated polyesters (UPR), vinyl esters, epoxies (ER), and polyurethane (PU) resins are combustible. The flammability of the resin depends not only on its chemical and physical characteristics (e.g. flashpoint, thermal conductivity, heat of combustion), but also its form (e.g. shape, thickness, surface), and its proximity to the flame.

The flammability of a resin can be changed by altering the chemical composition. One example is the incorporation of a halogenated material such as bromine into the polymer.

Glass fiber-reinforcement materials are generally resistant to combustion. Resistance to combustion depends on glass content, construction, and thickness. For example, specific fiberglass types (S-glass, quartz) can be used for operating in high temperature applications, versus E-glass which is less resistant to heat. Special core materials, such as phenol foam (flame retardant) can be included in the construction.

When a FRP is exposed to sufficient heat, the cross-linked polymer chain thermally decomposes, in a process known as pyrolysis. Pyrolysis causes long chain polymers to break apart into smaller pieces (Figure 2-15), releasing heat, smoke, and combustion gases. Pyrolysis also produces non-flammable gases and char (inert solid). Pyrolysis causes changes in the polymer chemical structure and a loss of physical, mechanical and electrical properties.

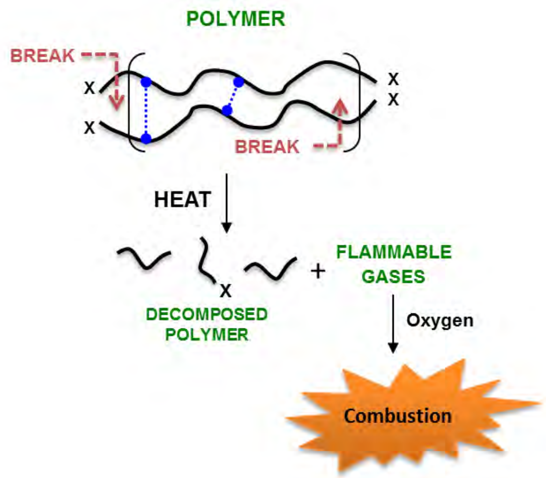


Figure 2-16. During pyrolysis polymer chains break apart into fragments and release flammable gases, heat and smoke.

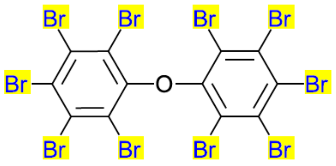
2.4.4. Flame Retardant Types

A fire retardant becomes "active" when it is exposed to a specific temperature and environment, during ignition or once the material starts to burn. The burning polymer and fire retardant release chemicals into the environment. Some are non-toxic, while others are toxic. Examples of toxic chemicals are carbon monoxide, hydro-halogen acids, dioxins, hydrogen cyanide, and other harmful chemicals. Optimal fire retardants minimize the release of dangerous chemicals and maximize their ability to extinguish fires.

Flame retardants are additive or reactive. Additive fire retardants are added to the polymer before, during or after polymerization, and are not chemically bonded to the polymer. Reactive fire retardants are added during polymerization and bond to the polymer, giving the polymer flame retardant properties. Some flame retardants improve their efficiency by combining with other fire retardants.

Halogenated

Halogenated flame retardants are most commonly made by adding a halogen source to the resin as an additive or by binding the halogen to the polymer. They can be added to materials with minimal changes to their properties. They have good mechanical properties, processability and low cost. Some examples include polybrominated diphenyl ethers (e.g. DecaBDE, Figure 2-16), Tetrabromobisphenol-A (TBBPA) and brominated (polystyrene). Their FR properties can be enhanced by combining with phenols, alcohols, anhydrides, phosphates, epoxies or by working in synergy with zinc borates and/or antimony oxides (Sb_2O_3). They are effective for electronics, printed circuit boards, building materials, wires and cables, textiles, foams, and plastics applications. However, halogenated composites can release corrosive and toxic fumes, in the form of halogen acids, brominated-dioxins and brominated-furans and brominated antimony, which are toxic. Due to their toxicity, halogen-based fire retardants are often avoided. Flame retardant development and smoke toxicity legislation has been steering markets away from the use of halogenated chemicals.



Decabromodipheny lether (DBDPE)

Figure 2-17. Polybrominated diphenyl ethers (DecaBDE).

Phosphorous

Phosphorous flame retardants can be reactive (phosphates, phosphonates) or additive (ammonium polyphosphate). It can be combined with halogens or phenols to increase effectiveness. They are used with UPRs, epoxies and polyurethanes, providing good physical properties, UV stability and are used in transportation applications.

Nitrogen

Nitrogen flame retardants include melamine, melamine derivatives and melamine homologues (melam, melem, melon). They are mostly used with nitrogen-containing polymers such as polyurethanes and polyamides. Advantages to using melamine based FRs include excellent resistance to ignition, corrosion resistant, good mechanical properties, heat sink, char formation, intumescence, low toxicity, low smoke, and low cost.

Inorganic

Inorganic flame retardants are fillers and additives. The most common inorganic FRs are metal hydroxides and synergists. They can be added to typical thermoset resins including vinyl esters, unsaturated polyesters (UPRs), and epoxy resins. Aluminum trihydrate (ATH) and magnesium dihydroxide (MDH) are easy to manufacture, chemically inert, non-corrosive, show good weatherability, yield non-toxic smoke, reduced smoke density, are available in different particle sizes, do not affect color (versus SbO_3), are relatively inexpensive and are very effective flame retardants. ATH-filled thermosets are used in vehicle parts, electrical, seat and panel applications.

In general, the more filler, the better the fire retardant properties. Large amounts of fillers are usually required, sometimes >50% by weight of ATH to achieve suitable fire retardant properties. However, the high filling requirement can degrade the mechanical properties of the FRP. This problem is often addressed by using either low viscosity polymers, such as modified acrylics or by using less material and combining with halogen FRs.

Other inorganic flame retardant examples include ammonium polyphosphate (NH_4PO_3), borates, red phosphorous, antimony oxides (SbO_3), zinc, tin, iron and molybdenum compounds. Additives, such as antimony trioxide (SbO_3) and zinc borate are used as synergists when combined with brominated FRs. However, by adding synergists and brominated flame retardants toxic gases are released.

Intumescent

Intumescent flame retardants use a combination of chemical reactions to make insulating foam and a char with low thermal conductivity which protects the polymer material. Intumescent systems are very desirable since they do not form any toxic fumes, do not need fillers or additives, and can be formulated with some renewable and recyclable material contents. Intumescent materials have minimal impact on the environment over the life cycle of the product.

Others

Phenolic flame retardants degrade to produce a char, along with water, CO_2, and H_2. Typical examples include Novalacs (Figure 2-17) and Resol resins. Phenolic resins are widely used in industry due to their high heat resistance, dimensional stability, resistance to corrosion, high strength to weight ratio, light weight, low smoke and toxicity and produce high amounts of insulating char. Phenol resins can be further improved by chemically modifying the phenolic structure, and by combining them with phosphate esters and epoxies. They can be used with a variety of composite fibers and fillers. In FRP applications, they are used in resin transfer molding, hand lay-up, pultrusion, and filament winding. FRP phenol FRs are used in aerospace applications for high temperature aircraft ducts, wings, fins and more.

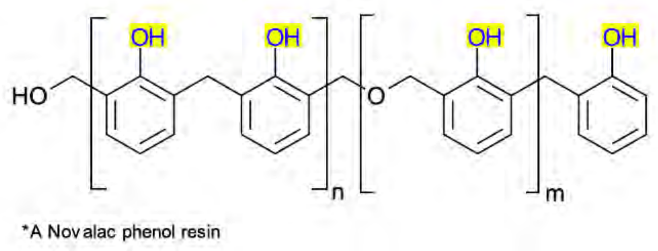


Figure 2-18. Novalac phenol resin.

Epoxy resins are not inherently flame retardant, but when combined with bromine or phenol groups, their flame retardant properties are improved. When bromine is added, the resin becomes FR, acting through a radical quenching mechanism. They can be used in the fabrication of materials requiring resistance to chemical environments.

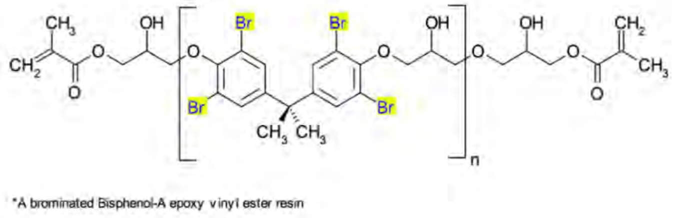


Figure 2-19. Brominated Bisphenol-A epoxy vinyl ester resin.

2.4.5. Flame Retardant Mechanisms

Fire retardants target different steps of the combustion cycle by chemical and/or physical means using four general mechanisms (Table 2-1). Many FRs work by more than one mechanism.

Table 2-5. General mechanisms and actions of fire retardants.

Mechanism	Action
Endothermic degradation	Lowers temperature
Gas phase quenching	Quenches exothermic radical reactions
Dilution of the gas phase	Dilutes combustion gases
Thermal shielding	Insulates flammable materials

The amount of fire retardant needed to be effective typically ranges from 5-20%, but may be less than 1% for a highly effective FR and greater than 50% for filled systems. The most chemically effective FR methods use thermal shielding and gas phase quenching mechanisms.

Endothermic degradation

When a flame retardant, such as ATH, is heated sufficiently (>200°C), it breaks apart the material to yield Al_2O_3 (non-toxic) and water (Figure 2-19). This cools the flammable material and quenches volatile gases and smoke (dilution of gas phase mechanism). The most common examples are inorganic fillers, such as ATH or MDH.

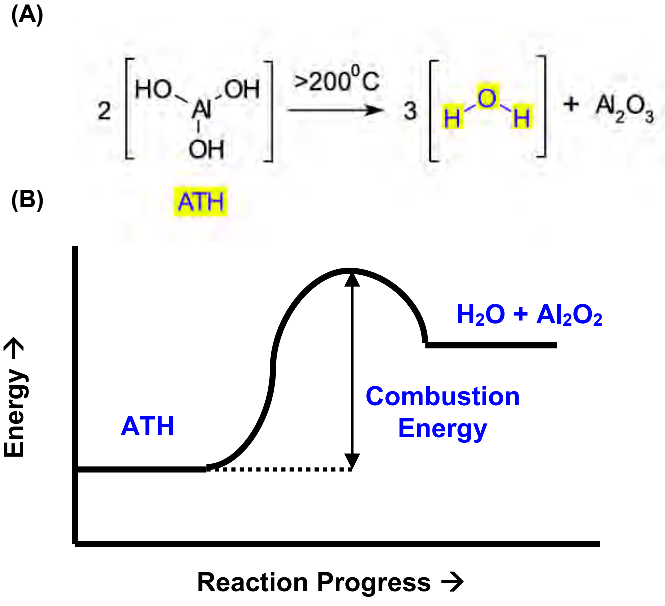
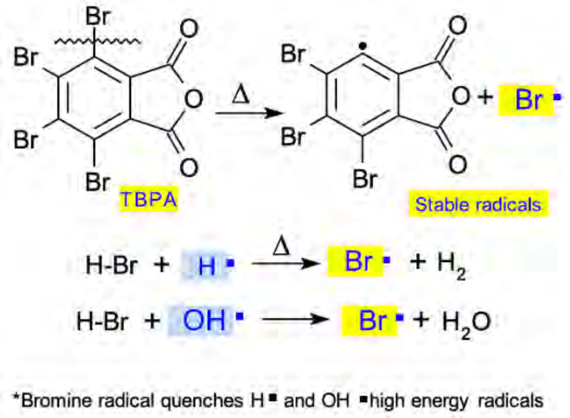


Figure 2-20. Heat absorbing reaction: (A) chemical breakdown of ATH to water and Al_2O_3. MDH requires 300°C to break down and release water. (B) energy diagram for endothermic reaction of ATH.

Gas phase radical quenching

During combustion, high energy H● and ●OH radicals are formed which undergo exothermic reactions. Some flame retardants form stable radicals when heated, such as halogenated FRs. They react with high energy radicals to quench exothermic reactions and slow or stop combustion. For example, when tetrabromophthalic anhydride is heated, it releases stable radicals that react with H● or ●OH forming H_2 (an accelerating flammable gas) and water (Figure 2-20). The bromine-radical regenerates itself, continuing to quench combustion radicals. Byproducts from this reaction can be HBr acid, brominated-furans and brominated-oxiranes. These fire retardants are effective but the chemical byproducts are toxic



*Bromine radical quenches H▪ and OH ▪high energy radicals

Figure 2-21. When TBPA is heated, a bromine radical is released (stable), TBPA-radical (stable) and hydrogen bromide (HBr). HBr reacts with hydrogen and hydroxy radicals, in a radical quenching mechanism, to release hydrogen gas and water.

Dilution of the gas phase

This mechanism is a component of the other FR mechanisms. Nonflammable gases (H_2O, CO_2, N_2) or physical barriers (char) will dilute or insulate flammable gases from being involved in the combustion cycle. The example below (Figure 2-21) shows the release of inert nitrogen gas (N_2), which dilutes flammable gases in the vapor phase.

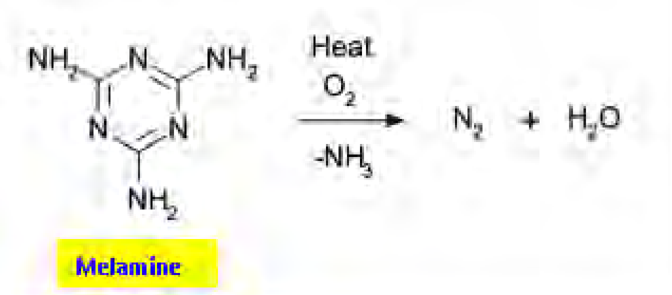


Figure 2-22. Melamine heated in the presence of oxygen releases nonflammable N_2 and water.

Thermal shielding

When sufficiently heated, the fire retardant material(s) degrades to form a solid insulating barrier (e.g. foam, char) with low thermal conductivity. This protects the unburned polymer from volatile gases, heat and oxygen. Many fire retardants operate through this mechanism, for example phosphates (Figure 2-22), intumescents, and phenolics.

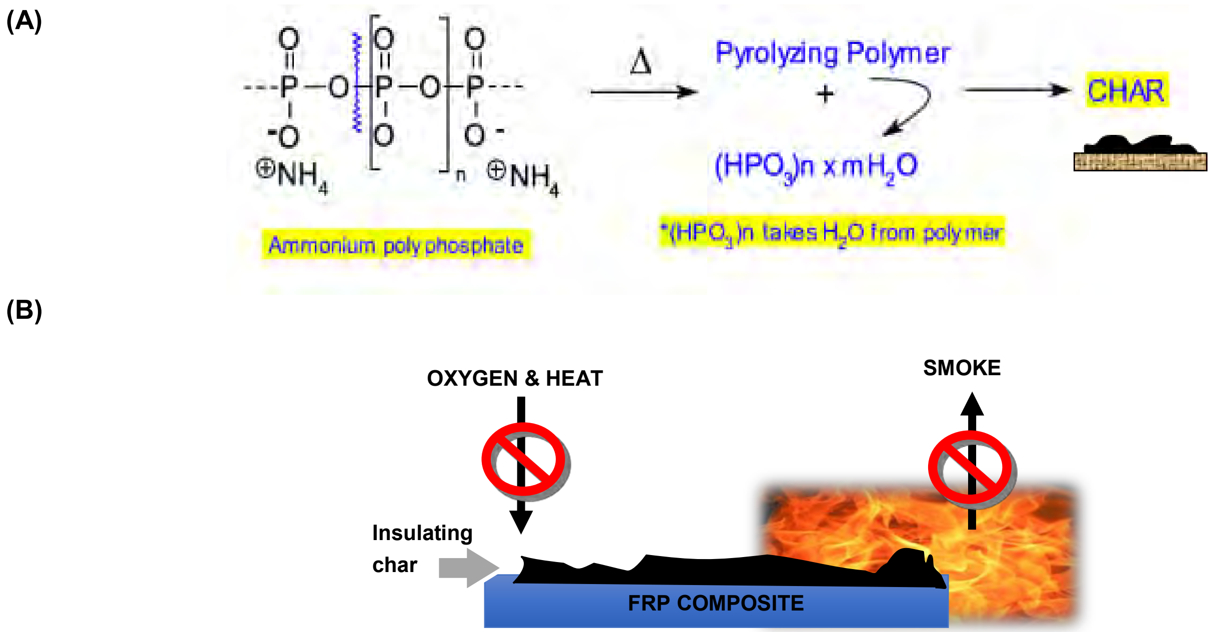


Figure 2-23. Thermal shielding: (A) phosphorous FRs thermally decompose to phosphoric acid, which extracts water from the pyrolyzing polymer, in the condensed phase, causing it to develop a shielding, thick glassy layer of carbon material on the burning side; (B) the char protects the flammable material, insulating from oxygen and heat, and prevents smoke release.

2.4.6. Industry Fire Safety Standards

Fire safety requirements are defined by national and international safety standards and regulations. Fire safety tests determine fire performance properties of substances including: ignitability, smoke density, smoke emission, flame spread, vertical and horizontal burning, evolved heat, required temperature rises, flaming time, mass loss, combustibility, heat of combustion, reaction to fire, and more. Some common fire tests which have been used to rate the burning properties of polyesters are described in Appendix A.

Once testing is completed, the material is given a classification rating, which must fall within the acceptable range for usability in specific industry applications. Classifications denote the level of fire safety provided by that product. Many tests measure fire safety of FRPs with or without flame retardants. Table 2-2 provides a list of common industry standard tests by type and classification. Flammability testing standards are market specific, continually changing and therefore the test requirements, classifications, retirement of methods and development of new testing standards must be checked continually.

Table 2-6. Common industry fire safety standards

INDUSTRY FIRE TESTS	TYPE	CLASSIFICATION / RATING
INDUSTRIAL: ductwork, smoke stacks, utility boxes with FR specs.		
UL 94 (devices, appliances)	Ignition characteristics with small open flame or radiant heat source, vertical or horizontal	HB rating: horizontal—burn slowly, flame at end V rating: V-2, V-1, V-0—vertical, flame at bottom
ASTM E84 (building materials)	Tunnel test—surface burning	Flame spread index (FSI): 0 = non-flammable, 100 = wood; Class I <25, Class II 25-75; smoke developed <450
ARCHITECTURAL: panels (interior and exterior), building materials, facades, theme parks		
ASTM E84 *(see above)*	--	--
NF P 92-501 (building material), France	Reaction to fire tests (Epiradiateur), for rigid materials—time to flame, flame height, heat, smoke generation, burning droplets, etc.	M1 = non-flammable q<2.5 , M2 = low flammability q<15, M3 = moderately flammable q<50, M4 = combustible q>50, q = classification index
BS 476 Part 6-7, UK	Part 6: Fire propagation, Part 7: Flame spread	Classify 0 (best) to 4 (worst)
DIN 4102 (building materials), Brandschacht, Germany	Flammability—vertical shaft furnace Combustibility furnace (750°C)	Class A (combustion), B (flammability): A1 100% non-combustible, A2 = 98% non-combustible , B1 = difficult to ignite , B2 = “normal” flammability (wood), B3 = Easily ignited
EN 13501-2, Europe	Fire resistance	Classes A1, A2, B, C &D: EN ISO 11925-2 (ignitability), EN ISO 9239-1 (radiant panel), EN ISO 1716 (bomb calorimeter), EN 13823 (single burning item), EN ISO 1182 (little furnace)
AEROSPACE / MILITARY: plane interiors, cargo bins, naval submarines		
MIL-STD-2031 (SH) (Naval submarines)	Fire tests, toxicity	Oxygen-temp. index, ASTM E162, ASTM E1354, ASTM E662, burn-through, quarter-scale, large scale open and pressurizable, N-gas Model smoke toxicity screening
MIL-R-21607 (marine and shore uses)	Flame resistance—weathered and unweathered “Specification covers translucent resins used to fabricate fire-retardant GRP laminates for use in boats, tanks and other Naval applications”	Grade A: Standard flame resistance, avg. ignition time = 55 minimum, avg. burning = 125 max. Grade B: Superior flame resistance, avg. ignition time = 70 sec minimum, avg. burning time = 65 sec maximum

Table 2-6. Common industry fire safety standards (cont.)

INDUSTRY FIRE TESTS	TYPE	CLASSIFICATION / RATING
AEROSPACE / MILITARY: plane interiors, cargo bins, naval submarines (cont.)		
Boeing BSS 7239 (aircraft material)	Toxic gases generated by materials on combustion	Amount of toxic gases generated , including: CO = carbon monoxide, HF hydrogen fluoride, HCl hydrogen chloride, NO_x nitrogen oxides, SO_2 sulfur dioxide, HCN = hydrogen cyanide
FAR 25.855 (aircraft cargo bins), *(AITM 2.0004, BSS 7230, ASTM F1103)*	30 sec., 45 degree Bunsen burner test, resistance to flame penetration, flame and glow propagation	Flame time <15 sec., Flame penetration—none, Glow time <10 sec.
AITM 2.0002 (Airbus), *(FAR 25.853 a-b)*	Vertical Bunsen burner test—resistance of material to flame; ignition time at 60 and 12 sec.	Flame time: <15 pass, Drip time: <5 pass, Burn length: <203
FAR 25.853 (b-2)	Horizontal Bunsen burner test—rate a flame front moves over a specified distance	Burn rate: <2.5 in./min. pass **OR <4 in./min.pass for FAR 25.853 (b-3)*
AITM 2.0006 *(FAR 25.853 (a-1), BSS 7322, Modified ASTM E906)*	Heat release and heat release rate, OSU calorimeter	Heat release rate (5 min.) <65 kW/m^2 Total heat release (2 min.) <65 kW min./m^2
AITM 3.0005 (Airbus), *(BSS 7239, Bombardier SMP 800-C)*	Toxicity fumes	Concentration limits in ppm: HF (100), HCl (150), HCN (150), SO_2/H_2S, (100), NO/NO_2, (100) CO (1000)
AITM 2.0007 (Airbus), *(BSS 7238, FAR 25.853 (c-1))*	Smoke opacity (NBS smoke)	Optical smoke density (Ds @ 4 min.), Flaming (<200), Non-flaming mode (<150 pass)
TRANSPORTATION: buses, trains, subways, ferries		
ASTM E662	Smoke density (NBS chamber)	Specific optical density, (D_s)
ASTM E162	Surface flammability of materials using radiant heat source.	Flame spread Index, Fs
BS 6853:1999 (railway components), UK	Ignition, heat release, flame spread, smoke opacity, toxicity	BS 476 -6, -7, BS 5438, BS 4589-2, -3, BS 6853 Annex B, D, BS EN 60332-1, -2, BS EN 50306, BS EN 50264, BS EN 50305, BS ISO 5659-2, NF X 70-100, -702, BS ISO 9239-1, BS EN 50266-2-4, -2-5, BS EN 50305 s. 9.1.1, -9.1.2
Bombardier SMP 800-C	Toxicity	Analysis of CO, CO_2, HF, HCN, HCl, HBr, SO_2 and NO_x in combustion gases

Table 2-6. Common industry fire safety standards (cont.)

INDUSTRY FIRE TESTS	TYPE	CLASSIFICATION / RATING
TRANSPORTATION: buses, trains, subways, ferries (cont.)		
EN 45545 (railway—walls, floors, ceiling, etc.), Europe	Defines fire test performance criteria of railway products, categorized by infrastructure and environmental risk	Category R1 to R25 ; Rating, HL1 (least), HL2, HL3 (most severe) , Lateral flame spread: ISO 5658-2 (radiant panel), Heat release: ISO 5660-1 (cone calorimeter), Smoke density (Ds, VOF4), toxicity : EN ISO 5659-2, EN TS 45545-2 annex C
NF F 16-101-102 (railway components) France	Classification of materials for rolling stock from combustion, smoke opacity and toxicity tests;	Type of rolling stock: Category A1, A2, B; Epiradiator: M0 (no combustion) to M4, Glowing wire: I0 (no ignition) to I4, Smoke toxicity (NBS smoke chamber) : F0 to F5
DIN 5510-2 (railway components), Germany	Fire classification of railway material and structure: burning behavior, smoke density, dropping behavior, toxicity	Combustibility: S1 to S5, Smoke emission: SR1 to SR2, Dripping test: ST1 to ST2

(1)Antimony oxide is SbO_3 and ammonium dimolybdate is $(NH_4)_2Mo_2O_7$

2.4.7. Environmental Impact

During a fire reaction, the breakdown of certain flame retardants and matrix materials can release toxic gases such as carbon monoxide (CO), hydrobromic (or chloric) acid, brominated furans, brominated dioxins, polycyclic aromatics, hydrogen cyanide (HCN), etc., into the environment.

Environmental concerns not only focus on the immediate toxicity of chemicals, but also their recyclable and renewable capabilities. Harmful chemicals are not only a concern when they are first released into the environment, but they are also released into the environment over the life cycle of the product. Thus, it is vital to consider the type of chemicals used and their overall effects on the environment.

2.4.8. Polynt Fire Retardant Resins and Gel Coats

Polynt has developed a variety of effective flame retardant resins and gel coats. These products are made using different fire-retardant system and designed for specific industry needs. These systems are shown in Table 2-3.

These products are designed for different FRP composite applications, such as spray-up, RTM, hand-layup, pultrusion and filament winding. Each FRP flame retardant product is approved for use in specific classes of flame retardant applications, according to EPA requirements and national and international flammability standards (see Technical Data Sheets for details). These materials are designed for use in a variety of industry applications, such as construction, building, architecture, electrical, marine, bus, automobiles and trains. Currently, Polynt's intumescent FIREBLOCK™ resins and gel coats show the most promise as effective flame retardants, are approved for the broadest range of applications and are the most environmentally friendly.

The pictures in the top row of Figure 2-23 show the flame retardant properties of FIREBLOCK™ 2330PAWK745 gel coat and Norsodyne® FIREBLOCK™ H81269TF resin. The pictures in the bottom row show that ArmorFlex® 99F gel coat and a non-flame retardant resin burn.

Table 2-7. Flame retardant resins and gel coats.

PRODUCT	RESIN OR GEL COAT	FLAME RETARDANT TYPE
FIREBLOCK™ 2330PAWK745	Gel Coat	Intumescent
Norsodyne® FIREBLOCK™ H81269TF	Resin	Intumescent
STYPOL® 040-8003	Resin	Brominated styrene, ATH & Synergist
Polycor® 947 SFP Series	Polyester Gel Coat	Brominated and Brominated-SbO_3
STYPOL® 040-2806 and 040-2832	Laminating Resin	Brominated with SbO_3 and/or $SbO_3/(NH_4)_2Mo_2O_7$
STYPOL® LLPE3421	L-series laminating resin	ATH

Figure 2-24. Top Row – Demonstration using FIREBLOCK™ 2330PAWK745 gel coat and Norsodyne® FIREBLOCK™ H81269TF resin. Bottom Row - Demonstration using non-flame retardant gel coat and resin.

2.5. Fabrication of FRP Composites

Overview

- **Introduction**
- **Open Molding**
- **Low Volume Closed Molding**
- **Compression Molding**
- **Process Selection**

2.5.1. Introduction

Fiber reinforced plastics are fabricated using a variety of methods. Examples include:

- **Hand lay-up lamination**
- **Spray-up lamination**
- **Continuous lamination**
- **RTM and variations on RTM**
- **Infusion**
- **Pultrusion**
- **Fiber placement**
- **Spin casting**
- **Filament winding**
- **Compression molding**
- **Injection molding**

In this book, we focus on three main categories of fabrication processes. These categories include:

FOCUS
Open molding
Low-volume closed molding
Compression molding

Characteristics of a part, such as size, surface and number of parts, can dictate the method chosen for FRP fabrication. A comparison of part characteristics and fabrication method are shown in Table 1.

2.5.2. Open Molding

Open molding is the most widely used process for fabrication of FRP parts. In contrast to many other fabrication processes where the exterior coating is applied after the main structure of the part has been built, open mold parts are built from the exterior to the interior. The first step in open molding is to apply the gel coat (the exterior coating of the part) to the mold. The remaining layers of the laminate design are applied behind the gel coat.

Open molding is generally done under ambient conditions. The mold is commonly one-sided. It can be male (part is molded onto) or female (part is molded into). The cosmetic surface of the part is fabricated next to the mold. The back side of the mold is open.

Commonly used materials for open molding are:

- **Gel Coat**—The exterior coating of the part serves several purposes. During manufacturing, the gel coat protects the mold from abrasion and chemical attack. It also provides a releasable coating. After manufacture, the gel coat becomes the exterior cosmetic coating of the part and also provides protection against water exposure and weathering. Most, though not all, open-molded parts are gel coated. Examples of non-gel-coated, open-molded parts include spas, bathtubs, and shower stalls where acrylic or ABS is used in place of gel coat as the exterior coating.

Figure 2-25. Laminate structure materials.

- **Barrier Coat**—An additional coating applied behind the gel coat. A barrier coat improves part cosmetics, reduces cracking, and improves osmotic blister resistance in marine parts.
- **Skin Laminate**—A relatively thin glass fiber-reinforced laminate fabricated behind the gel coat, the skin laminate is specially formulated to cure completely as a thin laminate and to improve part cosmetics. Skin laminate resins are typically formulated with high performance polyester or vinyl ester polymers to improve osmotic blister resistance.
- **Print Blocker**—Sprayable syntactic foam material used behind a skin coat to improve laminate cosmetics.
- **Coring Materials**—Lightweight materials used to build part thickness and stiffness without adding weight.
- **Bulk Laminate**—The main portion of the laminate that provides most of the structural properties.

Chapters 3-8 review gel coat and resin materials used in open molding, application techniques, troubleshooting guidelines, and field service issues.

Table 2-8. Comparison of FRP fabrication processes.

PROCESS COMPARISON			
Part Characteristic	**Open Molding**	**Low-Volume Closed Molding**	**Compression Molding**
Maximum part size	Any size	Any size	Up to 100 square feet
Factors limiting part size	Mold and part handling	Mold and part handling	Press size
Part surface	One side	Two-sided, smooth or textured	Two-sided, smooth or textured
Part-to-Part Consistency	Fair	Good to Excellent	Excellent
Cross section	Completely variable	Better if uniform	Easily varied
Number of Parts per Year	<1000	<10,000	>5,000
Parts per 8-hour shift per mold	1-2	16-90	100-500
Mold construction	Composite	Aluminum nickel shell, or composite	Chrome plated tool steel
Mold lead time	2-4 weeks	4-8 weeks	16 weeks or more
Tons of Composite per Tons of Emissions	37(1)	135-1630(2)	135-1630(2)

(1) Numbers taken from unified emissions factors; 35% styrene content resin; mechanical non-atomized application; and 30% fiberglass.

(2) Numbers taken from EPA AP-42 emission factor; 35% styrene content resin; compound paste (25-100% resin); and 30% fiberglass.

Glass fiber reinforcement used in skin and bulk laminates can be applied by hand lay-up or spray-up. Hand lay-up is used when applying roll good reinforcements such as chopped strand mats and textile constructions that are stitched or woven. Brushes, rollers, or wet out guns can be used to apply the resin.

Spray-up is used when the laminate reinforcement is chopped roving. Chopped roving and catalyzed resin are sprayed onto the lamination surface with a chopper gun. The glass is wet out and compacted with lamination rollers. Hand lay-up and spray-up can be combined within the same part or laminate.

The part size for open molding is restricted only by part and mold handling considerations. Open molding is labor intensive in comparison to some other processes.

Part-to-part consistency is dependent on operator skill and is generally variable. Emissions from open mold processes are significant and are regulated by federal NESHAP standards and, in some cases, state and local regulations.

2.5.3. Low Volume Closed Molding

The category of low volume closed molding processes includes processes in which liquid resin is transferred into a closed cavity mold containing reinforcing materials. Over time, many variations of low-volume closed molding processes have evolved. Some examples are:

- Vacuum infusion (Figure 2)
- Seamann Composites Resin Infusion Manufacturing Process (SCRIMP®)
- Conventional RTM
- Light RTM (shell laminate RTM)
- Silicone bag RTM
- Closed Cavity Bag Molding (CCBM®)
- Multiple Insert Tooling (MIT®) RTM
- Zero Injection Pressure (ZIP®) RTM

Parts fabricated using these processes may or may not have gel coat on the exterior surface. For parts fabricated with gel coat, the gel coat is applied to one half of the mold using the same techniques as used for open molding. The mold is then loaded with reinforcing materials and closed. Catalyzed resin is transferred into the mold. After the part is sufficiently cured, the mold is opened and the part de-molded.

The part size for these processes is limited by mold and part handling considerations. Part-to-part consistency is better than with open molding due to less dependence on operator skill. Also, two-sided cosmetic parts can be produced. Emissions from these processes are still regulated; however, they are much lower than with open molding due to the closed portion of the process. Emissions from the gel coat application, if used, are the same as for open molding.

*Source: Wind School 2012

Figure 2-26. Vacuum bag infusion—wind blades.

2.5.4. Compression Molding

Compression molding is another closed molding process that uses clamping force during mold closure to flow a pre-manufactured compound through a mold cavity. A hydraulic press generally provides the clamping force. Compression molds are generally made from chrome-plated tool steel. Sheet molding compound (SMC), bulk molding compound (BMC), and wet molding compound are examples of pre-manufactured compounds.

If an external coating is needed on a compression molded part, it is generally post applied; however, in-mold coatings are available. Part size is limited by press plate size. Part-to-part consistency is excellent. Emissions from compression molding are still regulated; however, they are much lower than with open molding due to the closed nature of the process.

2.5.5. Process Selection

The best process to use for fabrication of a specific part may be obvious. However, when the best process is not obvious, process selection is best accomplished through a process trade study.

A process trade study involves comparing the part fabrication costs and part performance factors for a specific part fabricated by various processes. Part fabrication costs include but are not limited to equipment costs, tooling costs, material costs, and labor costs. Part performance factors are dependent on the specific part being studied but can include weight, strength requirements, and appearance requirements. Emissions of Hazardous Air Pollutants (HAP) or other regulated materials vary by process and may also factor into process selection. An example trade study follows.

The subject part is from the deck of a run-about boat (Figure 3). It is a hinged hatch cover that provides access to an under-deck storage compartment or cooler.

The step face features a non-skid profile on the external surface. The step face comprises glass skins over foam-filled honeycomb core. The part measures 11 inches by 25 inches with a 1.5-inch tall perimeter flange. The design criteria includes an impact requirement of 300 pounds from a three-foot elevation.

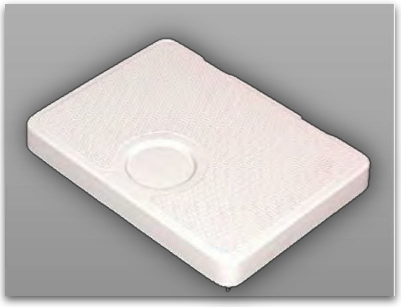


Figure 2-27. Trade study marine hatch cover.

Processes considered in the trade study were open molding and several low-volume closed molding processes, including vacuum infusion, silicone bag RTM, light RTM, and conventional RTM. Equipment costs, tooling costs, material costs, and labor costs were calculated for each process on a per part basis. Costs were based on typical values in the year 2008 and were presented as relative costs with open molding at 100 parts produced as the baseline.

The number of parts to be produced varied from 10 to 9,000. Parts were to be produced over a three-year time frame with an equal number of parts per year. Process trade study cost results are shown in Figure 4. The cost per part decreases as the number of parts produced increases. However, the amount of decrease depends on the process, meaning that different processes were the most cost-effective at different production rates.

Conventional RTM is not a cost-effective option for hatch cover production at production run sizes of less than 1,000 parts. For production run sizes greater than 1,000 parts this process becomes competitive with light RTM, but does not become cheaper than light RTM, even at production run sizes of 9,000 parts, due to the need for a gel-coated surface.

The cost comparison could be different for large production runs of a non-gel coated part.

While competitive with light RTM, silicone bag RTM is never the cost effective process for hatch cover production. This is due to the cost of the materials needed to fabricate the silicone bags. However, silicone bag RTM can be an excellent process selection for parts with closed contours that are not easily fabricated by other processes.

Light RTM is the low cost process for hatch cover production at production run sizes greater than 100 parts.

Vacuum infusion is competitive with open molding as the low cost process for hatch cover production runs of less than 100 parts. At higher production rates, vacuum infusion is not cost effective due to the cost of the consumable materials (vacuum bag film, sealant tape, etc.) needed for each part.

Open molding is the low cost process for hatch cover production runs of less than 100 parts. It is not cost effective for production runs greater than 100 parts.

Overall process trade study results, including part appearance, strength, cost and emissions, for the hatch cover are shown in Table 2.

Use of a closed molding process reduces emissions by 50 percent in comparison to open molding with low VOC materials. The emissions differences as well differences in part appearance could influence process selection for hatch cover production.

This trade study is provided as an example of the type of evaluation that can be done to make an informed decision on process selection. The conclusions reached are not valid for all part types, sizes, complexity, and specific combinations of labor, material, and capital costs.

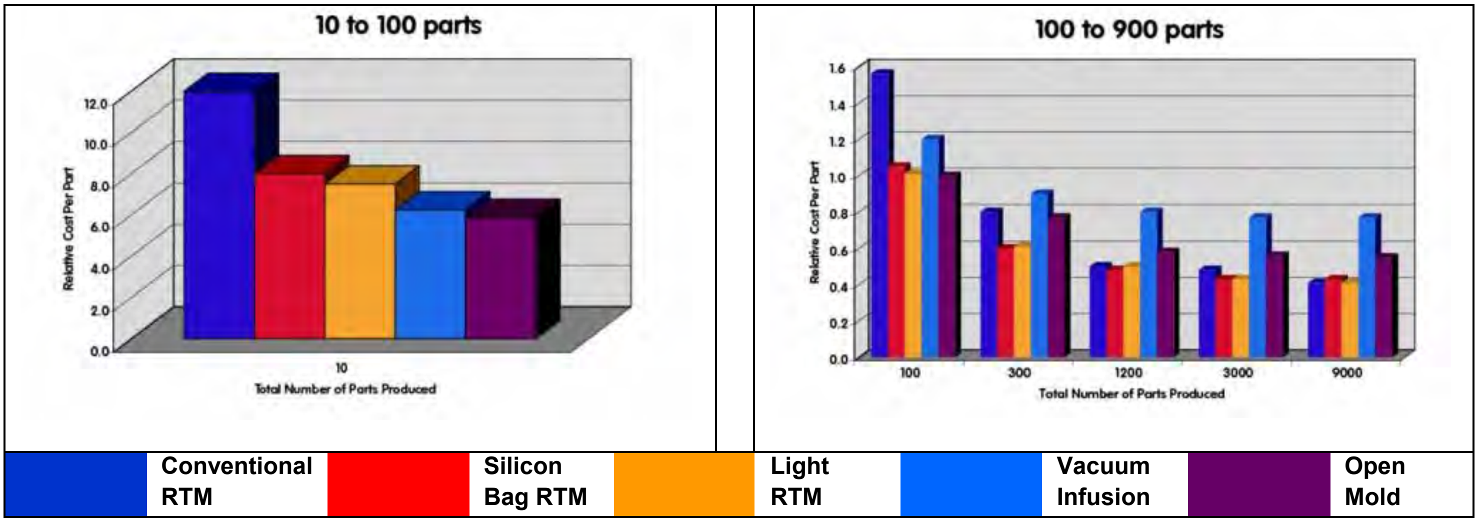


Figure 2-27. Process Trade Study Cost Results

Table 2-9. Comparison of RTM Processes

Property	**Open Molding**	**Vacuum Infusion**	**Light RTM**	**Silicone Bag RTM**	**Conventional RTM**
Part Appearance	Part back side is rough	Part back side is matte	Part back side is smooth	Part back side is matte	Part back side is smooth
Strength	Acceptable	Comparable to open molding	Comparable to open molding	Comparable to open molding	Comparable to open molding
Cost Effective Production Run Size	<100 parts	<200 parts	100 to 9,000 parts	100 to 9,000 parts	>1,000 parts
Emissions	0.126 lbs./part	0.064 lbs./part	0.064 lbs./part	0.064 lbs./part	0.064 lbs./part

3. Open Molding-Conventional Gel Coat

Overview

- **Materials**
- **Color**
- **Spray Equipment**
- **Application**
- **Troubleshooting Guide**

3.1. Materials

Overview

- **Introduction**
- **Polymer**
- **Monomer**
- **Fillers**
- **Thixotropic Agents**
- **Promoters and Inhibitors**
- **Specialty Additives**
- **Pigments**
- **Quality Control**

3.1.1. Introduction

A conventional gel coat is a pigmented, polyester coating that is formulated for use in ambient temperature, open mold processes. The gel coat is applied to the mold surface and becomes an integral part of the finished product. The gel coat provides a durable, cosmetically appealing finish and also protects the part from environmental exposure.

Conventional gel coats are formulated from several components, including the polymer, reactive monomer, pigments, fillers, thixotropic agents, promoters, inhibitors, and specialty additives. The specific materials and amounts significantly affect the performance of the gel coat both in the manufacturing shop and in the part’s end application.

3.1.2. Polymer

Polyester polymers can have a wide range of properties, depending on the raw materials (acids and glycols) used to produce them. All polyester polymers have an unsaturated acid component, typically maleic anhydride. This unsaturation in the polymer provides sites for reaction with the monomer, also known as cross-linking. Polyester polymers used in gel coats also have a saturated acid component. In some cases, the saturated acid has been orthophthalic acid, but the most commonly used saturated acid is isophthalic. Polyester polymers containing orthophthalic acid have been used in gel coats for general purpose applications. Polyester polymers containing isophthalic acids impart superior weathering, water resistance, and chemical resistance properties to the gel coat. (See the section on General Chemistry of FRP Composites in Chapter 2 for more information.)

3.1.3. Monomer

The monomer fulfills two roles in a gel coat. The first role is to react and cross-link with the reaction sites in the polymer to form a cross-linked thermoset material. Secondly, monomers reduce the viscosity of the gel coat to a workable level for application. Some common monomers used in gel coats are styrene and methyl methacrylate (MMA). The amount and combination of these monomers affect the flash point, evaporation rate, reactivity of the system, weathering properties, and other characteristics. Regulations typically limit the type and/or amount of monomers that can be used in gel coats.

3.1.4. Fillers

Fillers are used to achieve certain characteristics of the gel coat and also influence spray properties. Fillers can influence the cured physical properties of the gel coat, as well as resistance to water and other environments that may change color or influence chalking. Commonly used fillers are calcium carbonate, talc, and aluminum trihydrate.

3.1.5. Thixotropic Agents

Gel coats are formulated to be thixotropic, i.e., have a viscosity that is dependent on shear rate. A gel coat should have a low viscosity during spraying, which is a high shear operation. Once deposited onto the mold and under low shear, the gel coat should recover to a high viscosity to prevent sag. This thixotropic behavior is obtained through use of thixotropic agents. These materials form a network with the polyester polymer through hydrogen bonding. During high shear this network breaks down and lowers the viscosity of the gel coat. After the high shear is completed, the network reforms, or recovers, and the viscosity of the gel coat increases. The faster the rate of recovery, the lower the risk of sag but the higher the risk of air entrapment.

The thixotropy of a gel coat is commonly determined by measuring a low shear and a high shear viscosity of the product and calculating the ratio of these two values. The ratio value is reported as Thixotropic Index (TI). Two major classes of thixotropic agents are fumed silica and organoclays. Other thixotropic agents called synergists are used to further enhance the thixotropic network.

3.1.6. Promoters and Inhibitors

The types and levels of promoters and inhibitors used in gel coats determine the cure behavior including gel time and lay-up time. The gel time must be long enough to allow for spraying, air release and leveling. The lay-up time must be short enough to meet desired production rates. Short gel times reduce the possibility of under cure issues, including alligatoring, caused by styrene solubility of the gel coat. Short cures can also improve gloss, but are more prone to prerelease.

Most gel coats are cured under ambient conditions with peroxide initiators (catalysts).

Promoters, also called accelerators, split the peroxide into free radicals. These free radicals attack the unsaturation sites in the polyester polymer, preparing them for reaction with the monomer. The most common promoter used in gel coats is cobalt. However, cobalt by itself does not typically result in proper cure behavior.

Other materials called co-promoters are used to further enhance the cure behavior. Co-promoters enhance the ability of promoters to split the peroxide catalyst into free radicals. They are very effective in shortening the gel time and accelerating the cure rate.

Inhibitors provide shelf life stability to gel coat, as well as help control the gel time. Free radicals generated in the gel coat during storage or after addition of peroxide react preferentially with the inhibitors. Only after all the inhibitors are consumed does the cross-linking or curing process begin.

3.1.7. Specialty Additives

In addition to the above materials, a number of other additives can be used in gel coat formulations to effect properties. Some examples include air release agents to reduce porosity and UV absorbers and light stabilizers for weathering performance.

3.1.8. Pigments

Pigments are used to produce gel coats in a wide variety of colors. The specific pigments used determine not only the color of the gel coat and fabricated part, but also significantly affect performance characteristics of the coating.

Pigment type and concentration affect the hiding capacity (opacity) of the gel coat. Bright yellows, oranges, reds and dark blues will have slightly less hiding capacity than pastels. The high pigment loads necessary to achieve better hide with these bright colors can cause spray and cure problems. Careful pigment selection can also slow chalking that occurs with outdoor exposure and provide an abrasion resistant coating that can be readily cleaned, waxed and buffed to a high gloss.

The most commonly used pigment in gel coats is titanium dioxide. Titanium dioxide is the primary pigment in white gel coats and is also used in combination with other pigments in non-white colors.

3.1.9. Quality Control

When producing gel coats, manufacturers run a variety of quality control tests to ensure that the product being produced will meet the end-users needs. Standard quality control tests for gel coat are gel time, viscosity, Thixotropic Index, weight per gallon, color, sag, porosity, pigment separation and hide. Each of these tests is briefly described below.

Quality control values typically reported on a certificate of analysis (COA) include the gel time, viscosity, Thix Index, and weight per gallon. See Appendix A for additional information on quality control testing procedures.

Gel Time

The gel time is a measure of the time required from catalyzation for the gel coat to turn from a liquid to a solid. With few exceptions, gel time tests are run at 77°F (25°C) on a 100 gram sample of gel coat using 1.8 percent of a standard 9.0 percent active oxygen MEKP initiator. The 100 gram mass or cup gel is a standard in the FRP industry for characterizing gel coat cure. These parameters are valuable to the resin manufacturer when producing the product and to the end-user for verifying that the product will be suitable for use in their process. However, it is important to the fabricator to understand that the reaction that takes place in 100 gram mass will not correspond to the reaction observed in the actual application. Specifically, the gel of the 100 gram mass is faster and reaches a much higher exotherm temperature than the sprayed film.

Viscosity

Viscosity is a measure of how a liquid material flows when a force is applied. The higher the viscosity of the material, the more resistant the material is to flow. For example, water has a lower viscosity or flows more easily than molasses. Gel coat viscosity is typically measured using a Brookfield RV model viscometer with a #4 spindle at 4 RPM. The spindle speed will vary depending on the gel coat. Viscosity is measured at 77°F (25°) and reported in centipoise (cps).

Thixotropic Index (Thix)

The Thix Index indicates the dependence of the gel coat’s viscosity on shear rate. It is typically reported as the ratio of the Brookfield viscosity readings with an RVF #4 spindle at two (2) and twenty (20) RPM (2/20) at 77°F (25°C).

Weight per Gallon

The weight per gallon is the density of the gel coat and is reported in pounds per gallon. It is measured at 77°F (25°C).

Color, Sag, Porosity, and Pigment Separation

A color panel is prepared for each batch of gel coat and compared against a color standard. This color panel is also used to visually check sag resistance, porosity/pinholes, and pigment/resin separation.

Hide

Hide is evaluated by drawing down the gel coat sample on a gray and white patterned paper. The draw down bar is tapered creating a variable gel coat film thickness. The gel coat film is visually inspected to determine the point at which the pattern on the paper is no longer visible. The gel coat thickness at this point is measured using a mil gauge. Refer to Figure 3-1. This mil gauge thickness is the hide. The thickness required for hide is generally less than the recommended gel coat thickness.

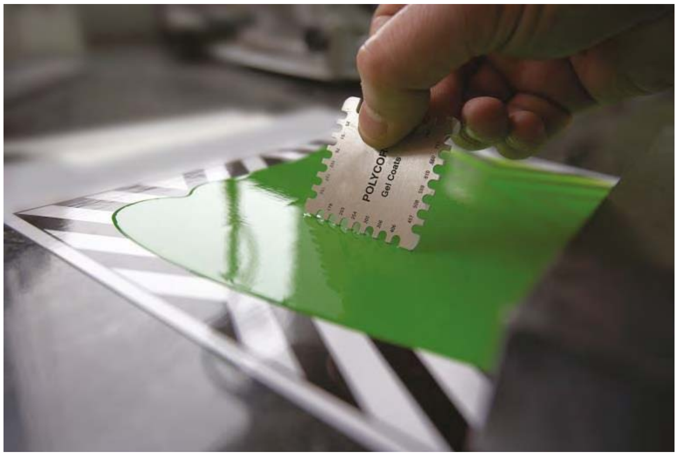


Figure 3-1. Gel coat hide test.

3.2. Color

Overview

- **Introduction**
- **Describing Colors**
- **Color Matches and Standards**
- **Color Matching Instrumentation**
- **Color Determination**
- **Color Matching Techniques**
- **Tinting**

3.2.1. Introduction

Color perception is unique to each individual. The human eye can differentiate among 300 colors from memory and about 10 million colors when placed side by side; yet color is very hard to define or explain.

Texture and gloss also affect color perception. These will cause a color change with viewing angle. In general, the glossier something is the darker and more saturated (less gray) it appears. An example of this may be seen by sanding an area of a dark gel coated panel. The sanded area and sanding dust will appear to be whiter than the unsanded panel. This effect is due to how light is reflected from that roughened area.

The type and amount of light under which an object is viewed affects its color. Visible light is measured by wavelengths using ‘nanometers’ as the unit of measure. A nanometer is equal to one billionth of a meter. Wavelengths of light outside the visible spectrum (Figure 3-1) are not seen by the human eye.

When all light is reflected back from a panel, the color is ‘white.’ If the panel surface absorbs all light, it is ‘black.’ If the panel absorbs all the wavelengths except the ‘red’ wavelength, it is ‘red.’ But if a red light is shined on a white panel, the only wavelength of light it can reflect is red and the panel appears to be red.

To review a color properly requires a light source which has all the visible wavelengths of light. North daylight is considered the classic standard for color viewing. But even daylight changes from day to day. Artificial lights are strong or different in one area. Tungsten-A lights are strong in the yellow-red range, giving a yellow-red cast to an object. Incandescent lights are rich in red. Mercury vapor is deficient in red, giving a greener cast to objects.

Each pigment or dye has unique absorption and reflection characteristics in the visible light spectrum and is dependent upon the light source as well. For this reason, one type of yellow pigment used in a color chip appears different than another yellow pigment used on a chair. They may not always appear to be the same color depending on the light. Under one light source, yellow objects may appear to be the same color, but in another type of light, they will appear to be different (i.e. more red, more green). This is called color flip, or metamerism. The amount of light also affects color. It is difficult to determine color differences in a darkened room or in a very bright light.

Color is quantified instrumentally using three pairs of antagonistic color contrasts. The contrast pairs are shown in Table 3-1. Using these pairs, the eye determines all colors.

Table 3-1. Color contrasts.

Color Contrasts

Light	**vs.**	Dark
Red	**vs.**	Green
Yellow	**vs.**	Blue

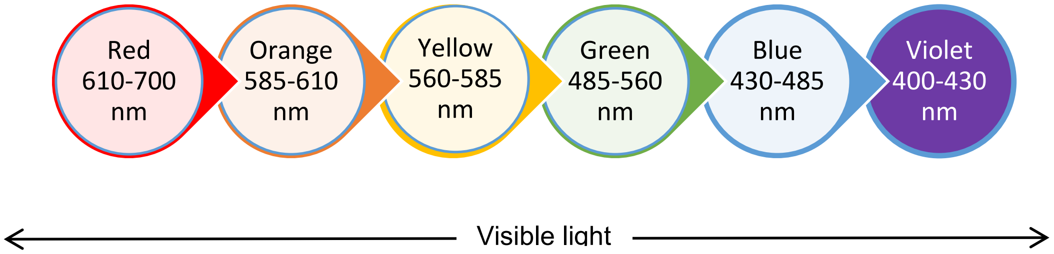


Figure 3-2. Color wavelengths.

3.2.2. Describing Colors

Three terms must be used to describe any color: hue, chroma and contrast.

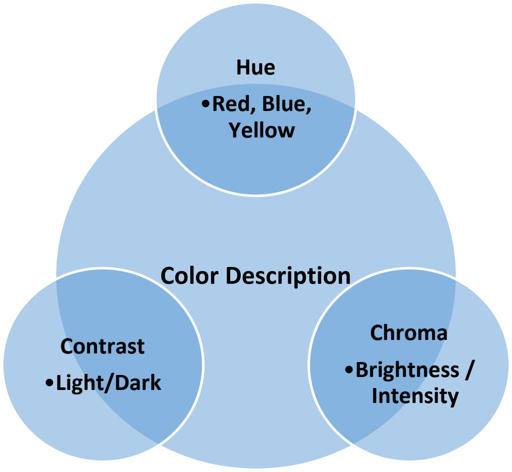


Figure 3-3. Primary colors—red, blue and yellow are hues; Chroma is brightness/intensity of a color; Contrast is lightness or darkness.

3.2.3. Color Matches and Standards

Criteria for judging a color match is like any other test: all variables must be held constant except the object being tested. Or, in simpler terms, one wants to judge colors under the same conditions and using the same standard.

A number of things can affect color. These must be held constant in order to judge color.

Observer

The person who is judging color must be free from any type of color blindness. Many times the opinions of two or three people are used as a safeguard. Instrument type and accuracy will influence measurement values. Instrumentation is described in this section.

Light Source

The type of light affects the color. Therefore, the best judgment of color is made when two or more different types of light are used for viewing. The classic standard is north light. To use this method, the tester stands with his or her back to a north light, holding the panels to be judged out in front at a 135 degree angle. The color is checked again under an incandescent or fluorescent light. When color judgments are critical, a light booth is used. These booths have multiple light sources, typically, daylight and horizon (yellowish).

Background

Color is influenced by the background or surroundings. Best color judgments are made when the background is a neutral dull gray. Color booths have a light gray viewing background.

Viewing Angle

The standard and test panel should be positioned side-by-side at the same angle. The best color viewing angle is 135 degrees. The best viewing of gloss is at the same, but opposite, angle from the light source. Switch the panels from side to side to prevent bias.

Size and Texture

The object size affects color perception. A larger area observed provides a broader color sample. The smaller the area observed, the more limited or restricted the perception.

Texture and gloss also affect color perception. Higher gloss is perceived as darker, while lower gloss appears lighter.

Temperature and Humidity

Pigments are subject to color change depending upon conditions. When temperature alters the color, then the object is considered to be 'thermo-chromatic.'

Standard

The choice of a standard is very important. It should:

- Not change color with aging
- Be uniform in color
- Be the same material as the test panel
- Measure at least three inches by five inches

Three types of standards are as follows:

A. **Master Standards**—This type is used to set the original color. It is stored in the dark when not in use and should be refrigerated to prevent color change. It is only used as a final color check or as a reference for what the absolute color should be.

B. **Working Standards**—These standards are the ones that are used in the preliminary comparison for color. They can be sections of the master standard or the agreed upon 'perfect match.' As these standards are handled daily, exposed to light and general wear, they will drift in color. These standards must be checked periodically against the master and discarded when they drift too far from the original.

C. **Electronic Standards**—These standards are spectral measurements by instrument stored on a color computer. Master and working standards can be replaced. Color drift is limited by the instrument accuracy.

Once the standard method of viewing and variances is established, there are still a few things to remember:

- When a new standard is selected, all holders of the old one must also change the standard at the same time.
- The supplier must be provided adequate time and a target date to switch over to the new standard. When comparing batch to batch, always refer to the standard. It is possible to obtain a batch on the light side of the standard (good match) and a second batch on the dark side of the standard (good match), but the batches might be unacceptable matches to each other.

3.2.4. Color Matching Instrumentation

Although there are instruments to help in color matching and judgments, these will not solve color problems. There are two types of instruments: those that measure color magnitude differences (tristimulus colorimeter) and those that measure color wavelength differences (spectrophotometer). Each instrument has its own limitations. They are still dependent on a consistent reference standard and a good test panel with the same gloss as the standard.

If the standard used to set the reference point is mottled (not uniform color) or distorted, the reference point will vary. If the test panel is distorted or different in gloss, it will provide different readings in different viewing areas. In some wavelengths of color, one instrument will be more accurate than others. Usually, dark colors are more difficult. Some of these instruments include:

- **The Colorimeter**—This device views color differences using three color filters in groups of wavelengths. A standard is placed under a view port and the machine reference points are set. Then the sample is inserted and color difference is read from the four readings shown in Table 3-2.

Table 3-2. Colorimeter color readings.

Color Differences	Negative (-)	Positive (+)
dL	dark	light
da	green	red
db	blue	yellow
DE (ΔE)	Total color difference	

This instrument is good for determining which direction a batch is off and can be used for tinting.

- **Spectrophotometer-**When coupled with a computer system, these newer and more expensive systems provide more (and more useful) information. These instruments use a monochromator that measures wavelength by wavelength, detecting the amount of light reflected by the standard versus the test sample. Multiple light sources are used for the four readings for each light shown in Table 3-3.

Table 3-3. Spectrophotometer color readings.

Color Differences	Negative (-)	Positive (+)
DL	dark	light
DCRG	green	red
DCYB	blue	yellow
DE (ΔE)	Total color difference	

These readings can be given in various color systems, such as MacAdam, CMC, CIE, or Hunter units. One MacAdam unit is normally considered as the minimum amount of color difference to be detectable by the normal human eye. Besides measuring color differences, this instrument will spot metamerism (color differences based on lighting conditions) and aid in formulating and tinting batches by selecting pigments for the best possible color match.

NOTE: These instruments are helpful, but the final decision on suitability of a color match should always be made with the trained eye. These instruments can produce numbers that indicate a good match, while visually it is not, or the match may appear closer than the numbers indicate.

3.2.5. Color Determination

Now that the conditions are set for viewing a color match, the hardest part involves judging the color. Does the test panel match the standard or is it just an acceptable match? It is nearly impossible to make a product over and over so that each batch perfectly matches the standard.

It can be a challenge to set up allowable limits of color differences. To set up allowable color variances, first determine how important color differences are. If the final product is sold as one item part and will rarely be next to another part of the same color, a wider variance is more acceptable. If parts are used side-by-side or need to match the color of another part, the variance in color must be kept at a minimum. Usually, reasonable allowable color variations are set by trial and error and are not absolute. Keeping samples of acceptable batches is one way to get a feel for allowable variance.

NOTE: Tighter color control will take more time and therefore cost more.

In comparing color, there are two possible approaches:

- **Visual**—Subjective, but usually the final determining method.
- **Instrumentation**—Quantifiable and easily defined, but may be misleading if numeric values are not properly interpreted.

Before covering the specifics of these individual approaches of color comparison, some general considerations must be given.

Rating system

Whether comparing the color with the unaided eye or by instrumentation, a rating system is useful. At Polynt Composites, color matches are rated as AA, A, B, or C in quality.

Color Standards

Color standards are made with gel coat products. These standards can drift in color. Whites and off-whites can drift the most. To slow this color drift, storing the gel coat standards in a freezer is recommended. The life of a standard may be extended to a year or more by this method.

Sample

For this discussion, sample refers to a cured gel coat film. This film may be laminated or simply ‘taped’ (gel coat film backed with masking tape). The preparation of the sample is important to standardize. Factors which influence the final color are:

- **Agitation—**The amount of mixing prior to application and the application method (drawdown, conventional spray, airless spray, etc.).
- **Catalyst Level—**The gel coat color typically becomes comes darker and greener with more catalyst.
- **Curing**—The gel coat color will differ depending on the temperature at which it is cured as well as the cure time. Higher curing temperatures may make the color darker and cause yellowing.

  NOTE: Gel coat castings made for color comparisons are not reliable since the exotherm of a gel coat in a mass may cause color variations.
- **Thickness of the gel coat film and type of substrate—**Thin gel coat films will present different color appearances depending upon the color of the substrate. Gel coats typically will hide at 15 mils cured film thickness. Bright colors, such as reds and yellows, typically require 20 to 25 mils cured film thickness for appropriate coverage. Thinner films might allow the substrate to show through the gel coat film, affecting the perceived color. Tape-backed samples might read lighter than laminated samples.
- **Low-gloss samples will appear lighter-**There is a color difference between the front and back of a gel coat film. Color comparison of the gel coat versus the standard should be made using the front or mold side. Obtaining the same color on a respray of a particular gel coat is limited by the above factors. Generally, the variations are hardly noticeable (if at all) to the unaided eye; however, for tight color control, all factors must be considered.

Visual comparisons

Visual comparisons are, by far, the most common method. No matter what instrumental readings may show, the color match must ‘look’ good.

Visual comparisons are usually the final determining factor in acceptance of a color match. The light source, background, and observer influence the decision. There is no way to eliminate the subjectiveness created by the observer; however, the other factors can be standardized.

Note: Generally, three-inch by five-inch color panels are compared under a standard light source in a light booth. Panels are placed side-by-side at a 135 degree angle. Viewing colors under more than one light source is important in identifying the metamerism.

Instrument comparisons

Polynt uses only high-accuracy spectrophotometers. With this type of equipment, Polynt can accurately correlate data generated from one instrument to another and from one day to another. Without this type of equipment, accurate color comparisons against stored or absolute values are not possible. Also, because of the variation of instruments, coordinating the readings of two different models of instruments (even from the same manufacturer) is not possible when Class A color matches are desired.

CAUTION: Taking a single instrumental reading of a large panel may not provide a representative reading of the overall panel. When possible, Polynt suggests taking multiple readings of the standard and sample, using the average color values for determining color differences.

3.2.6. Color Matching Techniques

Polynt believes the following method of color matching provides the most accurate and reproducible production color matching in the industry. The electronically stored value provides a consistent standard regardless of the Polynt manufacturing site, and eliminates the inherent color drift of ‘master standards’ that are based on FRP polyesters (even under freezer storage), or from damage to standards due to day-to-day handling.

Polynt does not recommend matching to the ‘last batch’ panel or by side-by-side drawdown since these techniques lead to a color drift from the standard. This is particularly true for whites and off-whites where there is a natural tendency of the observer to approve the current batch on the light and clean (red and yellow) side of the ‘last batch.’ There is also a natural shift of color in the container for whites and off-whites to the light and clean side due to the interaction of promoters and fillers/thixotropes over time.

A. **Equipment**—Datacolor’s 600 series spectrophotometer with formulated correction software.

   Note: Sample preparations using system ingredients are required. Accuracy is critical to successful formulation and correction.

B. **Calibration/verification**—Calibrate instrument at initial setup, after repair, or at any time where output is in question. Individual instruments are verified by a ‘color tiles’ test on a weekly basis. Further instrument accuracy can be confirmed by a BCRA (British Ceramic Research Association) color tiles test.

C. **Color standards**—Electronically stored spectrophotometric values as determined on a master instrument maintained in Polynt’s Kansas City Corporate Research facility. These electronically stored values are shared among all Polynt plants through a common electronic network.

D. **Color sample preparation**—Catalyze and spray out onto a freshly waxed glass mold. Cure for 30 to 40 minutes at 150°F (66°C). Apply masking tape to the back side and demold.

   Note: Mold preparation, the amount of catalyst added, spraying, and cure cycle have a dramatic influence on color. These parameters must be controlled carefully.

E. **Tolerances and measurement methods**—Color readings are Specular Included (eliminates influence of gloss and distortion of the color sample) and color differences are computed by the CMC (1.00:1.00) method.

   Typical color match tolerance is 0.30 ΔE (barely detectable visually). Other DE tolerances are used depending on product, color, and customer requirements. A visual reference to the ‘last batch’ or ‘a master standard’ may also be required as an additional precautionary step.

3.2.7. Tinting

At times, tinting in the field is required (for example, for a part made several years previously which must now be patched, or for a one-time small job). To do this. tinting accurately and quickly requires skill and experience. Polynt normally does not recommend tinting in the field, but for those who must do this, there are a few rules:

A. **Use only pigment concentrates** designed for polyester.

B. **Tint at least one-half gallon** of gel coat at a time. It is much harder to work with small quantities.

C. **Make small additions**, mixing well and scraping down the sides of the container between additions. These additions should get smaller as the color comes in closer.

D. **To determine the undertone** of a concentrate, it is helpful to check that concentrate in white.

E. **Obtain the basic color shade** first (i.e., yellow, blue), then look for shade differences (i.e., redder or greener, etc.)

F. **If the match is not good** at the start, put a wet spot of the batch on or next to the wet solid part. As the color gets closer, it will be necessary to switch to catalyzed sprayouts because some colors change from wet to cured.

G. **Once a match is made**, record what pigments and amounts were used to obtain the color, in case it has to be matched again. Listed below are the approximate effects of adding the following pigment concentrates:

Table 3-4. Effects of adding pigment concentrates.

COLORANT	COLOR EFFECT	
	Primary	**Secondary**
Titanium Dioxide or TiO_2	Lighter	Chalky in dark colors
Carbon Black	Darker	Gray in pastels
Phthalo Green	Green	Darker
Phthalo Blue	Blue	Darker
Iron Oxide Red	Red	Darker; pink in pastels
Ferrite Yellow	Yellow	Red

3.3. Spray Equipment

Overview

- **Introduction**
- **Equipment for Operating a Spray Gun**
- **MACT-Compliant Gel Coats**
- **Spray Equipment Considerations**
- **Types of Spray Equipment**
- **Spray Selections and Settings**
- **Calibration**
- **Clean-up Procedures**
- **Maintenance**
- **Equipment Troubleshooting**
- **Additional Equipment Information**
- **Equipment Suppliers**

3.3.1. Introduction

The application of gel coat is an involved operation with its success dependent on the material, equipment, environment and gel coat operator. All of these factors determine the quality of parts produced.

Most gel coats in North America are designed for spray application. Brushing is generally not recommended. A well sprayed part will have good cosmetics and optimal performance. Selecting the appropriate spray equipment is of fundamental importance. Spray equipment is selected based on the method of delivering gel coat to the gun, the mode of mixing catalyst with gel coat, and the way in which the material is atomized, meaning dispersed into fine particles.

The information compiled in this section is designed to help in the selection of spray equipment and assist in determining preliminary settings. Since each ambient environment is different, only general recommendations are provided. The plant or shop, operator, production speed, and the part will ultimately determine the exact equipment, spray gun(s), and settings to be used. It is important to read the spray equipment manufacturer's manuals, parts lists, and safety guides before use.

3.3.2. Equipment for Operating a Spray Gun

Before spraying gel coat, a number of conditions in the surrounding area must be considered, such as temperature (77°F (25°C) is ideal), effective exhaust ventilation, and a means to confine gel coat overspray.

To use a spray gun efficiently and safely, the following items need to be considered:

- Ventilation
- Manifolds & Regulators
- Moisture & Oil Traps
- Heaters
- Quick Disconnect
- Hoses
- Main Air Lines
- Compressor
- Pump Accumulators

Ventilation

Figure 3-4. Gel coat spray booth, *Source*: Gruber-Systems.com

Fabricators must abide by state and federal regulations for design, location and construction of spray booths/rooms and for the type and amount of chemicals being used. A properly designed and safely operating spray booth is required for protection of booth operators, the environment, and for production of quality finished parts. In spray booths, rooms, or areas, exhaust ventilation systems are needed to exhaust contaminated air (gel coat fumes) away from the work area and replace it with clean air. In order to ensure that an area is properly ventilated, it is important to consider the size of the part being sprayed and the spray area. A spray area should have an exhaust fan that is rated at the necessary exhaust rating, expressed as cubic feet per minute (CFM), to ensure that airflow is at the ideal rate. The National Fire Protection Association (NFPA) standard for spray application using flammable or combustible materials (NFPA 33, 1995), estimated sufficient airflow velocity of 100 feet per minute (FPM) can be used to calculate a sufficient CFM rating for an exhaust system. Keep in mind that compliance with NFPA 33 (ed. Chapters 4-5, 2011) does not ensure conformity with the Clean Air Act standards for exhaust emissions.

A. Size—General 'Rule of Thumb'

The size of the spray booth is governed by the size of the part.

Measure the largest part to be sprayed and increase the size of the booth by the minimum dimensions shown below to ensure adequate working area.

Height—add minimum of 2 feet
Width—add minimum of 4 feet
Length—add minimum of 6 feet

B. Air flow

There are two methods for measuring air flow: 1) air volume (cubic feet per minute, CFM); and 2) air velocity (feet per minute, FPM). The amount of exhaust air needed for the spray booth is calculated by multiplying the booth area (width x height) times the typical FPM. The average air velocity required to expel fumes is 125 FPM.

Exhaust air: CFM = width x height x 125

To figure out the existing air velocity (FPM), divide the exhaust by the booth filter area.

Air velocity: FPM = CFM / Booth filter area

It is recommended to use disposable filters only.

Lights and electrical switches in the booth need to be explosion proof. Contact equipment supplier for recommendations.

Manifolds and Regulators

Manifolds and regulators should have a CFM capacity of at least 1½ times the total CFM required by the equipment they supply.

Table 3-5. Example of the amount of exhaust air (CFM) required for tools.

Tool	CFM Required
Air motor	4
Polisher	2
Sander	5
Dusting gun	2.5
Nailers and staplers	6

Atomizing air should be on a separate regulator with a water trap. All gauges must be readable, working correctly, and should be permanently attached.

Moisture and Oil Traps

Moisture and oil traps should be installed and drained daily on all air lines at the spray booth. These not only keep contaminants out of gel coats but also protect and lengthen spray equipment life. Do not install moisture and oil traps within 25 feet of a compressor.

Heaters

Polynt does not recommend using band heaters because of the possibility of creating localized hot spots, which can cause the material to prematurely gel.

Quick Disconnect

If quick disconnects are used, use the largest size possible. Quick disconnects can reduce the volume of air and fluids that pass through them. If a quick disconnect is used on fluid lines, a ball valve may be installed in front of it to help reduce leaking.

Hoses

Hoses should only be used for delivery of air and fluid from a regulator on a main air line or fluid pump to the gun. The length should not exceed 50 feet (normally only 25 ft.)

Hoses should be large enough to deliver the proper volume of material at the appropriate pressure that the gun demands when the trigger is pulled. A pressure drop will always occur between the source of the air or fluid and the exit.

Table 3-6. Drop in air pressure that takes place when using various hose sizes and pressure settings.

	Pressure (lbs.)		
	60	**70**	**80**
¼" I.D. air hose	**Drop in Pressure at Spray Gun (lbs.)**		
20 ft.	16¾	19½	22½
25 ft.	19	22½	25½
50 ft.	31	34	37
5/16" I.D. air hose			
20 ft.	5½	6	11½
25 ft.	6¾	7¾	13
50 ft.	8	8¾	14½
⅜" I.D. air hose	**Non-MACT Compliant (1)**		
20 ft.	13	15	17
25 ft.	15	17	19
50 ft.	24	26	28½
½" I.D. air hose	**MACT Compliant**		
20 ft.	9	11	14
25 ft.	10	12	16
50 ft.	14	16	20

(1) **½" I.D. air hose is also acceptable.**

NOTE: Catalyst and airless hoses are made of special material. Consult the equipment manufacturer about replacement parts.

Main Air Lines

The main air lines should be made of steel pipe and should meet the following requirements:

- Large enough to supply air to all facilities with no CFM or pressure drop.
- Capable of supplying the pressure and volume of air to run all air-powered equipment used at the same time.
- Laid out as straight as possible.
- Minimal fittings.
- Drop lines that come off the top of main air lines.
- Slant lines to drain any water to one end, with a low-end drain.
- Air lines off drop lines that are not taken off the end but at least 12 inches above a drain valve should be on the bottom.

Air lines should be pressure tested for leaks annually.

Recommendations are shown in Table 3-7.

Table 3-7. Minimum pipe size recommendations.

Minimum Pipe Size Recommendations			
Compressing Outfit		Main Air Line	
Size (HP)	Air Flow (CFM)	Length of Pipe	Pipe Size I.D.
3 & 5	12 to 20	≤ 200 ft.	¾ inch
		> 200 ft.	1 inch
5 & 10	20-40	≤ 100 ft.	¾ inch
		100 to 200 ft.	1 inch
		> 200 ft.	1¼ inch

Compressor

The compressor must supply the volume of air required by all air tools in the plant (total draw plus 50 percent).

If a compressor is to be purchased, estimate the future requirements for all air tools in the plant and match the compressor size to the estimate.

Rule of thumb: one (each) horsepower delivers approximately four cubic feet per minute (CFM) of air.

1 HP ≈ 4 CFM

Pump Accumulators

The fluid pump accumulator is also called surge chamber. The accumulator is a cylinder that is designed to act like an air shock to dampen or minimize pressure drop when the pump changes direction. The accumulator is typically located on the pressure side of the fluid delivery system and is an integrated part of the filtering system.

3.3.3. MACT-Compliant Gel Coats

With the emphasis on reducing the emissions of Hazardous Air Pollutants (HAP), Maximum Achievable Control Technology (MACT, or MC) Compliant gel coats have been introduced to the industry. Since MC gel coats have less monomer, they will pump, spray, and flow differently than non-MC gel coats.

Because MC gel coats are high solids gel coats, they do not flow through hoses or pipes as easily as non-MC gel coats. There is a greater pressure drop at the end of small hoses or pipes while spraying.

Since lower spraying pressures are needed and there are fewer monomers in MC gel coats, material temperature and fluid line size become more critical.

Temperature

For good spray characteristics, the temperature of the MC gel coat should be 70°F (21°C) or higher. Fewer problems will be encountered if the work area is temperature controlled (preferably 80°F (27°C)), rather than relying on the use of band heaters or in-line heaters.

A. **Band (Drum) Heaters**-Use of band or drum heaters is not recommended because gel coat is an insulator and can be overheated very easily, which will cause premature gelation. Also, malfunctioning thermostats or heaters left on overnight can cause the whole drum to gel.

B. **In-Line Heaters**-Use of an in-line heater will allow use of smaller tips as well as lower flow rates.

While in-line heaters present fewer problems than band or drum heaters, gelation can occur. If an in-line heater is used, make sure it can be disassembled and bored out if gelation occurs.

Also, when using in-line heaters, the lines should be insulated. A bypass valve near the gun can be used to draw off material until heated gel coat reaches the gun. This valve should be a locking type, so it cannot be accidentally bumped on. The material coming out of the gun should be 90-95°F (32-35°C). Do not heat gel coat over 100°F (38°C) because stability is greatly decreased as the temperature rises.

Fluid Line Size

For non-MACT-compliant gel coats, a 3/8-inch hose with a 3- or 4-foot, ¼-inch whip works well, but a ½-inch diameter hose with a 3/8-inch whip works better because lower pump pressure can be used.

For MC gel coats, a ½-inch hose with a 3-foot, ⅜-inch whip is recommended for up to 50 feet.

For up to 75 feet, use a ¾-inch hose for the first 50 feet, and then drop down to a ½-inch hose with a 3-foot, ⅜-inch whip. Runs of more than 75 feet should be hard-piped with large lines, 1-inch or larger. For recommendations, contact your equipment supplier.

3.3.4. Spray Equipment Considerations

Before selecting a spray gun, consider the following.

QUESTIONS
Q: What type of part is going to be sprayed? Is it a small, large, flat, curved, simple, or complicated part?
Q: How many parts are going to be sprayed per day? Will they be sprayed all at once, spaced out evenly during the day, or at several different times?
Q: How many different colors are going to be sprayed through this gun?
Q: What are the future requirements for this spray gun, and will it be adaptable to other operations?
Q: Is it a **temporary or permanent installation**?
Q: **How much physical labor** is involved in this spray application, including the distance the gun must be moved to spray the part, time required to spray one part, dragging of hoses, setting up, and cleanup?
Q: **What type of a maintenance program** is in place or can be set up to protect this investment?
Q: **What are the safety precautions** that must be considered?
Q: **Do local air quality regulations require** or disallow a specific type of gun?

After answering the above questions, determine, in general, what type of gun is needed by looking at the characteristics of spray guns on the market.

3.3.5. Types of Spray Equipment

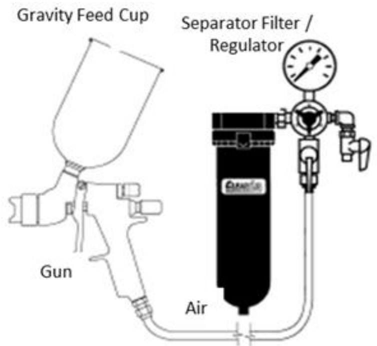
In general, a spray gun is selected according to how the material is delivered, the method of catalyzation, and by what method the material will be atomized.

Material Delivery

This refers to how the material is delivered to the gun. There are three methods of material delivery.

A. **Gravity**—Material is delivered from a cup above the gun and flows to the gun by the force of gravity.

Gravity feed guns are not commonly used for gel coats, except sometimes when spraying metal flake and very heavy (high viscosity) materials.

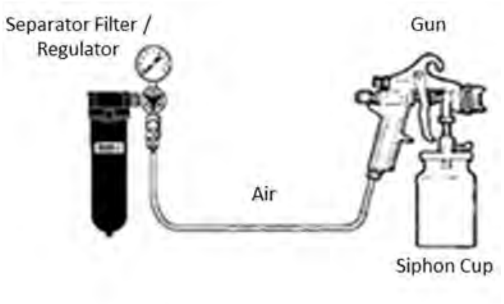


*HVLP Gravity-Feed, Source: Binks

Figure 3-5. Example of material fed by gravity.

B. **Siphon**—Material is siphoned from the cup to the spray nozzle, by passing air over a tube inserted into the material (no direct pressure on the material).

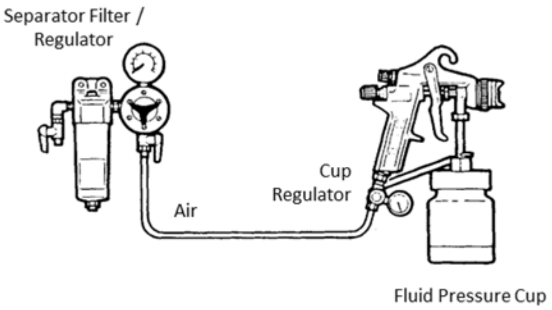
This process is not commonly used for making production parts due to slow delivery rates. It can be used for small jobs, such as patching.



*Siphon-Feed, Source: Binks

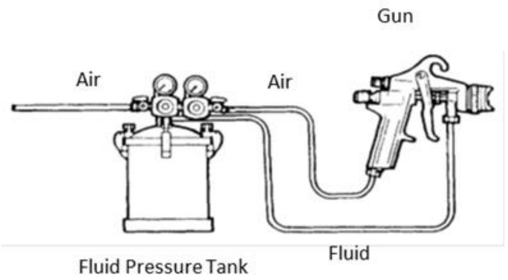
Figure 3-6. Example of material fed by siphon.

C. **Pressure**—Material is forced to the gun by direct air pressure from a pressure tank, piston pump, etc.



*Pressure-Feed Cup, Source: Binks

Figure 3-7. Example of material fed by cup pressure.



*Pressure-Feed, Source: Binks

Figure 3-8. Example of material fed by tank pressure.

With a piston pump, the air driven piston drives the fluid piston forcing the material out to the spray gun at high pressure. The difference between the diameter of the air piston and the fluid piston is called the pump ratio. Pump ratios can be from 2:1 (two to one) up to 33:1. This means that if a pump ratio is 4:1, there is 4 psi of fluid pressure for every 1 psi of air pressure (in theory).

Question—How much fluid pressure is at the spray tip with a 4:1 pump at 30 psi?

Pump ratio x Pump pressure setting = Fluid tip pressure

Answer: 4 psi x 30 psi
= 120 psi fluid pressure at spray tip

In actual practice, the delivery pressure is lower than theoretical. Pressure feed systems (mainly pumps) are the systems most commonly used with gel coats.

Method of Catalyzing Gel Coat

The method of catalyzing gel coat refers to how the gel coat is catalyzed, by ‘hot pot’, an injection system, or with a catalyst slave pump. The method of catalyzation can depend on the type of gel coat.

A. **'Hot Pot’**—Catalyst is measured into a container (pressure pot) and mixed in by hand. This is the most accurate method but requires more clean-up.

B. **Catalyst Injection**—Catalyst is added and mixed at (or in) the gun head, requiring separate lines and a means of metering catalyst and material flow.

C. **Catalyst Slave Pump**—A small slave pump is driven by the master fluid pump. It is engineered to deliver (by volume) ratios of 1-3% catalyst to the volume of gel coat/resin that is being delivered. Catalyst slave pumps are the most common systems used today for both gel coating and laminating.

Atomization

With a conventional air-atomized system, the material is ‘broken up’ by direct contact with an air stream at 60-90 psi. This can be done in several ways.

A. **Internal**—Air and gel coat meet inside the gun head and come out a single orifice (Figure 3-9). This system is not recommended for gel coats, except for one or two special type products, since it has a tendency to cause porosity and produce a rougher film. It also requires a solvent flush system. The internal mix nozzle is often employed in high production applications of materials where fine finish is not required. The internal mix air nozzle can be used only with pressure-feed systems.

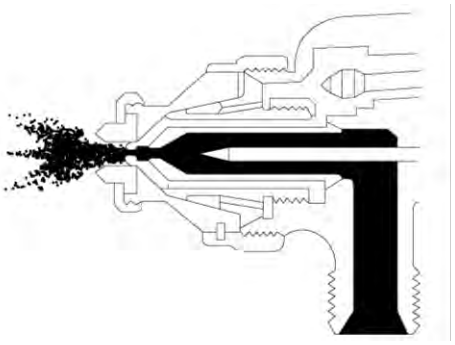


Figure 3-9. Internal spray gun.

Less air volume is required than with external mix nozzles and this, coupled with the lower air pressure, minimizes the amount of overspray and rebound. For this reason, internal mix may be referred to as semi-airless.

Disadvantages of the internal mix air nozzle are few but important:

- The spray pattern size and shape are controlled by the air cap.
- A relatively coarse atomization is produced (not suitable for fine finishes).
- Nozzles are subject to considerable wear (although replacement is easy and low in cost).
- Certain types of materials, such as ‘fast driers,’ clog the exit slot or hole.
- Film porosity is worse.
- The gun must be flushed after each use.

B. **External**—Air and gel coat meet outside of the gun head or nozzle. This is the most common system. The gel coat is atomized or broken up into a fine spray in three stages (Figure 3-10).

- **First Stage Atomization**—As the fluid being sprayed leaves the orifice of the nozzle, the fluid stream is immediately surrounded by an envelope of pressurized air emitted from the annular ring (Figure 3-10- #1) around the fluid nozzle tip. The resulting turbulence mixes or coarsely atomizes the fluid with the air.
- **Second Stage Atomization**—Immediately after the first stage atomization, the fluid stream is intersected by jets of air from converging holes (Figure 3-10- #5) on each side of the annular ring. Two straight holes indexed 90 degrees are containment holes which keep the stream from spreading. The turbulence occurring at the intersecting point of the material stream and air jets results in a finer atomization.
- **Third Stage Atomization**—The angular projections on the nozzle (often called ‘wings,’ ‘ears,’ or ‘horns’) contain passageways for the air jets. These jets intersect the stream just after second stage atomization, and at 90 degrees to the two sets of converging holes (Figure 3-10, #4). The primary purpose of these jets is to form or shape the round cross section of the fluid stream into an elongated one referred to as ‘fan’ shaped. Additional turbulence occurs at this point, resulting in additional atomization. The spray pattern size is determined by the design of the air nozzle, the fan control, the method of feeding the spray gun, and the cohesive nature of the material being sprayed.

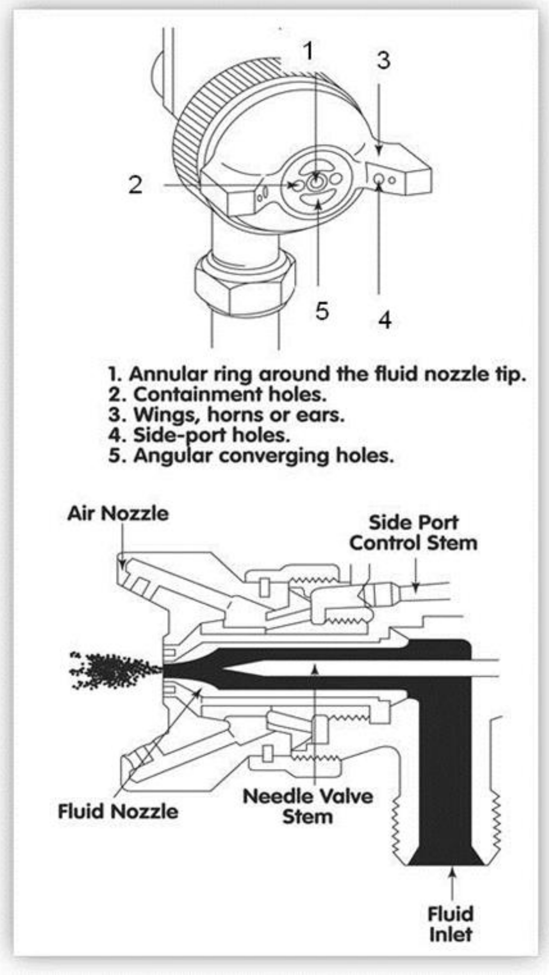


Figure 3-10. External spray gun atomizes gel coat in three stages.

C. **Airless Atomization**—The gel coat does not come in direct contact with compressed air nor is it atomized by air. Instead, a high ratio pump (22:1 to 33:1) puts the gel coat under high pressure (1,000-3,000 psi) and forces it through a small orifice (0.015 inch to 0.26 inch). As the material passes through the orifice, the material is atomized, similar to water as it exits a garden hose with a spray nozzle. Airless systems are used where high volumes of gel coat can be handled by the operator on large, essentially flat or open parts. It is cleaner and more efficient than conventional air atomized.

Contrary to what may be assumed, airless atomization does not atomize more monomer than conventional air atomized spray.

Tests have shown that a sprayed film will retain more monomer (harmful to yellowing and chalk) under these conditions:

- Airless atomization retains more styrene than conventional air atomized.
- Airless atomization retains more styrene than 'properly' atomized airless air-assist equipment.
- The closer the gun is to the mold, the more styrene is going to be retained.
- The fewer the number of spray passes, the greater the amount of styrene retained. Typically, a 'finer atomization' (small particles/droplets) will provide a finer orange peel, and therefore better gel coat film/surface/laminate, which will also offer better resistance to yellowing/chalking.

D. **Airless Air-Assist**—Equipment is a combination of conventional air atomization and airless techniques.

Material is supplied to the airless tip at much lower pressure (400 -1,000 psi) than for standard airless spraying, which is normally 1,000-3,000 psi. At this low pressure, however, the spray pattern is coarse and has poor atomization. Atomizing air is now introduced to the spray pattern at low pressure, typically 3-30 psi, to refine the spray pattern. Excess atomization would return the operation back to the state of conventional air atomization.

Pump ratios range from 10:1 to 30:1. High pump ratios will deliver higher fluid pressures at a given input air pressure. Higher pressures may be necessary for certain materials, such as MACT-compliant gel coats and vinyl ester gel coats.

With the low pressure and no atomizing air, a very coarse orange peel pattern is developed due to larger than normal droplets of gel coat hitting the mold. This causes a wide range of film thicknesses, as high as 20 mils at the high point and 11 mils at the low point.

This wide variance causes problems such as:

- Blister resistance on a 20/11 mils orange peel-type situation would only be as good as the 11 mils area, but with much more material actually used.
- Quick sand through in thin areas of orange peel.
- Roll out of skin coat over coarse orange peel is often more difficult and will contribute to a defect customers call shot-gunning or buckshot, which is small air bubbles trapped in the low areas of coarse orange peel. These small air bubbles show up on the finish after buffing or after the parts are heated in the sun.

A 22:1 or higher pump ratio is recommended to achieve a good breakup with pump pressures in the 30-75 psi range. This reduces wear and tear on seals, minimizes the effect of plant air fluctuations, and allows for adjustments due to wear on the tip.

E. **MC Gel Coat and Non-MC Air-Assist Airless or Airless Equipment**

Because MC gel coats contain less monomer, emissions are reduced. However, this also alters how the gel coats flow and break up.

MC gel coats are harder to spray than standard gel coats through air-assist airless and standard airless equipment, but this can be achieved.

Because MC gel coats flow differently, Polynt recommends a 22:1 pump to ensure that air pressures can be kept in the 40-75 psi range for better control and less wear on the pump. Pump pressure should be adjusted with the air assist turned on just enough to produce proper breakup. Always use minimum pump and air assist pressure.

Spray the gel coat on in a continuous film thickness of 6-10 mils per pass. Rely on a mil gauge, since the backside will have a different appearance than non-MC gel coats.

The chart below shows the recommended tip size and flow rate for various parts.

Table 3-8. Tip size and flow rate for various parts.

Part	Tip Size	Flow Rate (Pounds per Minute)
Clears & Small Parts	0.018"	2½
Decks & Complex Parts	0.21" or 0.23"	2½ to 3½
Large Flat or Open Parts (Hulls)	0.26"	4

F. **High Volume Low Pressure (HVLP)** equipment uses high air volume (measured in CFM) at low pressure to atomize gel coat. HVLP spray equipment is intended to cut down on emissions, or monomer loss. Government environmental legislation limits atomizing air pressure for HVLP equipment to a maximum of 10 psi. Similar application and monomer retention can be obtained with a conventional air atomized gun by reducing the atomizing air to a low level (Table 3-9, Test 5).

HVLP spraying results in larger droplets and a lower quality finish. Examples include: a film with very coarse orange peel (causing rollout to be more difficult); and a wetter, more styrene-rich film that is more prone to sag.

Note: Airless and air-assist airless spraying retains more styrene in the film than conventional air-atomized equipment.

Table 3-9. This table shows the monomer percentage found in gel coat film using different atomization methods.

PERCENT MONOMER IN GEL COAT FILM						
Control *(material not sprayed)*	**Conventional Air Spray**		**Airless**		**Air-Assist Airless**	**HVLP**
Test 1						
38.3%	32.9%		34.4%, (2140 tip)		—	—
Test 2						
			(1750 tip)	(2640 tip)	(2640 tip)	—
35.8%	—		20.7%	27.4%	24.9%	—
34.6%	—		—	28.0%	23.1%	—
36.4%	—		22.6%	28.6%	24.7%	—
Test 3						
41.8%	—		(2140 tip)		—	—
2 to 3 ft.*	—		34.7%		—	—
6 ft.*	—		30.8%		—	—
Test 4						
47.0%	—		(0.021 inch tip)		—	—
1.5 ft.*	41.4%		43.8%		—	—
3.0 ft.*	32.5%		41.7%		—	—
4.5 ft.*	—		40.0%		—	—
6.0 ft.*	—		37.4%		—	—
Test 5						
	(60 psi),	(20 psi),				
34.3%	26.6%	28.9%	—		—	29.0%

* Distance of spray gun from mold surface.

Table 3-10. Summary of spray equipment conditions and uses.

Item	Hot Pot A	Hot Pot B	Hot Pot C	Air-Atomized Catalyst Injection	Airless Catalyst Injection	Air-Assist Airless	FIT or Convergence
Material Supply	1 quart	2 quart	1 or 2 gallon	1 to 20 gal. pressure pot or pump	Pump	Pump	Pump
Part Size	Small up to 20 sq. ft.	Small to medium up to 40 sq. ft.	Medium to large 150 sq. ft.	Various	Various	Various	Various
Number Of Parts	One or two	One or two	One or two	Any number	Any number	Any number	Any number
Use	Intermittent	Intermittent	Intermittent	Constant	Constant	Constant	Constant
Switching Colors	Easy	Easy	Fair (hose must be cleaned)	Fair (separate pressure pots normally used)	Pump and lines must be cleaned	Pump and lines must be cleaned	Pump and lines must be cleaned
Future Use	Very flexible, tooling prototype small runs	Tooling, small jobs	Tooling, small jobs	Large production	Large production	Medium to large production	Large production
Portability	Easy to move	Easy to move	Easy to move	Fixed or cart mounted	Fixed or cart mounted	Fixed or cart mounted	Fixed or cart mounted
Number Of Hoses	One	Two	Two	2 to 4 hoses may be on a boom	2 to 4 hoses may be on a boom	2 to 4 hoses may be on a boom	2 to 4 hoses may be on a boom
Catalyst Measurement	Weight or volume	Weight or volume	Weight or volume	Metered (requires calibration)	Metered (requires calibration)	Metered (requires calibration)	Metered (requires calibration)
Mixed By	Hand	Hand	Hand	By gun	By gun	By gun	By gun
Cleaning	After each use	After each use	After each use	Wipe gun off intermittently. Clean pots or pump	Wipe off tips intermittently. Clean pots or pump	Wipe off tips intermittently. Clean pots or pump	Wipe off tips intermittently. Clean pots or pump

G. **Non-atomized Spraying, Fluid Impingement or Convergence**—With this method, gel coat is sent through two orifices in the head which converge or impinge on each other. When this happens, a fan pattern occurs. This is accomplished at lower pressures than with the other systems. Larger tips are used with less overspray. Note that the fan pattern will have a different appearance than with current systems (large droplets and slightly more orange peel.) Because of this backside texture, impingement systems are not commonly used with gel coats.

H. MC Gel Coat and Non-Atomized Application Technology (NAT)

Fluid Impingement Technology equipment uses two streams of gel coat which hit (collide) with each other to form the gel coat fan pattern. This is done under low pressure (11:1 pump) and produces larger droplets than an air-assist airless or airless setup. The lower pressure and larger droplet size account for the lower emissions and reduced over-spray. These factors will alter the appearance of the spray pattern.

Gun pressure settings will need to be adjusted, sometimes to settings that will be the opposite of those used with air-assist airless or airless systems.

The impingement tip will have two holes angled so that the fluid streams will meet (impinge) each other within an inch of the tip. Usually the first two numerals of the tip number will indicate the size of each hole (in thousandths of an inch). The third and fourth numerals doubled will indicate the approximate fan angle. The larger these last two numbers, the wider the fan pattern will be.

Tips are available in orifice sizes of 15, 17, 20, 22, 25, 27 and 30 (tip size below 17 is not recommended as plugging can occur). Fan angle sizes are 17, 20, 22, 25, 27 and 30. Starting tips for non-MC gel coats are 1720 or 2520, with a 40-60 psi pump pressure.

While larger tips are used with whites and colors, smaller tips may be appropriate for both colors and clears.

The chart gives examples of pressure drops for an MC white gel coat.

Table 3-11. Change in pressure at the gun with different tip sizes, pump pressure and hose lengths.

Tip	Pressure @ Pump (psi)	Feet of ¾-inch Hose or Pipe	Feet of ½-inch Hose	Pressure Drop at Gun
2520	700	20	0	0
2520	600	20	20	0
2520	650	0	40	-400
2320	500	70	0	-150
2320	700	70	0	-100

As a startup procedure, start the pump at zero, and increase the pressure in five psi increments until the fan droplets are all about the same size. This uniformity will appear immediately following the disappearance of the ‘fingers.’

NOTE: The droplets will be larger in size compared to using air-assist airless or airless equipment.

With impingement technology, spray will be coarser with a rougher pattern but will have fewer tendencies for porosity.

Do not adjust to achieve a finer particle size because porosity can occur, emissions may increase, and fan edges may be ragged. To clean up edges, use a small amount of refinement air.

Some adjustments will be opposite those normally used with air-assist airless and airless equipment. For example, with impingement technology, better breakup can be achieved by using a larger tip at a lower pressure. (Air-assist is not used for break-up. It is turned on only slightly to clean up fan edges. If turned too high, emissions go up and porosity occurs.) If breakup is not achieved, or if pump pressure is running above 80 psi, try a larger tip and/or a larger hose (opposite of the action to take with air-assist airless). Catalyst air should be 10-15 psi.

In cases where flow rates are slightly higher and more material is going into the mold, only two passes will be needed to achieve proper film build.

NOTE: Do not dust coat. Use a thin continuous film for the initial coat.

Because the fluid velocity is lower, the maximum spray distance from the mold is 3 feet. Tight areas may be more challenging to spray.

The chart below shows flow rates using impingement equipment with 25% HAP white gel coat.

Table 3-12. Effects of tip size, flow rate and temperature on atomization (break-up) of material.

Tip	No Heat (Lbs./Min) (1)	Heater (Lbs./Min)	Breakup
1925	2 to 3	2 to 3	Fair
2120	2.5 to 3	2 to 3	Good/Fair
2520	4 to 5.5		Good

(1) With the heater off, pump pressure must be increased for good breakup; therefore, the flow rate is higher.

For smaller, more intricate parts, use a smaller tip. Use larger tips for large, wide open, easy-to-spray parts.

Because impingement equipment operates at lower pressure, there may be a very slight ‘wink’ in the fan pattern; however, it should not be pronounced. If that is the case, use a larger surge chamber, or warm the material (if it is cold).

Due to the larger droplets, the pattern will be rougher looking; the final film backside may also appear slightly rougher than it would with an airless or air-assist gun. However, adjusting to a finer droplet may create porosity and increased emissions.

It is important to use a mil gauge.

Adjusting pump pressure (½-inch hose with a ⅜-inch whip) for proper breakup, using various tips and without heat, yielded the results shown in the chart below.

Table 3-13. Effect of tip size and pump pressure on material atomization (break-up)

Heater	Tip	Pressure (Psi)	Break-Up	Flow Rate Lbs./Min.
Off	2120	90	Poor	NA
Off	2520	75	OK	5.7
On	2520	40	OK	3.4
On	2120	45	OK	2.1
On	1925	50	OK	1.8

3.3.6. Spray Selections and Settings

Once a spray system has been selected, the next step is to determine the recommended starting pressure settings and spray procedures. These settings may have to be changed slightly to match a part and spray operator. Also check with the equipment manufacturer for setup procedures and handling precautions.

3.3.7. Calibration

Since polyesters require the proper amount of catalyst to be added and mixed in to achieve desired properties, it is necessary to calibrate catalyst injection spray equipment.

Because of wear on equipment and temperature, and the differences of flows between materials change the catalyst ratio, it is not possible to rely on setting pressure readings once and then using them continuously day after day.

Different colors produce different flow rates (at equal pressures) and present another reason to be concerned with calibration. Calibration should be done weekly or for each batch change. Setting up a calibration routine, such as the first thing every Monday morning, is an easy and worthwhile habit to establish.

Consult the equipment manufacturer and the literature for recommended calibration methods and procedures.

Safety Considerations

- ✓ Always wear eye protection.
- ✓ Never point the spray gun at self or others.
- ✓ Always ground spray equipment.
- ✓ Before working on equipment, depressurize by turning the air supply off and then pulling the trigger of the spray gun and bleeding the bypass at the filter.
- ✓ Never trust spray equipment even if all the gauges say zero pressure. If there is any doubt that the equipment is still pressurized, and it must be dismantled to relieve the pressure, keep protection between the operator and the equipment (such as a piece of cardboard or rag), and always wear eye protection.
- ✓ Airless (high pressure) systems can create enough pressure to force the material through human skin—BEWARE!
- ✓ Read all Safety Data Sheets and Equipment Safety Sheets.
- ✓ Always turn valves on slowly to avoid sudden surges of pressure that can rupture hoses.

General Procedures

General procedures for determining flow rates of gel coat and percent catalyst include:

A. Measure the amount of gel coat, in grams or lbs., that is collected in 30 seconds. This can be converted to lbs./min. or grams/min.

Example

Collected 0.66 lbs. of gel coat in 30 sec. How many g/min (GPM) gel coat was collected?

$$\left(\frac{0.66\ lbs.}{30\ sec.}\right) * \left(\frac{60\ sec.}{1\ min.}\right) = 1.32\ \frac{lbs.}{min.}$$

$$\left(\frac{1.32\ lbs.}{1\ min.}\right) * \left(\frac{454\ g}{1\ lb.}\right) = 600\ \frac{g}{min.}$$

Shortcuts

$$X\ lbs.* \left(\frac{2}{1\ min.}\right) = Y\ (\frac{lbs.}{min.})$$

$$\left(\frac{X\ lbs.}{1\ min.}\right) * \left(\frac{454\ g}{1\ lb.}\right) = Y\ \frac{g}{min.} (GPM)$$

B. To determine the amount of catalyst needed for a flow rate, multiply the grams per minute of gel coat by the percent catalyst desired.

Amount of catalyst needed for a given flow rate:

Example (continued)

Gel coat flow rate is 600 g/min. and the desired amount of catalyst is 1.8% (or 0.018). How much catalyst is needed, in grams or cc's (milliliters)?

$$\left(\frac{600\ g}{min.}\right) * 0.018 = 10.8\ g\ of\ catalyst$$

or

$$\left(\frac{600\ g}{min}.\right) * 0.018 = 10.8\ cc's\ of\ catalyst$$

Do not assume that a catalyst slave pump is always delivering the correct amount of catalyst.

The catalyst delivery can be off due to inaccurate slave pumps, wear, leaks, clogged filters or atomizing pressure that is too high.

If the slave pump is suspected to be inaccurate, calibrate the pump according to the manufacturer's recommendations. Equipment manufacturers offer calibration kits for checking slave pump calibration.

In addition, slave settings are based on volume percentages. Polynt's catalyst specifications are based on weight percentages. There is an inherent error introduced due to the variation of the weight per gallon of the gel coat.

Table 3-14. Error introduced due to variation of the weight per gallon of gel coat.

Weight/Gallon of Gel Coat	Slave Pump Setting	Actual Weight %
8.8 (Clears)	1.8	1.9
9.8 (Colors)	1.8	1.7
10.8 (Whites)	1.8	1.5
11.8 (Low VOC)	1.8	1.4

Stroke Counting Method

An alternative procedure, but not quite as accurate, to a calibration kit is to use the stroke counting method. The stroke counting method is as follows:

1. Count the pump strokes while checking the flow rate.
2. After the flow rate is determined, disconnect the gel coat supply to the gun.
3. Open the bypass valve on the pump.
4. Adjust the valve so the pump is stroking the same number of strokes per minute as when the flow rate was checked.
5. Collect catalyst out of the tip of the gun while allowing the pump to pump gel coat through the bypass at the determined stroke-per-minute rate.
6. Divide the catalyst flow rate by the gel coat flow rate to get percentage of catalyst. The catalyst percentage should be approximately ± 0.10 percent of the slave pump setting.
7. Confirm by running gel time comparisons of a hand catalyzed sample to a sample collected from the spray gun. It is important to collect the same mass and same container size of gel coat in both samples. If the gun is properly calibrated, it is reasonable to assume that both samples will gel with a difference of less than 10% of the gel time. For example, with a hand mixed sample that gels in 10 minutes, the sprayed sample should gel in 9-11 minutes. With a hand mixed sample that gels in 30 minutes, the sprayed sample should gel in 27-33 minutes.

In addition, the pump must be checked and primed each day because gas pockets can form, causing cavitation.

Monitor the filter to ensure it is not plugged or restricted.

3.3.8. Cleanup Procedures

1. **Relieve** all pressure from pump and lines.
2. **Place pump** in container of wash solvent.
3. **Wipe down** outside of pump.
4. **Remove and clean** spray tips.
5. **Turn up** pressure slowly until pump just starts with trigger pulled.
6. **Run 2 to 3 gallons** of solvent through pump and lines, and then relieve all pressure. Spray into bucket for disposal. Do not let the pump cycle (both strokes) more than one per second.
7. **Carefully open** bypass at filter.
8. **Remove and clean** filter; replace if necessary. Check and/or clean surge chamber every two weeks.
9. **Put pump** in container of clean solvent.
10. **Repeat** steps 6 through 7.
11. **Wipe** hoses and gun down.
12. **Grease or lubricate** necessary parts.
13. **Inspect** for worn parts and order replacements.
14. **Make sure** pump is stopped in down position to prolong packing life (make sure lubricant cup in pump shaft is full).
15. **Relieve** all pressure and back regulators out to zero.

3.3.9. Maintenance

The spray gun and support equipment represent a considerable investment. To protect the investment, it is important to implement a planned maintenance program. It should include the following:

A. **An inventory of spare parts** for all spray guns, pumps, hoses, catalyst injector or catalyst slave pump to include:
   - Air cap, nozzle and needle
   - Packings and gaskets
   - Extra hoses—fittings
   - Extra gauges

B. **Be in constant awareness** of the following:
   - Catalyst flow.
   - Condition of all hoses, both gel coat and catalyst. No kinks or frayed hoses.
   - Spray pattern and technique.
   - Contamination. If present, remove.
   - Use of proper protective equipment.

C. **The daily checklist** for the beginning of each shift should include:
   - Drain water traps morning, noon and afternoon (more often if needed).
   - Mix gel coat (just enough to keep resin and styrene mixed in). Do not overmix gel coats. Overmixing breaks down gel coat viscosity, increasing tendencies to sag, and causes styrene loss, which could contribute to porosity. Gel coats should be mixed once a day, for 10 minutes. The gel coat should be mixed to the sides of the container with the least amount of turbulence possible. Do not use air bubbling for mixing gel coat. It is not effective and only serves as a source for possible contamination.
   - Inventory gel coat for day's use. Check catalyst level. Always add catalyst which is at room temperature. If using a slave arm catalyst system, check for air bubbles in the catalyst line. Disconnect catalyst pump and hand pump until resistance is felt on both up and down strokes, or until proper pressure is reached on catalyst gauge (if the system has one).
   - Start pumps with regulator backed all the way out. Open valve and charge air slowly, checking for leaks. Do not let the pump cycle (both strokes) more than one per second.

D. **Shutdown**
   - Turn off all air pressures and back regulator out.
   - Bleed lines.
   - Store pump shaft down to keep it wet.
   - Check for material and catalyst leaks.

E. **Cleanup**
   - Remove spray tips, clean, then store safely.
   - Lightly grease all threads.
   - If the tips and cap are placed in solvent overnight, make sure it is clean solvent.

F. **Secure the area**
   - Remove all solvents and check for hot spots.
   - Remove and properly dispose of any collections

of catalyzed material or catalyst/materials combinations.

G. **Weekly checklist** should include:

- Calibrate each spray gun for material flow.
- Calibrate each catalyzer or catalyst slave pump for catalyst flow.
- Check gel time of gel coat through the gun versus gel time of known control.
- Clean filter screens.

H. Pump Accumulators

An often overlooked but very important aspect of regularly scheduled equipment maintenance is the fluid pump accumulator

If the accumulator is ignored, and not cleaned on a regular basis, material will 'gel' inside it. When this material breaks loose, it will cause plugging of the tip, leading to part defects and lost production time. The accumulator may gel to the point where it no longer is doing its intended job.

Accumulators used on most equipment are not easily cleaned. This is believed to contribute significantly to problems.

NOTE: If equipment is cleaned when changing from one color to another, the accumulator must also be thoroughly cleaned.

Care should be taken to thoroughly flush the accumulator to remove any residual material that could contaminate the next material. After cleaning, dry the inside of the accumulator to remove any cleaning material that may be trapped inside.

Some equipment manufacturers have started to design and distribute accumulators that can be easily disassembled for cleaning. If the accumulator in use is old and difficult to clean, it may be cost-effective to invest in a new, more easily cleanable model. In addition to time saved and better productivity, a reduction in part defects should result.

3.3.10. Equipment Troubleshooting

The majority of polyesters used today are sprayed or pumped through semi-automatic equipment. The care and operation of this equipment will determine whether or not the polyester will achieve its maximum properties and performance. Fabrication equipment operators must be trained on how to use and maintain their equipment.

Anyone who uses spray equipment should have (and read) all the literature available from the manufacturer of the equipment. This includes warnings, parts diagrams, setup instructions, operating instructions, maintenance requirements, safety and troubleshooting guides.

If this information has not been obtained or if a question arises, contact both the company from whom the equipment has been purchased and the manufacturer. They will help because they want the equipment used efficiently, correctly and safely. Also, they will have general literature on spraying, and technical service people to help.

Always remember the investment in the equipment and that it was purchased to do an important job. If it is not maintained and if worn parts are not replaced, the investment will be lost and the equipment will not do the job for which it was selected and purchased.

One way to determine if a cure-related problem is caused by material or equipment is to make a small test part where the catalyst is mixed directly in the gel coat. If this part does not exhibit the problem, then the cause is more likely in the equipment or operator. Another way to check is to run a different batch of material through the equipment; however, this could generate bad parts, making the first test method preferable.

A list of some of the more common problems that can occur with fabrication equipment follows. Since there are many different types of equipment in use, it is impossible to cover each one individually or to list all the possible problems or solutions. See the manufacturer's literature for the particular type of equipment in use, or contact the manufacturer.

Table 3-15. Equipment Troubleshooting

Problem—Gel Coat/Spray	Suggested Causes And Remedies
Atomization Poor (large droplets)	• Check air pressure, length of hose, hose diameter (which may be too small) • Clogged or worn nozzle or air cap • Check if valves are stuck • Too much fluid flow • Regulator not working properly
Drips (Gun): Fluid	• Worn, clogged or bent needle • Seating adjustment of needle • Overspray on gun • Worn packings or seals • Loose connection
Catalyst	• Worn seat or seals • Damaged air valve • Trigger out of adjustment • Overspray on gun • Loose connection • Clogged valve or seat • Gun head not aligned to gun body • Fan control may trap catalyst in dead air space and drip catalyst out of air horns
Solvent	• Clogged or worn valve • Worn seals • Sticking needle or button
Gelled hose	• Bad fluid nozzle • Bad seat
Material (none on down stroke)	• Foot valve, spring, spring retainer or foot valve ball worn or dirty
Material (none on upstroke)	• Piston cups, piston ball or pump cylinder worn
Pattern of Spray Off to One Side	• Partly clogged air cap • Damaged nozzle • Worn nozzle or air cap • Bent or worn fluid needle
Plugged Filter Screen	• Seedy or partly gelled batch • Trash from material falling off pump when placed in new drum • Due to normal build up, screens and pumps must be cleaned periodically • Dirty surge chamber
Pump Cycles When Gun Not in Use	• Worn piston cups • Bottom check ball not seating
Shaft of Pump Drops an Inch or Two—Shudders	• Starved pump—check filters or worn internal packings. Check for worn packing by stopping pump at top of stroke. If with no material flow shaft creeps down, packing is worn.
Shaft of Pump (material coming up around)	• Loose or worn seals—clean and tighten. Stop pump in down position when system not in use • Worn shaft
Siphon Wand Jumps	• Dirt on check ball in pump
Slow Gel Time and/or Cure	• Check catalyst and material flow for oil or water contamination • Check gun trigger for proper activation • If slave pump, check for air bubbles

Table 3-15. Equipment Troubleshooting (cont.)

Problem—Gel Coat/Spray	Suggested Causes And Remedies
Surging: Material	• Inconsistent or low air pressure on pump • Worn or loose pump packing • Out of material • Sucking air through loose connection • Balls not seating in pump (dives on down stroke—bottom ball; fast upward stroke—top ball; flush pump) • Filter plugged • Siphon line has air leak • Screens plugged • Too much material flow • Cold or high viscosity • Plugged surge chamber
Catalyst	• Inconsistent or low air pressure • Out of catalyst • Check valve sticking in gun or catalyzer • Loose connection • Screen plugged • If Binks equipment, install Plug-Groove valve at the gun • Keep hoses straight rather than coiled
Tails (airless): Material	• Pump pressure too low • Worn tip • Too large of tip • Viscosity too high
Catalyst	• Worn tip • Low pressure • Wrong tip • Viscosity too high • Too large a fan
Tips Spitting or Trigger Will Not Shut Off	• Worn seat or needle or weak spring—check packing
Trigger Stiff	• Bent needle or trigger • Worn needle guide
Water in Air Lines	• No extractor • Extractor too close to compressor—should be no closer than 25 ft. • All take offs from main line should come off the top
Worn Packings	• Pump overheating from being undersized • High pressure or pumping without any material • Do not let pumps jackhammer—no more than 1 cycle (both strokes) per second • Use glass-reinforced Teflon® packings • Keep idle pump shaft in down position to keep dried material from damaging packings
Fan Pattern Width Varies on the Up Stroke Versus the Down Stroke	• Worn inner packing—replace
Chunks in the Filter Larger Than the Mesh of the Strainer on the Pickup Tube	• Gelled material in the surge chamber or pickup hose—clean or replace
Tails (non-atomized)	• Use larger tip or hose • Use in-line heater
Catalyst Pump Feels Spongy When Hand Pumping	• Trapped air pocket—open and close bypass or pull trigger and pump up again

3.3.11. Additional Equipment Information

- **If pump packing** is too tight, it will cold flow and there will be strings at the edges of the packing.
- **Always put catalyst tip on bottom** so catalyst does not spray on glass.
- **Pre-orifice or insert**—Softens spray (less force); in some cases, requires less pressure for proper breakup.
  NOTE: Use same size (or smaller) insert than tip.
- **To tighten upper packings**, relieve pressure; tighten 1/8 turn at a time; run pump five strokes; repeat until no leak under pressure.
- **Catalyst condenses** out of atomizing air in the hose in 10 to 15 minutes (system at rest).
- **When ordering** gun, specify nozzle and air cap.
- **Transfer pumps** go through bung 4:1 or 8:1 only.
- **Binks pump**— Lower screen-30 mesh; Upper filter-50 mesh. Upper filter is half the orifice size.
- **Starting pump**—Open bypass until flow is steady.
- **To prevent leaks**, avoid swivel fittings.
- **Compressor electric**—1 horsepower is approximately four CFM.
- **Quick disconnect** restricts air flow.
- **Catalyst tip angle**—Same as material; want equal fan pattern.
- **When spraying**, pull trigger all the way; it's all or nothing—no partial flow.
- **Lubricant**—Can use Vaseline.
- **Never** insert a sharp object or probe into tip orifices. Blow out with compressed air from the front of the tip to prevent lodged particle from becoming more deeply lodged in orifice.
- **Ask the equipment manufacturer** about glass-filled fluid packings for pumping polyesters.
- **Always install** shutoff valves in combination with fluid quick connects.
- **Always flush** a filled system (resin/styrene) with unfilled resin, then solvent. Then always clean the filter.
- **Use water-soluble grease** in between chevron packings to reduce resin buildup between them.

3.3.12. Equipment Suppliers

The following is a partial list of equipment suppliers. They have many detailed booklets on spraying and equipment. Write (or call) these suppliers and ask for their literature and recommendations.

Complete systems

ITW-Binks-Polycraft
195 International Blvd.
Glendale Heights, IL 60139
Ph: 630-237-5006
Fax: 630-248-0838
www.binks.com

GS Manufacturing
985 W. 18th St.
Costa Mesa, CA 92672
Ph: 949-642-1500
Fax: 949-631-6770
www.gsmfg.com

Graco Inc.
P.O. Box 1441
Minneapolis, MN 55440
Ph: 612-623-6000
Fax: 612-623-6777
www.graco.com

Magnum Venus Products
5148 113th Ave. North
Clearwater, FL 33760
Ph: 727-573-2955
Fax: 727-571-3636
www.mvpind.com

Pumps only

The ARO Corporation
One ARO Center
Bryan, OH 43508
Ph: 419-636-4242
www.ingersollrandproducts.com

GRACO
P.O. Box 1441
Minneapolis, MN 55440
Ph: 612-623-6000
www.graco.com

3.4. Application

Overview

- **Introduction**
- **Overview**
- **Material Preparation**
- **Equipment and Calibration**
- **Spray Operator**
- **General Spray Methods**
- **Spray Methods for Particular Parts**
- **Pulling Tape**
- **Brushing Gel Coat**

3.4.1. Introduction

Proper application of gel coat is critical to producing cosmetically appealing and durable parts. Improperly applied gel coat increases the cost of the part. The amount of additional cost incurred depends on the number of rejected parts as well as the effort required to rework the parts. Making the investment of properly applying the gel coat can pay big dividends by reducing rework and scrap. Proper gel coat application includes material preparation, equipment calibration, use of trained spray operators, appropriate spray methods and tape pulling technique.

3.4.2. Overview

A conventional gel coat is applied with spray equipment as described in the previous section, Conventional Gel Coat: Spray Equipment. Brushing of gel coats is not recommended. The following information assumes that the proper gel coat spray equipment has been selected and that equipment is being properly maintained.

The ideal catalyst level for most gel coats is 1.8% at 77°F (25°C). However, the catalyst level can be between 1.2-3% to compensate for specific shop conditions. Catalyst levels below 1.2% or above 3% should not be used as the cure of the gel coat can be hindered permanently. Refer to product data sheets for specific catalyst recommendations.

There are a number of catalysts available for both resins and gel coats. It is imperative that the proper catalyst be selected. Only MEKP-based catalysts should be used in gel coats.

Broadly speaking, there are three active components in a MEKP-based catalyst. They are hydrogen peroxide, MEKP monomer, and MEKP dimer. Each of these components plays a role in the curing of unsaturated polyesters. Hydrogen peroxide initiates the gelation phase, but does very little for overall cure. MEKP monomer is involved in initial cure as well as overall cure. MEKP dimer is mainly active during the film cure stage of polymerization. Historically, catalysts with high levels of MEKP dimer have been identified as more likely to cause porosity in gel coats.

Environmental factors that may require catalyst range variation include temperature, humidity, material age, and catalyst brand or type. Manufacturers should always verify gel times under specific plant conditions prior to gel coat usage.

The gel coat should be applied in three passes for a total wet film thickness of 18 ± 2 mils thickness. A coating that is too thin (under 12 mils) could cause under cure of the gel coat, while a film that is too thick (over 24 mils) could crack under flexing. Gel coat that is spray applied on vertical surfaces (using this multiple-pass procedure) typically will not sag due to the gel coat's thixotropic properties. The gel coat is also resistant to entrapping air (porosity) when spray applied per instructions.

Film build is quicker with an MC gel coat due to less overspray. Film build speed increases even more when non-atomized application technology (NAT) equipment is used because the spray is softer (less atomization).

MC gel coat should be sprayed in at least two passes. The first pass should be the thinnest continuous wet film possible, typically between 6-10 mils. The second pass can be another 6-10 mils, for a total film thickness of 12-20 mils. If necessary, a third pass should bring the overall thickness to 18-22 mils. If spraying below the water line, another 4 mils can be added for a total of 22-26 mils for better water blister resistance.

Under normal conditions, gel coats are ready for lamination 45-60 minutes after catalyzation. The actual time is dependent on temperature, humidity, catalyst type, catalyst concentration, and air movement. Low temperatures, low catalyst concentrations, and high humidity retard gel and cure, meaning that longer times will be required before the gel coat is ready. A reliable test to determine if the gel coat is ready for lamination is to touch the film at the lowest part of the mold. If no material transfers, it is ready for lay-up.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, problems can occur due to poorly atomized catalyst, surging problems with the gel coat or catalyst, contamination, and poor application procedures. These problems will quickly negate all benefits of calibration.

The equipment and application procedures must be monitored on a routine basis to ensure proper application and cure of the gel coat. Inquire about and adhere to all equipment manufacturers' recommendations.

3.4.3. Material Preparation

Gel coat materials are supplied as completely formulated products. No additional materials other than catalyst should be added.

Prior to use, gel coats should be mixed for 10 minutes to ensure product consistency. The agitation level should allow for product movement all the way to the walls of the container, but with the least amount of turbulence possible.

Do not over mix. Over mixing can break down the thixotropy, increasing the tendency to sag. Over mixing can also cause styrene loss that may contribute to porosity.

Do not use air bubbling for mixing. Air bubbling is ineffective and only serves as a potential source for water or oil contamination.

Gel coats are designed for use at temperatures above 60°F. Below 60°F, the viscosity, thixotropy, and cure of the gel coat are affected. The lower the temperature, the:

- Higher the viscosity.
- Lower the thixotropy.
- Longer the gel time.

Catalyst viscosity also increases with decreasing temperatures. This can influence catalyst injector readings.

These factors combine to affect flow rates and atomization as well as make sagging a possibility.

In addition, the effect of cold weather on cure can result in poor part cosmetics. The slower gel times and cure times of gel coats in cold conditions can lead to postcure that can be seen as print-through and/or distortion.

Polynt has developed a few helpful hints to facilitate gel coat usage during cold weather. These include:

- **Calibration of the spray equipment** - While always important, it is especially important during cold weather due to the increase in viscosity of the gel coat and catalyst.
- Allow ample **time for warming** and make sure to check **material temperature** prior to use. Drums can take two to three days to warm, even inside a warm shop. In extremely cold weather, even longer warming periods may be needed (three to four days). A cold floor will extend the warming time.
- If the plant has a cement floor, there should be **insulation** (such as a wooden pallet) underneath the material container. This procedure will keep the material warmer by preventing the heat from being drawn out by the concrete.
- **Review inventory** very carefully and place orders well in advance.

3.4.4. Equipment Calibration

General equipment calibration procedures for material delivery rate and catalyst concentration are discussed below. Always consult the equipment manufacturer for proper calibration of a particular type of equipment.

Batch Mix (Hot Pot)

A. **Material Delivery Rate** (**Fluid Supply)**—The material delivery e, or fluid supply, is the rate at which the gel coat flows from the spray gun. For optimum spray application, the material delivery rate should be between 1.5-2.5 pounds per minute. Determine the material delivery rate:

1. Back out the fluid needle adjustment, allowing maximum material delivery through the gun with the trigger pulled.
2. Weigh (in pounds) the container that will be used to capture the gel coat.
3. Spray gel coat into the container for 30 seconds.
4. Reweigh the container and gel coat in pounds.
5. Calculate material delivery rate (in pounds per minute) by subtracting the original weight of the container from the container with gel coat weight and multiply this figure by 2.

$$Material\ Delivery\ Rate\ \left(\frac{lbs.}{min.}\right) = \big((Container + Gel\ Coat\ weight) - (Container\ weight)\big)\ x\ 2$$

Adjustment is made by changing the air pressure on the pressure pot or pump, or by changing the orifice size. Material delivery rate checks must be done by weight, not volume, since gel coat densities vary.

B. **Atomizing Air**—Correct air pressure is essential for proper material atomization. To measure:
   1. Read the pressure gauge attached to the spray gun when the trigger is pulled (dynamic pressure) and the fan is fully open.
   2. Adjust as necessary to a minimum of 60 psi. This will help produce a porosity-free film.

      NOTE: Long air lines, small inside diameter air lines, or a number of fittings within the line can reduce the volume of air supplied to the gun and can create erroneous results.

C. **Catalyst**—Proper catalyst level is accomplished by accurate weight or volumetric measurement, so that the catalyst level is exact as well as consistent. Always maintain the catalyst level between 1.2% and 3% as needed, based on specific plant conditions.

   Note: Catalysts used to cure polyester resins are very reactive chemicals. Contact with many materials can cause decomposition that can present real fire hazards. Good housekeeping practices need to be maintained at all times.

Catalyst Injection

With most catalyst injection equipment, the peroxide catalyst is mixed externally with the gel coat. If sprayed alone, it can travel several feet or more, eventually settling onto surrounding surfaces. Accumulation of materials or other substances that can react with the catalyst has been the direct cause for fires in fiberglass shops. Cleanliness, constant removal and proper disposal of waste catalyst and contaminated materials are the only safe ways to deal with this potential hazard. Also, spraying only catalyst should be avoided.

Solvent, either from diluting the catalyst as required for some equipment or from cleanup operations, acts to increase the chances of an undesirable reaction.

Consult the catalyst supplier, as well as Chapter 1 on 'Health, Safety, and the Environment' and Polynt Safety Data Sheets for further information.

A. **Material Delivery Rate (Fluid Supply)**—Calibrates same as for batch mixing.
   - Air-atomized—1.5-2.5 pounds per minute.
   - Airless—1.5-3 pounds per minute for smaller, intricate molds; 1.5-4 pounds per minute for large, open molds.

B. **Atomizing Air (Air Volume)**—Calibration is the same as described for batch mixing with one exception; the catalyzer has a safety valve that will only allow 80-100 psi static air pressure (no air flowing through the gun). The maximum pressure allowed by the safety valve varies with the specific equipment. When maximum static pressure is reached, changing the inside diameter of the hose, using a shorter hose, and minimizing restrictions will permit more air volume.

   Airless systems have no air atomization of material so there is no calibration of air pressure required, or possible. Some airless systems do have air-atomized catalyst, which must be calibrated.

   Air-assist airless systems require additional atomizing air. It is important that air-assist air be kept as low as possible.

C. **Catalyst**—Specific equipment manufacturer's recommendations should be followed.
   Calibration methods work as follows:
   1. The intent is to collect some catalyzed gel coat just as it leaves the gun and time it to see how long it takes to gel. Comparing this gel time to that of a sample that has been catalyzed by accurately weighing the catalyst gives a basis of comparison for adjusting catalyst settings. This should be done at two different catalyst settings.

      The procedure:
      a. Collect about 100 grams of catalyzed gel coat in a small cup, recording fluid pressure, setting level of the catalyst ball (or balls), and the time.
      b. Collect 100 grams of uncatalyzed gel coat in a small cup, then weigh in the specified amount of catalyst, noting the time of catalyzation.
      c. Adjust catalyzer by the recommended method specific to the equipment until the two gel times are equal. It should be noted that ball settings are only relative guides and do not read in catalyst percent.
   2. After gel coat has been calibrated (delivery rate), turn gel coat off.
   3. Then run delivery rate on the catalyst.
   4. Compare catalyst delivery to gel coat delivery (catalyst percent) and adjust catalyst percent as required to stay in proper range.

D. **Do not assume a catalyst slave pump is working properly**. These also can be calibrated and should be monitored continually. See the previous section, Chapter 3 Spray Equipment, for additional calibration information.

Polynt's gel coat (944-L-A72) contains catalyst indicator which is used to show efficiency of catalyst atomization and mix.

3.4.5. Spray Operator

A spray gun is a precision tool. It requires a skilled operator to efficiently apply the material. Many defects can be traced back to how the gel coat was applied. A poor spray application can be very costly, so it is in the shop's best interest to select the proper person as the spray operator and to follow through with good training. A good spray operator should:

- Be conscientious.
- Have good coordination.
- Desire to do good work.
- Have some mechanical skill.
- Be patient.
- Possess good vision with no color blindness.

Good training is important because there are techniques that must be mastered correctly, from the beginning, to avoid use of bad techniques and costly shortcuts.

New spray operators should start out under the direct supervision of competent personnel. They should be assigned to spraying easy, non-critical parts. Progression to more difficult parts should be made in conjunction with the experience and ability of the individual.

Free informational literature is available from suppliers of raw materials and equipment manufacturers. Training schools are offered by most vendors.

3.4.6. General Spray Methods

A. **Check gun and lines** for contamination such as solvent, water, or oil. Clean and correct as necessary before spraying. Drain water from pressure regulator and traps daily; more often if necessary. If water is a constant problem, a temporary solution is to leave the bleed-off valve on the water extractor open slightly. Water in the air lines can lead to expensive repairs to equipment and affect the performance of the gel coat. It is best to avoid the problem (and less costly in the long run) by investing in a good drying system.

B. **Check air pressures** before spraying and adjust to achieve proper flow and break up. Droplets should be no larger than 1/16-inch.

C. **Do not** use a constantly recirculating system because it can cause viscosity to drop or can introduce large amounts of air into the gel coat.

D. **Always start spraying** nearest the exhaust fan to minimize overspray that could be pulled onto the mold.

E. **If catalyst injection is used**, make sure catalyst is flowing properly. Do not let raw catalyst fall onto the mold or sprayed gel coat.

F. **Check temperatures**; adjust catalyst as necessary (1.2 percent to 3 percent). Under extremely warm conditions, working times may become very short, necessitating the addition of inhibitor to allow enough working time. Consult a Polynt representative regarding what to add and the amount. Do not go below 1.2% catalyst or higher than 3%.

G. **Keep the spray gun** perpendicular to the mold during each stroke.

H. **Hold the spray gun** 18-24 inches from the mold when using conventional air-atomized equipment; if using airless equipment, 24-36 inches is the proper distance.
NOTE: Gel coats should not be sprayed more than 4 feet from the mold because they can go dry due to atomization loss.

I. **Do not arc the gun** while spraying.

J. **Keep the speed** of each stroke so a full and constant wet coat is applied.

K. **The first spray pass** should be a thin continuous film (5-8 mils, dependent upon temperature, gel coat viscosity, and mold wax). Use of this technique helps to prevent porosity, resin tearing, and mottling. About three passes are needed to achieve a total thickness of 18 ± 2 mils. Spraying is a two handed operation; a spray gun in one hand and mil gauge in the other.

L. **Overlap strokes** by 50%.

M. **Do not reach** with a stroke. Stroke length should be comfortable for the operator. Normally, this is 18-36 inches.

N. **Begin spraying** near an edge in a continuous stroke toward the opposite side. Each pass should be parallel to the former, developing a uniform thickness. Subsequent passes should be perpendicular or diagonal to the preceding pattern to ensure proper uniform coverage.

O. **When practical, spray in sections** from one end, working continuously to the other. Avoid (as much as possible) overspray onto other parts of the mold. Time lapse between spray passes or in spraying overlapping sections on large molds should not be excessively delayed. Maintain a wet line (i.e., cover up spray edges and overspray as soon as possible).
P. **Do not flood** the gel coat on or spray with the fan sideways.
Q. **Use a mil gauge** and touch up the tested area afterward.
R. **Clean the gun** immediately after using. This includes any part of the equipment that may have received over-spray, such as hoses and gauges.
S. **Inspect the gun** regularly and replace worn parts.
T. **Lubricate the gun** and packings with light machine oil daily. Do not contaminate the gel coat with oil.
U. **Accidental contact** with gel coat or catalyst can be hazardous. In the event of contact involving body or clothing, clean the affected area immediately. See appropriate data sheets and labels for proper precautionary steps to follow.
V. **Know the fire and toxic hazards** of polyesters, catalyst, and the particular cleaning solvent being used.
W. **Have a regular** preventive maintenance program.
X. **Place only one mold** in the spray booth at a time. This prevents overspray onto other molds.

Note: Some companies have a procedure that allows more than one mold in the spray booth at a time. Always follow a procedure that avoids dry overspray.

Y. **For all around end performance properties**, a wet film thickness of 18 ± 2 mils is recommended as ideal. Films less than 12 mils may not cure properly, may be hard to patch, have more print-through, and be more susceptible to water blisters. Films above 24 mils may pre-release, trap porosity, or crack, and are more subject to weathering discoloration. If water blisters are of a great concern (boat hulls), 20-24 mils will perform better than a thinner film, but resistance to sag, porosity, and cracking could suffer. If weathering (yellowing from sunlight) is of great concern, thinner films of 12-16 mils will perform better, but patchability and resistance to print-through and blister could suffer.
Z. **Never reduce gel coat** with a 'conventional' paint or lacquer thinner.
AA. **Disperse catalyst** thoroughly. Poor distribution causes uneven cure, color variation, blister potential, and premature release from mold before lay-up.
BB. **Do not over catalyze** or under catalyze. Excess catalyst plasticizes gel coat, thus degrading its water resistance and accelerating chalking and erosion. Poor cure also results from under catalyzation. A poorly cured gel coat is weak and will be degraded by weather.
CC. **Recommended catalyst level** is: 1.2-3% (1.8% at 77°F (25°C) is ideal) MEKP (9% active oxygen).
DD. Apply a **minimum of 16 mils** of gel coat if glass fiber pattern is to be suppressed appreciably. Never apply less than 12 mils as under cure may take place. The degree of protection against the outdoor elements is directly dependent on the amount of gel coat deposited and its quality.
EE. **Atomize the gel coat** thoroughly when spraying. Low spray pressures will result in poor breakup and leave entrapped air in the gel coat. Entrapped air causes blistering and high water absorption.
To check atomization:
    1. Spray gel coat over glass to a film thickness of 16-20 mils.
    2. Hold over strong light. Looking through the deposited gel coat will reveal any entrapped air.
FF. **Do not apply** gel coat over wet Polyvinyl Alcohol (PVA) Parting Film. Residual water in the film will retard gel coat cure and also cause 'alligatoring.'
GG. **Use the catalyzed gel coat** within its working life with a proper allowance of time for cleanup of equipment.

3.4.7. Spray Methods for Particular Parts

The shape and contour of each mold will dictate how it can best be gel coated. This should be considered in planning where to start, where to finish, and how everything in between will be handled. Unfamiliar parts should be given serious consideration as to how they will be sprayed before the actual application begins. Experience will show how it can be done better and more efficiently.

Suggestions on spraying different configurations in a mold are:

A. **Try to spray** the most difficult area first and work continuously out from it.
B. **Keep overspray** to a minimum.
C. **Use a series of passes** perpendicular or diagonal to each other for more uniform thickness.

D. **Keep laps (strokes) wet**. This is called ‘maintaining a wet line.’ Do not let a lap stay on the mold more than 5 minutes without covering with a ‘fresh’ lap. Alligatoring, and/or resin tearing, and ‘splotches’ could occur when the part is sanded and buffed.
E. **Flat areas**—These are easy to spray. Begin spraying near an edge in a continuous stroke toward the other side. Each spray pass should be parallel to the previous pass until a uniform thickness is achieved. Subsequent spray passes should be perpendicular or diagonal to the preceding pattern to ensure proper uniform coverage.
F. **Corners**—Spray a pass down each side through the corner and work out about 12 inches from the corners. Use short strokes, and then spray adjacent areas.
G. **Gentle Curves**—Spray by arcing the gun to keep it perpendicular to the working surface.
H. **Channels**—Spray the sides first. Most of the time, overspray will cover the bottom.
I. **Deep or Narrow Channels**—Turn the fluid control in to cut the flow down and narrow the fan. If using airless or air-assist airless equipment, consider a smaller fan. Less fluid and air pressure may be necessary, requiring more passes. Spray the sides first. Do not spray with the fan directly parallel to the channel. Keep the fan perpendicular to the channel (or as much as is possible).

   NOTE: If using catalyst injection, cutting back on material flow will change the percent of catalyst supplied to the gel coat. Adjustment for proper catalyst level will be necessary.

   Use a 1 quart pot gun to spray very difficult areas.

J. **Use a rotating platform** for round or small parts.

3.4.8. Pulling Tape

A crisp clean tape line is visually appealing to the consumer. Prior to the introduction of tapes and gel coats that allowed for razor sharp tape lines in gel coats, manufacturers often used vinyl tape to cover the tape line between two applications of gel coat. These vinyl products were prone to tearing and abrading as well as being relatively visually unappealing.

Pulling a smooth tape line is as much an art as a science, but the process starts with using the best materials available. A typical application, such as a boat, will consist of laying a line using a “fine line” tape, provided by companies like 3M or Tesa. These fine line tapes generally consist of a polymer backing material and a proprietary adhesive. Typical widths are ⅛", ¼" and ½". Once the fine line has been laid, a general purpose mask is applied over the area of the mold that is not being sprayed.

When applying gel coat to the mold, it is important to remember the gel time so that the gel coat has not started to gel before the application is complete and the gun cleaned. Often, the gel coater will try to avoid spraying directly on the tape line until the end of the application.

The typical application target for gel coat is 18-22 mils of wet gel coat. It has been found that thin gel coat application can lead to jagged tape lines; thick gel coat can lead to wavy tape lines, along with other potential problems. When pulling tape, the best technique is to pull the tape at an angle of 20-40 degrees towards the freshly sprayed gel coat. The proper amount of tension depends on the tape being used, but constant tension is a must.

Once the tape line has been pulled, it may be necessary to “clean” the tape lines further. Once the gel coat has completely gelled, but not yet cured, it is possible to use a non-metallic tool to smooth the tape line. Camel’s hair brushes may be used or a hard plastic tool. Timing is critical in this step. Too early will lead to smeared gel coat; too late may lead to a pre-released tape line edge.

Once the line has been sufficiently addressed, the subsequent color may be applied, and the part may be laminated and pulled. The recommended method of applying subsequent colors is to spray over the original get coat after the film gels (tacky to touch). It is also possible to spray subsequent colors over the original gel coat when it is still wet, although there are some potential issues, such as:

- May blow secondary color through the primary color.
- Original film may sag.

3.4.9. Brushing Gel Coat

In general, the brushing of gel coats is not recommended. There are a few instances where brushing gel coat is either acceptable or unavoidable. Refer to the Brushables section of Chapter 4 for more information.

3.5. Troubleshooting Guide

Overview

- **Introduction**
- **Problem / Diagnosis**
- **Common Gel Coat Problems and Solutions**

3.5.1. Introduction

Even under ideal conditions, problems can occur due to accidents, mistakes, and unanticipated changes and events. Listed in this troubleshooting guide are some of the various problems that may occur, along with the potential causes and suggestions for resolving the issues. It is important to keep in mind that the gel coat is also affected by the laminate, and even good gel coat will not compensate for a poor laminate.

3.5.2. Problem / Diagnosis

To isolate and diagnose the problem, give consideration to the following questions (at right):

Listed on the following pages are common gel coat problems and common solutions.

Photographs illustrating many of these problems are also included.

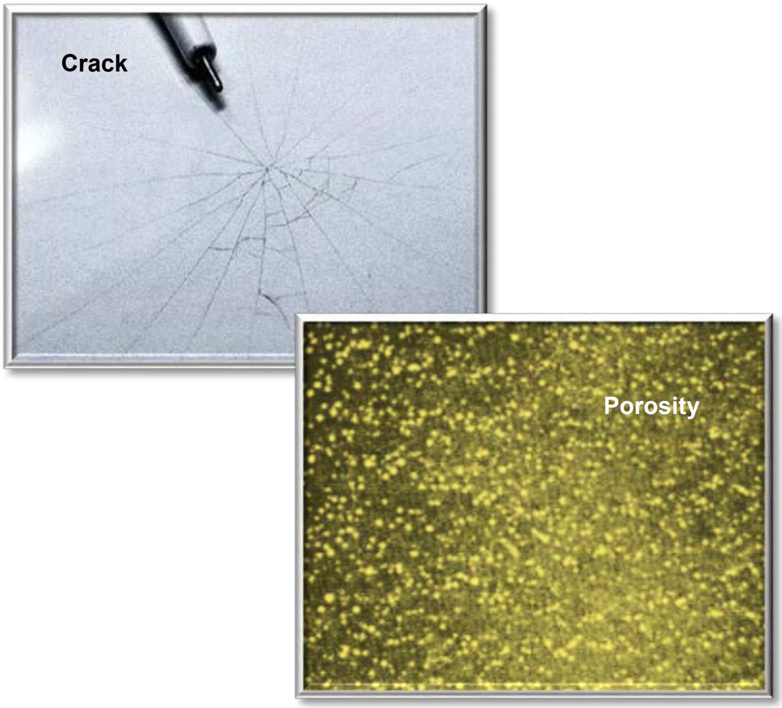
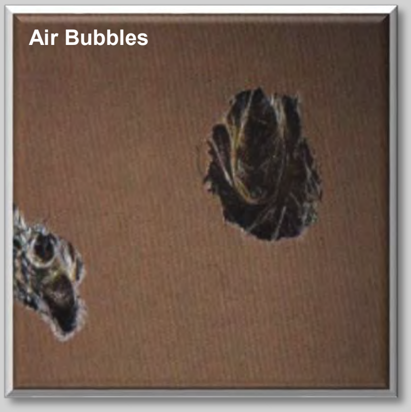


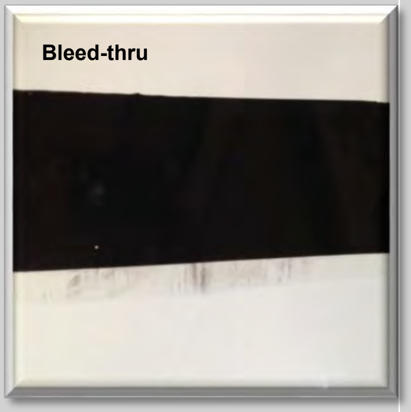
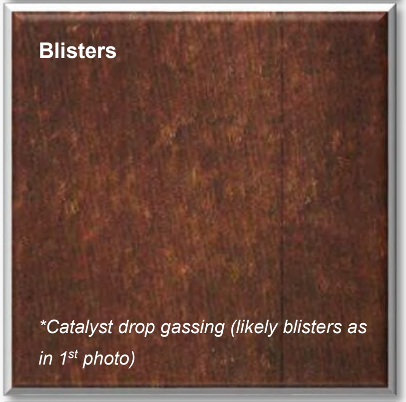
Figure 3-11. Examples of gel coat problems.

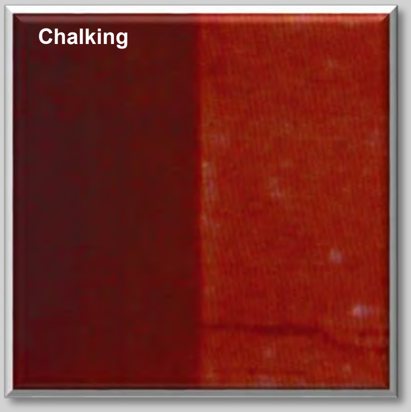
QUESTIONS

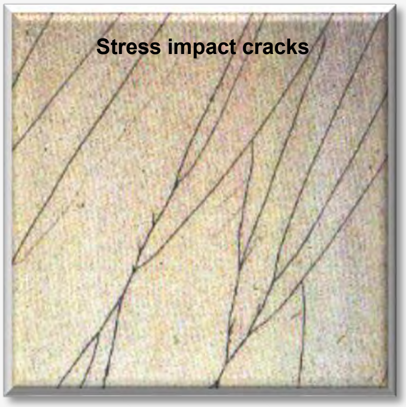
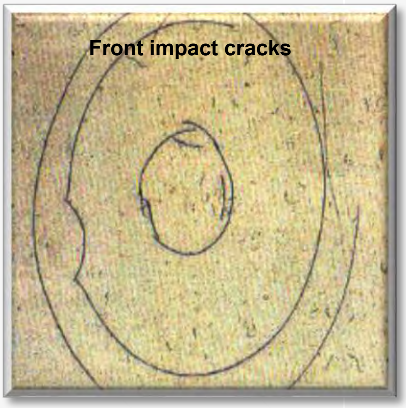
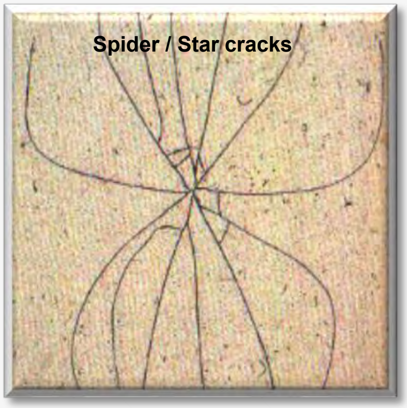
- What does the defect look like?
- Where does it occur? Is it all over, random, isolated on one side or section?
- Is it on all parts, some or just one?
- When did it first occur? Or when was it first observed?
- Does it match up to a defect in the mold?
- When were the defective parts sprayed? Which operator(s) sprayed the defective parts? Was it during a certain time of day, i.e. when it was hot, cold, damp, or other?
- Did the problem occur through all spray stations or just one in particular?
- Where does it occur? In the gel coat film? Against the mold? On the backs side? Within the film?
- What is the product code, batch #, and date of the material with which the problem is occuring? Were good parts ever sprayed from this batch or drum?
- Was anything done differently, such as a change in catalyst level, spray operator, method of application, or weather conditions?
- How would someone else identify or describe the defect?
- What were the weather conditions at the time the part was sprayed?
- What corrective steps were taken and were they effective?
- Check the material or laminate that was applied to or on the gel coat.

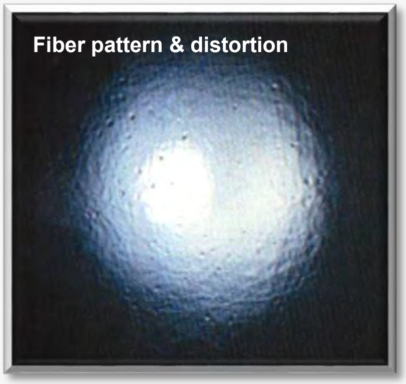
3.5.3. Common Gel Coat Problems—Causes and Solutions

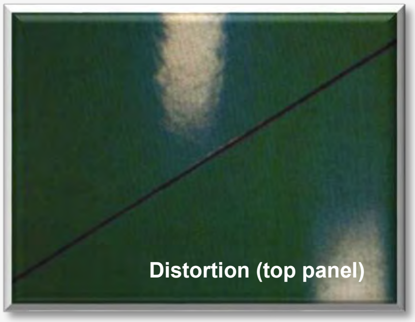
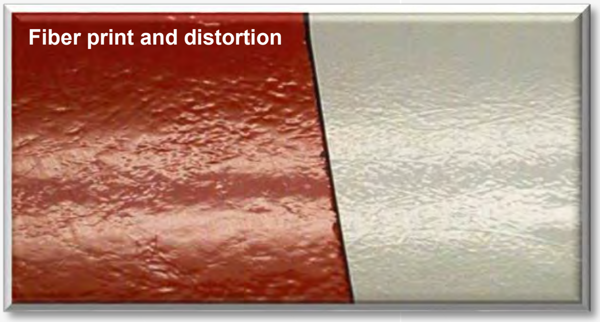
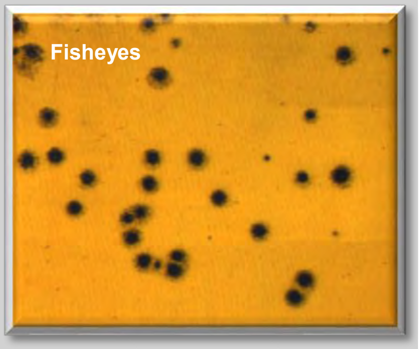
Problem	Cause	Items to Check / Solutions
Air Bubble 	• Air Pockets…………………………….	• Check rollout procedure.
Alligatoring: A wrinkling of the gel coat, resembling alligator hide.  	**<u>Before laminating</u>** • Raw catalyst…………………….......... • Solvent………………………………..... • 'Cured' overspray…………………… • Thin gel coat………………............. **<u>After or during lamination, or a second application of gel coat</u>** • Insufficiently cured gel coat………….. 	• Check for leaks or overspray. • Do not reduce with solvents. • Check for contamination. Maintain a wet line. • Use a minimum of 12 mils, wet. Discontinuous gel coat film. • Catalyst level too high or too low. • Temperature too low. • Gel time too long. • Time between coats or lamination insufficient. • Moisture or contamination in the mold.
Bleeding: One color shows on another, typically when color striping. (See pictures below)	**<u>Striping gel coat sagging over 'cured' gel coat</u>**…………………………. **<u>Laminate Bleed</u>** (cosmetic problem only) • Monomer in laminating resin…......... • Gel coat backside cure………………	• Check sag resistance of 'striping' gel coat. Spray stripe coat as soon as possible. Spray thin film of stripe color over the 'wet' base coat prior to pulling tape. • Check for monomer in laminating resin. • Change gel coat.

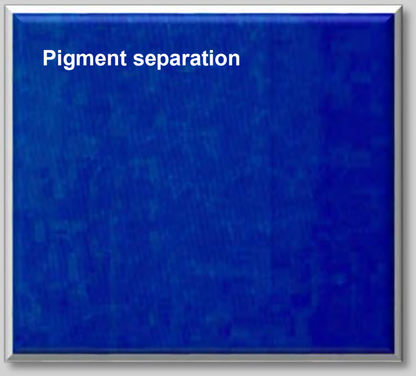
Problem	Cause	Items to Check / Solutions
		
Blisters (*Three examples below*)  **Blisters caused by catalyst drop*	**<u>Appear shortly after part is pulled, especially when put in sun</u>** • Unreacted catalyst or under cure…………………………………… • Solvent, water, or oil………………… • Air pockets……………………………	• Check percent catalyst, catalyst overspray, mixing, and leaks. • Check air lines, material and rollers. • Check rollout.
 **Catalyst drop gassing (likely blisters as in 1st photo)*	**<u>Appear after part in field</u>** • Unreacted catalyst……………………	• Check catalyst levels and distribution, film thickness of 18 ± 2 mils.
 *Small blisters–gel coat* *Large blisters–laminate*	**<u>Water blisters</u>** • Solvent, water, or oil………………… • Various……………………..................	• Check air lines, materials, and rollers. • See section Field Service: Blisters and Boil Tests.

Problem	Cause	Items to Check / Solutions
Chalking: Gel coats will oxidize or chalk, over an extended period of time. The degree of chalking is related directly to the environment (see section Field Service: Weathering). 	**Dry, chalk-like appearance or deposit on surface of gel coat (premature)**	
	- Cure……………………………………	- Under or over catalyzation, giving incomplete cure. Check air lines, material, and rollers; catalyst amount, film thickness, water and solvent contamination.
	- Contamination………………………..	- Surface soil picked up from atmosphere.
	- Insufficient buffing……………………	- Wipe buffed area with solvent rag. If gloss remains, area is okay. If gloss dulls, part needs more buffing.
	- Poor mold condition………...........	- Reduce sanding and buffing requirement on parts by keeping molds in good condition.
Mud Cracking: One or more crescent-shaped cracks. 	- Poor integrity of the gel coat film………………………………..........	- Trapped vapor or incompatible liquid which blows through the gel coat film on aging. - Temperature extremes.
	- Corrosion……………………………..	- Chemical attack.
	- Other………………….…………….	- Check catalyst level. - Check for water. - Solvent.
Craters - while spraying	- Chunks in the gel coat………………	- Dirt in the gun or gel coat. - Material old and starting to gel; need to rotate stock. Strain/filter the gel coat.
	- Equipment…………………..............	- Clogged gun—needs cleaning. - Improper atomizing air setting (too low)—adjust.
Cracks (Three types pictured below)	**Reverse impact cracks radiating out from a central point or in circles**	
	- Impact from laminate side…………..	- Check on handling and de-molding procedures. Caution people about hammering on parts.
	- Excessive gel coat film thickness………………………………	- Use a mil gauge to determine thickness; do not go over 24 mils.
	- Mold mark……………………………..	- Defect in the mold.
	Frontal impact cracks	
	- Frontal impact………………………..	- Use caution when handling parts.

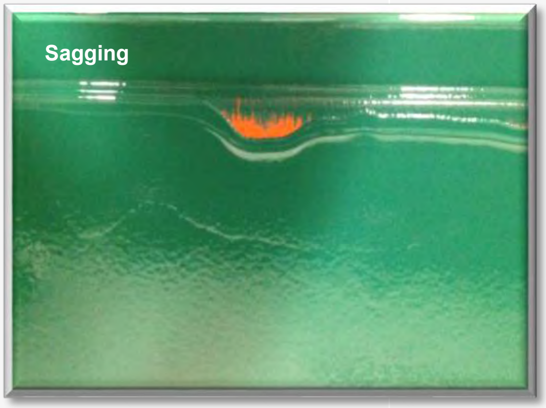
Problem	Cause	Items to Check / Solutions
	Stress (spider) cracks—cracking in parallel lines	
	• Stress due to flexing…………………	• Excessive gel coat thickness. • Laminate too thin. • Pulled too green; laminate under cured. • Demolding or handling procedure. • Sticking in the mold.
	• Mold mark…………………..................	• Defect in the mold.
		
Delamination	**In spots**	
	• Contamination………………………..	• Check for dust, solvents, moisture and catalyst getting onto the gel coat surface. • Excess mold release wax floating through to the gel coat surface, creating areas that will not adhere.
	Large area	
	• Gel coat too fully cured……………..	• Check for high catalyst level. Letting the gel coat cure too long, such as overnight; skin coat, rather than leave on the mold for long periods of time. • Excess mold release wax or wax in the gel coat.
	• Contamination………………………..	• Solvent wiping, then waxing (around taped off areas).
	• Dry laminate………………....	• Dry fiberglass.
Dimples - in the gel coat surface	• Contamination………………………..	• Check for water, solvent, or improperly mixed catalyst; overspray; seedy resin; excess binder on the glass mat.
	• Other………………………………….. .	• Thin laminate or gel coat. • Very dry laminate. • Pin air entrapped. • Post-curing of the laminate.
		

Problem	Cause	Items to Check / Solutions
Dull Gloss, Cloudy/Milky 	**When the part is pulled** Rough mold……………………………..	Polish out the mold.
	Mold buildup…………………….………	Wax and buff with cleaner. In most instances, what is called wax buildup is actually polystyrene buildup and should be treated as such.
	Polystyrene buildup………..........	Sand or scrub with a brush and strong solvent; read precaution on solvent before using. DO NOT USE STYRENE.
	Dirt or dust on mold………...........	Clean the mold. It is best to clean in the spray booth just prior to gel coating. Time span should be as short as possible between cleaning and gel coating. Use a tack rag.
	Solvent or water………………………	Check for solvent or water. Drain water traps regularly.
	Raw catalyst………………..............	Start catalyst flow from gun away from the mold. Only catalyzed gel coat should be sprayed into the mold.
	Rough PVA or wet PVA……………..	Check spray technique (see Conventional Gel Coat: Spray Equipment and Application sections).
	During and after part is pulled Insufficiently cured gel coat or laminate……………………..........	Check if catalyst level for gel coat and laminate is too low or too high. Check incorporation of catalyst into gel coat. Wait longer before pulling. Check for low temperature (minimum of 66 ˚F). Check for contamination: water, air, or solvent.
Dull or Soft Spots (at random)	Gel coat uneven………………………	Poor breakup—need to spray in three passes versus one.
	Catalyst poorly mixed into either gel coat and/or laminate…….............	Mix catalyst thoroughly or make equipment adjustments for good catalyst mix. Equipment surging (material pump and/or atomizing air). Improper catalyst setting (high or low). Gun held too close to mold (see Conventional Gel Coat: Spray Equipment and Application sections).
	Trapped solvent in gel coat and/or laminate………………………………	Check cleaning procedure. Check catalyst level with equipment using solvent-reduced catalyst.
	Trapped water in gel coat and/or laminate………………………………	Drain lines and correct the problem.
	Insufficient catalyst…………………..	Confirm correct catalyst concentration.
Fading - see Water Spotting (and Field Service: Weathering section)	Poorly cured gel coat………………..	Check catalyst levels and film thickness (should be 18 ± 2 mils wet).
	Improper cleaners or chemicals……………………………..	Do not use strong alkaline or acidic cleaners.
Fiber Pattern and Distortion  (More pictures below)	Insufficient cure………………………	Correct the excessive or insufficient catalyst level in gel coat and/or laminate. Wait longer before pulling. Do not pull while laminate still has heat. Check for low temperature. Check for contamination by water, oil, or solvent.
	Transferred from mold……………….	Refinish mold
	Glass cloth…………………………….	Too close to the gel coat. Should have two layers of cured 1.5 oz. mat or equivalent chop between gel coat and cloth.
	Woven roving…………………………	Too close to gel coat. Should have three layers of cured 1.5 oz. mat or equivalent chop between gel coat and woven roving.
	Gel coat too thin………………………	Use 18 ± 2 mils, wet.
	High exotherm of laminate………....	Cure laminate more slowly. Laminate in stages. Use lower exotherm laminating resin.

Problem	Cause	Items to Check / Solutions
 Distortion (top panel)	 Fiber print and distortion	
Fisheyes	• Water, oil, or silicone contamination…………………………… • Dust/dirt on mold……………………...... • Gel coat film too thin………………… • Low viscosity material…………….........	• Drain air lines. • Check mold release wax. Excess and/or fresh coat of wax is worse. • Check lubricating materials used within the equipment. • Use a clean tack rag to remove all debris. • Use 18 ± 2 mils in three passes. • Old material - rotate stock.
 Fisheyes	 Fisheyes	 Fisheyes
Material Gelled - in container	• Age………………………………………. • Storage condition…………………….	• Use partial container first; keep container covered. • Use within storage limitations, shelf life.
Jagged Tape Lines	• Gel coat starting to gel ………………	• Use less catalyst, but do not go below recommended minimum. • Use double tape process. • Use tape recommended for fine lines. • Pull tape towards freshly sprayed gel coat at a 30-45 degree angle.
Pigment darting or specks  Pigment darting	• Contamination……………………….... • Foreign particles……………………....	• Clean pump and lines. • Strain material and keep it covered. • Keep overspray minimized. • Be sure molds are clean. • Spray perpendicular to mold surface.

Problem	Cause	Items to Check / Solutions
Pigment Separation or Mottling  	• Pigments separate from each other • Other  	• Look for contaminants such as water or solvent and dirty equipment. • Dry overspray. Remember to always maintain a wet line. • Excessively applied gel coat causing sagging. • Excessively high delivery rates causing flooding onto the mold surface.
Pinholes  	• Insufficient atomization	• Too high gel coat delivery rate. • Not enough atomization pressure.
Porosity   	• Entrapped air • Wrong catalyst • No catalyst • Gel coat film thickness • Formulation • Water or solvent • Pump cavitation • Excessive mixing  	• Wrong air pressure. • Check gel coat vendor for recommendation. • Check catalyst supply and alignment. • Applied too thick; use 18 ± 2 mils wet. • Apply in two to three passes. • Improper viscosity and/or resin solids. Thix index high. Check with vendor. • Check for contamination. • Check pump for leaks. • Mix once a day for 10 minutes only. 

Problem	Cause	Items to Check / Solutions
Pre-release of the gel coat   	**<u>During cure</u>**—causing obvious surface distortion and low gloss	
	• Wrong catalyst…………………………..	• Refer to Polynt recommended catalyst list.
	• High catalyst level……………………	• Calibrate equipment and decrease catalyst.
	• Low catalyst level…………............	• Calibrate equipment and increase catalyst.
	• Uneven and/or too thick film………..	• Check thickness, not to exceed 24 mils, wet. • Ensure a consistent film thickness.
	• Gel coat allowed to cure too long………………………………….	• Gel coat should not be allowed to set on the mold for more than a few hours without laminating at least a skin coat. Varies with temperature-should be laminated same day.
	• Gel coat resin solids too low………..	• Check with manufacturer; do not add styrene without their approval.
	• Uneven cure…………………………..	• Improperly dispersed catalyst.
	<u>Occurs after cure</u>—seen as visible sharp distinct line (won't necessarily feel line) with increased fiber pattern on the side of the line that pulled away. Sometimes referred to as 'heat' or 'shrink' marks.	
	• Mold release………………..........	• Type and amount on the mold.
	• Clay……………………………………	• Some clays cause an oily residue and pre-release. Change type of clay, dust the clay with a very fine powder or overspray with PVA.
	• Too long of cure………………………	• Laminate sooner-don't lap or jar the mold.
	• Laminate curing too fast……………. .	• Check for proper catalyst level. • Build laminate in stages.
	• Wrong type resin……………………..	• Too high exotherm.
	• Laminate curing uneven…………….	• Low resin solids. • Uneven laminate thickness. • Check resin-to-glass ratio. • Resin drain-out or puddling.
Resin Tearing / Resin Separation 	• Pigments separate from resin………	• Check for sources of water contamination.
	• Application…………………………….	• Avoid overspray. Improper spray techniques create excessive overspray, droplets and flooding. Can be aggravated by long gel time and sagging. Do not allow overspray to dry; keep a wet line.

Problem	Cause	Items to Check / Solutions
Sags and Runs 	- Excessive gel coat…………………… - Spray techniques……………….......... - Low viscosity………………………….. - Mold wax………………………………. - Other……………………………………	- Apply 18 ± 2 mils, wet. - Atomizing air is pushing and blowing the gel coat. - Not enough styrene is being volatilized. - Check viscosity and thixotropic properties. - Over-agitated. - Material was reduced, but should not have been. - Silicone content too high. - Jarring the mold before gelation.
		
Softness	- Soft gel coat film which can be easily matted…………………………	- Incomplete cure of gel coat. Check catalyst levels, contaminants, and film thickness.
Splotches After Demolding 	- Solvent contamination………………	- Ensure that all solvent has been flushed out of spray equipment lines. For internal mix equipment, ensure that solvents flush line is not leaking.
Splotches After Parts are Sanded and Buffed: Also referred to as 'leathery', 'pebbly', and 'chicken skin'	- Overspray……………………………. - Not maintaining a wet line…………. - Cure……………………………………	- Do not allow overspray to accumulate. - Spray laps within five minutes. - The total film must cure as a total homogenous film rather than several independently cured thin films.

Problem	Cause	Items to Check / Solutions
Water Spotting - also see fading 	Usually caused by exposure of a combination of excessive heat and moisture………………………………	Use only a product recommended for the particular application. Improper shrink-wrap. Use only a product (and recommended procedures) applicable to gel coats.
	Poorly cured gel coat………………..	Check for both over and under catalyzation.
	Certain chemical treatments such as chlorine and/or cleaners……………..	Misuse of these chemicals.
	Exposure of parts to moisture too quickly after fabrication………………	Allow one week ambient cure before service.
Yellowing of Gel Coat: Gel coat yellows rapidly and unevenly when exposed to sunlight, heat and/or moisture (see Field Service: Weathering section).  **Inset shows 55 mil thickness of white gel coat*	Polystyrene/wax buildup on the mold which has transferred to the part during molding………………………..	Perform regular mold-cleaning program. Do not clean mold with styrene or used, dirty, or reclaimed solvent.
	<u>Inadequate gel coat cure</u>	
	Improper catalyzation which results in inadequate cure of gel coat………	Check catalyst (bad or old lot batch) and catalyst level. Use only a recommended catalyst and maintain the proper level of catalyzation. (See the product data sheet).
	Contamination such as solvent, moisture, or oil………………………..	These contaminants will affect the gel coat's cure. Look for moisture or oil in air lines, moisture or other contaminants in solvents used to cut the catalyst or other sources of contamination.
	Improper or unauthorized adjustment of the gel coat…………..	Do not add any material (other than the recommended methyl ethyl ketone peroxide catalyst) to the gel coat without the advice of a Polynt representative. The addition of solvents or excessive additions of styrene, inhibitors, accelerators, etc., will adversely affect the gel coat's cure and therefore its resistance to yellowing. Contact a Polynt representative if adjustment seems necessary.
	Cold temperature during application…………………………….	Do not apply gel coat at temperatures below 60˚F; permanent under cure of gel coat may result.
	Old material…………………………..	Old material may be slow in gel and cure and will need adjustment. Consult a Polynt representative.
	Film cure inhibited by styrene vapors…………………………………	Provide adequate air circulation for 'deep well' areas where styrene vapors may collect.
	Pre-release……………………………	Most of the conditions which cause pre-release will also result in unusual gel coat yellowing, i.e., uneven gel coat thickness, uneven catalyzation, uneven film gel and cure, etc. Check for and eliminate any pre-release causes.
	Excessively hot resin-rich laminates………………………………	Good laminating techniques must be followed. This is especially true in deep well areas where the gel coat is not likely to cure adequately. Unusually 'hot' laminates at this point in the gel coat's cure may result in permanent under cure and more yellowing of the gel coat.
	Resin tearing…………………………	Overspray, excessive film build, flooding, or contamination, all of which can result in vehicle/ pigment separation. A concentration of the gel coat vehicle on the surface of the part will result in more rapid yellowing of the finished part.
	Uneven gel coat film thickness……..	Avoid flooding the gel coat or applying excessively thick gel coat. Maintain the recommended 18 ± 2 mils wet film coverage. Excessively thick gel coat films will yellow more.

Problem	Cause	Items to Check / Solutions
	• Cleaning the finished part with an alkaline cleaner................................	• Do not use any strong alkaline cleaner (such as ammonia or other cleaner having a pH greater than nine) for cleaning a gel coat surface. A weathered gel coat can be yellowed by such cleaners.
	• Holding gun too close to the mold……………………………………	• Maintain proper distance.
	• Spray in one pass……………………	• Spray in multiple passes.
	• Insufficient atomization………………	• Gel coat must be atomized to fine particles.

4. SPECIALTY GEL COATS

Overview

- **Conductive Sanding**
- **Metal Flake**
- **Metallic**
- **Enamels**
- **Brushable Gel Coat**
- **Swimming Pool Recommendations**

4.1. CONDUCTIVE SANDING

Overview

- **Description**
- **Application**

4.1.1. DESCRIPTION

Polynt's conductive sanding gel coats have been used for several years in composite construction to enable electrostatic post painting of FRP parts. They are offered for both open mold and RTM processes. They may also be used as a gel coated surface to facilitate static electricity drain off (with proper grounding provided). Refer to Chapter 7 Painting Polyester Gel Coats for more information.

These products are available only in black. Conductivity comes from carbon particles, which are black. The liquid material will normally yield a maximum resistance of 0.10 megohms (MΩ) when tested by an ITW Ransburg #76634 meter. Users should determine that the product's conductivity meets the intended use.

These conductive sanding gel coats are made from resilient isophthalic polymers to meet normal flexing/fitting demands after paint baking. They allow quick powdering-sanding and surface preparation. They exhibit good chemical resistance and are considered very serviceable in a saltwater environment.

While the gel coat is only part of the composite/laminate structure, it must participate in the processing and service conditions of the total composite. Parts made with these conductive gel coats can withstand temperature elevations to 180°F (82°C), but normal operating temperature range is considered 0°F to 120°F (-18°C to 49°C). The cured gel coat will endure the lower temperatures of this range but can crack if stressed significantly. Temperatures as high as 285°F (141°C) for 30 minutes are withstood, but customers should expect some pinhole blowing and accompanying spew from trapped air pockets within the sanded composite.

These gel coats are ready to use and require only the addition of suitable methyl ethyl ketone peroxide (MEKP) to cure.

These gel coats will chalk when exposed to direct sunlight and are not designed (or recommended) for constant water immersion parts.

Conductive surface coats (or enamels) can be made from these products by adding 2.5% 970-C-949 wax solution.

4.1.2. APPLICATION

Conductive sanding gel coats are generally formulated for both airless and conventional spray application. Brushing or rolling is not recommended. Refer to the Chapter 3 Conventional Gel Coat sections on Application and Spray Equipment for additional specific recommendations.

Pits, pinholes, and porosity are, of course, very detrimental in a sanding gel coat which is to be post painted. It is important not to spray any of these defects into the film. Keeping the equipment properly calibrated (gel coat delivery/atomization and catalyst delivery/atomization) is as important as maintaining a minimum temperature of 60°F (16°C) (material, mold, and ambient) and applying the gel coat in at least three smoothly sprayed 6 mil coats using the appropriate spray distance.

Polynt recommends a gel coat delivery rate of no more than 2.5 pounds per minute with conventional air-atomized equipment, and no more than 4 pounds per minute with airless equipment.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, potential problems can occur due to: poorly atomized catalyst; surging problems (gel coat or catalyst); poor tip alignment (catalyst to gel coat mix); contamination; and poor application procedures, which will quickly negate all benefits of calibration. The equipment (and application procedures) must be monitored on a routine basis to ensure proper application and cure of the gel coat. Ask about and adhere to most equipment manufacturer's recommendations.

For best overall end performance properties, a wet film thickness of 18 ± 2 mils is recommended as ideal. Films less than 12 mils will have less conductivity, may not cure properly, may be hard to patch, have more print-through, and are more susceptible to water blisters. Films above 24 mils may pre-release, trap porosity, and crack.

Proper mold maintenance is important. Although conductive gel coats have excellent patching properties, minimal repair work is always desirable.

4.2. Metal Flake

Overview

- **Introduction**
- **Selecting the Right Gel Coat**
- **Recommended Application Procedure**
- **Equipment**
- **Unique Problems**
- **pH Test for Metal Flake**
- **Patching for Metal Flake**

4.2.1. Introduction

There is a unique appeal to a metal flake finish. When done right, it is eye-catching. The colors glisten, changing with shadows or light. Upon close examination, there is a distinctive richness and depth of luster.

Figure 4-1. Examples of metal flake gel coat.

Use of a metal flake finish will require increased investment in materials and labor, but if the design of the part warrants such an unusual finish, then the extra time and care should be taken to ensure the quality of the final product.

Metal flake suppliers recommend epoxy-coated aluminum and polyester flakes for use with polyesters. There are polyester flakes coated with epoxy or acrylic. Polyester flake generally makes better looking, more brilliant parts than aluminum metal flake, but also costs more.

Polyester flake density is closer to that of clear gel coat. However, an advantage of aluminum flake is its solubility in muriatic acid, which helps when patching. Muriatic acid will not dissolve polyester flake.

Questions about metal flake should be directed to the metal flake supplier.

4.2.2. Selecting the Right Gel Coat

The gel coat must be clear so that the full brilliance of each metal particle is visible in the final product. Clear gel coats are formulated for various specific applications, including use with metal flake. Always specify a marine clear rather than marble clear.

Polynt Composites produces several marine clear gel coats suitable for metal flake application. Polynt's marine clear gel coats are formulated for superior UV resistance and flexibility. Gel coats with flexibility and lower viscosity are preferred for metal flake applications. Contact a Polynt sales representative for more specific recommendations.

4.2.3. Recommended Application Procedure

A. **Clear gel coat** should be catalyzed at the recommended level; consult individual data sheets for these specifications.

  - **Over or under catalyzation** can cause premature yellowing, cracking, or crazing, or can cause physical deficiencies in surface gloss or general surface appearance.
  - **Spraying uncatalyzed** clear gel coat is not good practice. If sprayed too thick, the result can be an undercured film that will contribute to a distorted surface. In addition, an uncatalyzed film can be prone to porosity.

B. **To ensure** an enriched depth of metal flake, catalyzed clear gel coat should be applied 12-14 mils, wet, in two to three passes, allowing sufficient time for air release between each pass. This coat of clear helps prevent a rippled surface and protects the metal flake particles from the elements.

- **Less than 12-14 mils** can result in an undercured film, which will have greater alligatoring potential. Also, it is much harder to patch metal flake when there is little or no clear.
- **More than 12-14 mils** can interfere with clarity and produce a heavy gel coat thickness, which is more susceptible to cracking, crazing, and poor weathering.

C. **Once the clear coat** is ready, the metal flake coat may be applied. Opinions vary on how much metal flake to use. The normal range is 10-20% by weight.

- If greater hide or more brilliant color is desired, these may be achieved by mixing proportions of fine and coarse flake.
- It is important to remember when catalyzing clear and metal flake mixtures to subtract the weight of the metal flake. For example, with a 1,000 gram total mixture, if 20% is metal flake, then only 800 grams of the total mix will require catalyst.
- It should be noted that sufficient residual chemicals may remain on the metal flake, so that if higher percentages are used, gel and cure of the clear gel coat may be retarded. Normally, a reduction in metal flake can help correct this problem.
- Also, if pressure pot equipment is used, gel coat and flake mix should not be allowed to sit more than 60 minutes before being used. Longer contact time can cause gel/cure extension. Poor cure results from this extension. Poor cure will be observed as a grainy or rippled distortion. Reduced gloss may also be observed.
- Catalyzation of the metal flake gel coat should meet material specification, with application at 12-20 mils, wet.

D. **Generally**, regardless of how much metal flake is added to the gel coat, it will not (and should not) produce total hide. Orientation of the flakes will always produce small voids in the color.

- If not addressed, these voids can distract from the total effect, leaving a flatness in the finish. This can be overcome with a procedure that further enhances the final appearance. The procedure is to apply a pigmented layer directly behind the metal flake. Not only is complete hide assured with this procedure, but the use of a contrasting color (usually black), will provide greater depth and eye-catching appeal.

If everything has been done correctly to this point, about 30 mils of gel coat have been applied to the mold. More gel coat could create problems with cracking and crazing due to excess total gel coat thickness.

Two methods are commonly used. The most common is wet-on-wet.

A. Wet-On-Wet Procedure

Although Polynt recommends that each coat cures before the next coat is applied, metal flake has been sprayed successfully using the wet-on-wet technique. The advantage is in time saved. The procedure consists of spraying all coats on top of one another without waiting for each coat to cure. There should be no lag time once spraying is started. The following problems can occur:

- Alligatoring.
- Blow through (blowing the metal flake through the first clear coat, or blowing the backup through the flake coat).
- Metal flake rippling may increase.
- Checking - occurs when edges of the flake are within the clear coat and immediately next to the mold surface.
- Stretch marks - occurs when the backup coat cures much more quickly than the flake coat; worsened if the backup coat sags.

Proper catalyst levels must be maintained in all three coats.

1. **Cured Procedure**
2. Allow the clear coat to cure adequately before applying the metal flake coat. Time will vary, depending upon a number of conditions, including catalyst type and concentration, temperature, and humidity. Cure should be such that the metal flake coat does not cause the clear coat to alligator.
3. Once the initial coat of clear is ready, the metal flake coat can be applied.
4. After the metal flake coat has cured, the backup coat is applied.
5. Laminate and allow a good cure before pulling.

No pull should be made until after the part has exothermed and cooled to room temperature. Provide adequate heat or an undercured part can induce some surface rippling in the final part. Overnight cure is best.

4.2.4. Equipment

A. **Conventional air-atomized spray equipment** (suitable for spraying regular gel coats) is sufficient, but some changes will be necessary. The metal flake tends to clog, so larger fluid tips and nozzles will be required. Fluid tip sizes in the range of 0.090-0.110 inches should be sufficient.

High percentages of metal flake or larger metal flake particles can become trapped between the fluid nozzle and the needle. This can prevent the gun from shutting off properly. To prevent this, Binks has the Metal flake Nozzle Kit (#102-530) to fit its 7N gun.

B. **Pressure pots** are used instead of pumps for delivery to the gun. The metal flake particles can be damaged by pumping action. In addition, these particles can create problems with the pump and existing filters. Usually more than one specific color of metal flake is used, so small-batch mixing, of up to several gallons each, proves to be the most practical means of application. Mixed batches should not be allowed to sit for more than one hour before use.

C. Alternatively, metal flake can be applied with **standard airless air-assist gel coat equipment**, using a separate container of metal flake that is fed to the gun head.

To use airless air-assist gel coat equipment, some modifications are required.

- Gel coat and catalyst tips must be rotated 90°, creating a horizontal rather than vertical spray pattern, similar to the fan pattern in chopped fiberglass.
- The gun head must be fitted with a top-mounted tube, allowing directional control of the metal flake, again similar to a chop chute. The bulk dry metal flake is in a hopper at the spray booth or carried with the operator in a backpack.

  If using a backpack, the two most common types are hard cylinders or soft pouches. The gel coat gun must be modified with an air line, which can be fed to the backpack. Air from the gel coat gun to the backpack ‘fluidizes’ the metal flake and creates a pressure differential that forces flake down the delivery tube, normally 3/8-1/2 inch in diameter, to the gun head. This method allows for coverage of a much greater surface area than would be possible using a pressure pot, allows the same tips to be used for clear and metal flake coat, and is also a more efficient method, requiring no premixing.

4.2.5. Unique Problems

Color change and blistering of the metal flake film can be caused by a combination of:

- Metal flake
- Catalyst-the higher the catalyst level, the greater the problem
- Water

In the initial stages, the flake darkens and at the same time exhibits less brilliance. As the color change progresses, the flakes seem to disappear. Since the flakes become transparent, the backup color will begin to show through. The ultimate and final stage has been reached when all flakes seem to disappear (they are actually transparent), when there is no luster or brilliance, and when there is a dramatic color change. Magnification, about 10X, is very helpful to observe this process.

Figure 4-2. Example of color change in metal flake gel coat. Note the dark area near the bottom.

This problem seems to occur only with epoxy-coated polyester flake. Construction of this flake starts with a polyester film such as Mylar®. Pure aluminum is deposited onto the polyester film, providing an opaque, mirror-like surface. An epoxy coating is then applied. This coating contains colorants.

A. **Metal flake** - The visible change results when the aluminum is dissolved from the flake. At first, light corrosion of the aluminum causes darkening and loss of luster. With a lighted magnifying glass, this can be seen as a more random diffraction of light. In the final stages, when all of the aluminum is dissolved, the flakes are transparent and of a color representative of the colorant used in the epoxy coating and the color of the backup gel coat.

B. **Water** - Continued exposure to water makes this problem show up. High humidity can be worse than immersion. Pure or distilled water is more corrosive and worse than tap water. With elevated temperatures, corrosion occurs sooner.

C. **Catalyst** - MEK Peroxides are corrosive in the presence of both water and metal flake. Excessive amounts of catalyst speed the rate at which corrosion occurs. Raw catalyst spots can cause dramatic and rapid changes. Catalyst injection equipment may not always provide even catalyst dispersion, resulting in areas of concentrated catalyst that will increase susceptibility to corrosion.

Maintaining the recommended catalyst level with properly functioning equipment is one precautionary step the fabricator can use to control and minimize this problem. The recommendation is that metal flake should be catalyzed and applied via the hot pot system (i.e., a known amount of catalyst mixed into the gel coat).

If a particular operation will not allow use of the hot pot, then equipment should be calibrated weekly or more often if:

- A new batch of gel coat is used
- A new batch of catalyst is used
- A new pump is used
- A rebuilt pump is used
- Any equipment malfunction has occurred
- An extreme temperature change has occurred
- New equipment is placed on the same air line
- Pressures are changed
- Tips are changed

Key people, such as the supervisor, lead person and spray person, should be advised of this potentially damaging problem occurring due to a high catalyst level. They should be knowledgeable about calibration and be watchful for catalyst drops, excess catalyst, or a sudden decrease in gel coat flow.

4.2.6. pH Test for Metal Flake

The pH test can be helpful. This can be a standard incoming quality control test or specifically used to confirm problem lots of metal flake.

The procedure is simple.

1. **Mix** an equal volume of metal flake with distilled water and let stand for 30 minutes.
2. **Check** with pH meter (preferred) or pH paper (available from chemical supply houses).
3. **Check pH of the distilled water**, which should show a pH of 7.
    - A pH less than 7 indicates an acid solution. Stronger acid solutions are indicated by lower pH, or simply a smaller number.
    - Solutions with a pH 5-7 are generally trouble free.
    - Batches of metal flake that show pH from 2-5 are more likely to have gel/cure problems, and can be subject to field discoloration.

4.2.7. Patching Metal Flake

Metal flake is difficult to patch and requires more expertise and patience than regular pigmented gel coats.

The clear coat is very important. The main problem with patching metal flake is that when flake is sanded, color is removed and the flake turns bright silver. If a clear has been applied, minor scratches can be sanded or buffed out. If the first clear is not used, no sanding can be done until a clear spray patch is applied. It is the clear coat that can be worked and sanded, not the flake coat.

Use only the same clear gel coat (marine type) that was used to make the part. Do not use a gel coat intended for the manufacture of cultured marble.

Polynt offers special patching thinners developed specifically for patching metal flake. See the patching thinners data sheet for product selection and specific instructions.

A. **Small Spot Patch**

1. Prepare the area by routing, sanding to feather, and washing with solvent.
2. Brush with catalyzed accent color. Let dry.
3. Apply a small amount of catalyzed flake and clear (approximately 15% flake and 85% clear). Cover with a sweep made of waxed paper or

cellophane. Strike across the sweep as smoothly as possible.

4. Let cure overnight (due to inhibition tendencies of the flake).
5. Sand with 600 grit paper.
6. Buff.
7. Wash with hydrochloric (muriatic) acid to dissolve any exposed flake (only if working with metal flake rather than polyester flake). **CAUTION: Hydrochloric (muriatic) acid is very toxic and can be harmful if not properly handled. Always wear gloves and protective glasses**.
8. Wax.

B. **Very Small Spot Pa**tch (with no sanding)

1. Route area. Do not sand surrounding area.
2. Brush with catalyzed accent color. Let dry.
3. Apply a small amount of catalyzed flake and clear. Cover with a sweep made of waxed paper or cellophane. Strike across the sweep as smoothly and nearly flush as possible.
4. Let cure overnight and remove paper.
5. Trim and clean with knife blade.
6. Wax.

C. **Spot Patch with clear overspray**

1. Prepare the area just like a regular spot patch.
2. Brush with catalyzed accent color. Let dry.
3. Apply a small amount of catalyzed flake and clear mix. Cover with a sweep made from waxed paper or cellophane. Strike across the sweep as smoothly and nearly flush as possible.
4. Let set overnight and remove paper.
5. Scuff and solvent-wash the area to prepare for spray patch.
6. Overspray with catalyzed clear gel coat.
7. Let cure minimum of 2 hours. Sand, buff, and wax.

D. Spray Patch

1. After damaged area has been prepared, wash with solvent.
2. Mask off a large area around the repair.
3. Spray with catalyzed flake and clear mix (see patching thinner data sheet for product selection and specific instructions). Let cure for 2 hours.
4. Overspray with clear, making sure to go beyond the perimeter of the flake coat. Spray PVA or catalyzed Patchaid® on top of the clear for better surface cure. Let dry overnight.
5. Sand, buff, and wax.

E. Clear Gel Coat was not used for the part

Clear must be sprayed to provide a base coat to feather into.

1. Scuff an area larger in size than the actual repair area.
2. Use 600 grit sandpaper and be careful not to sand hard enough to turn the flake silver.
3. Spray this area with catalyzed clear.
4. Spray with catalyzed flake and clear mix (see patching thinner data sheet for product selection and specific instructions). Let cure for 2 hours.
5. Overspray with clear, making sure to go beyond the perimeter of the flake coat. Spray PVA or catalyzed Patchaid® on top of the clear for better surface cure. Let dry overnight.
6. Sand, buff, and wax.

4.3. Metallic

Overview

- **Description**
- **Application**
- **Precaution**
- **Weathering Performance**

4.3.1. Description

Polynt Composites offers a line of metallic gel coats for the FRP industry. These gel coats mimic the small metallic sparkle common in automotive finishes. They are used in passenger, camper, utility, and recreation vehicles for the transportation industry, as well as for decorative structural components and above-the-water-line marine vehicle surfaces.

Metallic gel coats use the same metallic pigments used in automotive finishes. These pigments are smaller than typical metal flake and provide a subtle brilliance and elegant appearance. However, differences between formulation and application of urethane paints and gel coats will result in some appearance differences.

Pigments used in metallic gel coats typically consist of flakes of aluminum, bronze, coated mica, copper, glass, iron oxide and thermoplastic or thermoset plastic. Type, size, concentration, orientation, transparency and opacity of the flakes, along with the presence of dyes or pigments contribute to the overall color and appearance.

4.3.2. Application

Application procedures for Polynt's metallic gel coats are similar to the procedures for conventional gel coats described in the Conventional Gel Coat: Application section.

Polynt's metallic gel coats are applied using typical air-atomized gel coat spray equipment or standard airless air-assist equipment. With most metallic gel coats, a minimum orifice size of 0.021" is recommended. Keep the spray gun two to three feet from the molds.

Prior to use, metallic gel coats should be mixed for 10 minutes to ensure product consistency.

- The agitation level should allow for product movement all the way to the walls of the container, but with the least amount of turbulence possible.
- Do not over mix. Over mixing can break down the thixotropy, increasing the tendency to sag. Over mixing can also cause styrene loss that may contribute to porosity.
- Do not use air bubbling for mixing. Air bubbling is ineffective and only serves as a potential source for water or oil contamination.

Changes in the setup of the spraying equipment and/or application technique will lead to variances in metallic color shades and patterns. To reproduce a metallic color, it is essential to keep spray equipment, pot pressure or atomization pressure, spray distance and spray angle consistent.

If the patterns of the metallic on the finished part are not satisfactory, use a dust-coat approach. Whether it is a 'heavy dust' or a 'light dust' is not as important as getting the dust coat consistent and uniform. A heavy dust will provide a different ultimate effect than a light dust. If the gel coat is sprayed to an extremely inconsistent dust coat, these different effects will be noticeable.

Apply metallic gel coats to the same to the same wet film thickness as conventional gel coats, 18 ± 2 mils.

- Thin films, less than 12 mils, may not cure properly, have more print-through, and may be more susceptible to water blisters.
- Films that exceed 24 mils may pre-release, trap porosity, or crack, and are more subject to weathering discoloration.

Patching metallic gel coats is very difficult, and patches are likely to be more noticeable than those for solid colors. Fabricators may have to be content with some color and appearance differences between the patch and surrounding area, due to the sanding/polishing disturbance of the metallic pigments.

4.3.3. Precaution

Metallic gel coats may contain aluminum pigments. Precautions for products that contain aluminum pigment must be exercised. All equipment should be well grounded. Chlorinated solvents in contact with aluminum can cause an explosion; refrain from cleaning the metallic spray equipment with such solvents.

4.3.4. Weathering Performance

Metallic gel coats weather similarly to conventional solid gel coat colors. Chalk development and gloss loss will vary with metallic content. High metallic content gel coats may demonstrate more rapid chalk development than other gel coats. Consult a Polynt Composites representative about specific formulations.

4.4. Enamels

Overview

- **Introduction**
- **Surface Preparation**
- **Application**
- **Cure**
- **Availability**
- **Cleanup**

4.4.1. Introduction

Polycor® enamels are formulated to be used as topcoats (surface coats, interior gel coats) for FRP. They are very similar to gel coats except that they cure tack-free.

Enamels are used like paint on FRP surfaces—a topcoat to seal and hide a substrate. Normally, enamels are used as interior finishes or to cover a laminate to provide a colored surface. Enamels cannot be used like mold contact gel coats because they contain wax and cure tack-free, which could cause delamination. Along with providing a tack-free surface, the wax in enamels helps to suppress styrene evaporation. This reduces the volatile organic content (VOC) emitted into the air.

Enamels can be made from isophthalic, ISO/NPG or orthophthalic base resin. Consult a Polynt Composites sales representative for more information about a particular product.

Enamels are multi-mil surface coatings formulated for use in boat and camper shell interiors. Standard enamels should not be used for water immersion service. Contact a Polynt sales representative for recommendations if water immersion is required.

Polycor® enamels are available in flat and high gloss finishes. High gloss products include the letters HG in the product code. Polycor® provides a hard, tough, durable, finish with good water resistance characteristics when applied correctly.

4.4.2. Surface Preparation

With fiberglass laminates such as boat and camper shell interiors:

- **Polycor® enamel** should be sprayed after the laminate has cured and while it has a tacky surface. Beware of glossy laminates which could cause the enamel to separate, sag, or provide poor adhesion.
- **While still wet,** the Polycor® enamel can be flecked or cobwebbed.
- **When using laminates** that contain a 'wax surface' or 'mold release,' remove this surface before coating with Polycor® enamel. Sand with rough sandpaper to remove all indications of wax or mold release. Then wipe with solvent.

In all cases, before applying Polycor® enamels to any surface, be sure the surface is clean, dry, and free from asphalt, dirt, dust, grease, oil, form oil, soap or cleaning agents, disinfectants, and deodorants.

4.4.3. Application

Enamels should not be applied to surfaces when the temperature is below 70°F (21°C); inadequate cure can result.

Normally, enamels are applied with spray equipment, but they can be rolled. Brushing is not recommended due to poor flow and leveling. Equipment, settings, and techniques for spraying gel coats are the same for enamels.

Polynt recommends a delivery rate of no more than 2.5 pounds per minute with conventional air-atomized equipment, and no more than four pounds per minute with airless equipment.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, problems can occur due to: poorly atomized catalyst; surging problems (gel coat or catalyst); poor tip alignment (catalyst to gel coat mix); contamination; or poor application procedures. Any of these conditions will quickly negate all benefits of calibration. The equipment (and application procedures) must be monitored on a routine basis to ensure proper application and cure of the gel coat. Inquire about and adhere to all equipment manufacturers' recommendations.

Equipment, pot pressure, temperature, and length of hoses will vary the spraying; therefore, it is necessary to adjust equipment to obtain a good surface.

- One gallon of Polycor® enamel will cover approximately 60-80 square feet, depending on the film thickness of the coating.
- A wet film thickness of 18 ± 2 mils is recommended for proper hiding, cure, and performance properties.
    - A film below 12 mils may not cure properly.

  - Excessive millage above 24 may pre-release, is more prone to cracking, and tends to trap porosity.
- If a 'fleck coat' of Polycor® enamel is desired over the base coat of enamel, it should be applied while the base coat is wet.

CAUTION: Enamels are not compatible in the liquid state with gel coats or resins. Equipment must be completely clean of these gel coats or resins before enamels can be used.

Enamel should be mixed once a day for 10 minutes.

- The enamel should be mixed to the sides and bottom of the container with the least amount of turbulence possible.
- Do not over mix enamels. Over mixing breaks down viscosity, increasing tendencies to sag, and causes styrene loss which could contribute to porosity.
- Air bubbling should not be used for mixing. It is not effective, and only serves as a potential for water or oil contamination.

Do not add any material, other than the recommended methyl ethyl ketone peroxide, to these products without the advice of a representative of the Polynt Composites.

4.4.4. Cure

It is recommended that gel time be checked in the customer's plant because age, temperature, humidity and catalyst will produce varied gel times. Refer to Polynt product data sheets for specific catalyst recommendations.

The catalyst level should not exceed 3% or fall below 1.2% for proper cure. Recommended range is 1.2-3%, with 1.8% at 77°F (25°C) being ideal.

Cure characteristics are dependent on material temperature, room temperature, humidity, air movement, and catalyst concentration. Special fast-cure versions are available but must be requested. These products offer layup times of 30 minutes or less, depending on gel times. Fast-cure products have shorter stability and should not be inventoried over 45 days.

These products (standard or fast cure) should not be used when temperature conditions are below 70°F (21°C), as curing may be adversely affected.

4.4.5. Availability

Polycor® enamels are available in clear, white, or any of the colors listed in the standard gel coat color deck.

Special colors are available upon request. Economy enamels also are available.

4.4.6. Cleanup

Clean all equipment upon completion of the application, as it will be impossible to clean equipment if the Polycor® enamel sets up and is allowed to cure in the hoses and gun.

4.5. Brushable Gel Coat

Overview

- **Introduction**
- **Brushable vs. Standard Production Gel Coats**
- **General Considerations When Brushing Gel Coats**
- **Brushing or Rolling Equipment and Methods**

4.5.1. Introduction

In North America, the vast majority of gel coat used is spray applied. However, there are instances where brush or roller application is used. In this section, we will discuss gel coat designed for brush and spray application, general considerations for brushing gel coats and brush or rolling equipment and methods.

4.5.2. Brushable vs. Standard Production Gel Coats

When brush or roller application of gel coat is required, Polynt Composites recommends use of a gel coat specially designed for this process. These products are known as “brushable” gel coats. They have a “B” at the end of the product designation and the word “Brushable” in the product description. Specifications for these gel coats will vary depending on customer needs, but in every case, brushable gel coats have a viscosity greater than standard production gel coats. Reasons to use a brushable gel coat include limitations on emissions from spray atomization, limitation of overspray, and simply customer choice. A common use of brushable gel coats is to coat the backside of a laminate.

Brush or roller application of standard production gel coats is not recommended, but is sometimes necessary. Mold design can play a role in determining if the brushing of standard production gel coat is required. The complex geometry of some parts requires a mold design that cannot be adequately sprayed to an even thickness. Additionally, challenging spray angles may produce a film with unacceptable backside texture or orange peel. In these situations, a combination of spray and brush application is needed and gel coat formulated for spray application is used.

4.5.3. General Considerations When Brushing Gel Coat

Monomer Content

It is important to remember that gel coats are generally formulated with an excess of monomer (reactive diluent). Gel coats are formulated this way for viscosity control, and to account for monomer loss due to atomization and evaporation. If a part is being made with standard production gel coat using a combination of spray and brush processes, the material used to brush this part should be obtained by spraying the material into a container. Suggested containers include mold flanges, cutout areas on a mold, cardboard boxes and/or paper cups suitable to capture sprayed gel coat.

Catalyzation

Proper catalyst level and mix are essential to producing a quality part. When hand mixing catalyst with a brushable gel coat, it is important to remember that the viscosity is higher than standard gel coats. Extra diligence is necessary to ensure thorough mix of catalyst. When hand mixing catalyst for a part that is being both sprayed and brushed, it is important to maintain a similar catalyst level between the sprayed and brushed material to avoid issues with alligatoring or pre-release.

Gel Coat Thickness

Regardless of the process being used, gel coats are formulated to be applied between 16-20 mils, with 12 mils being an absolute minimum. Refer the Conventional Gel Coat - Troubleshooting Guide section for a discussion of possible problems that may occur if the gel coat film thickness is outside of these ranges.

4.5.4. Brushing or Rolling Equipment and Methods

Rolling of catalyzed gel coats is relatively rare. The main consideration for rolling gel coats is to have a chemical-resistant roller (Figure 4-3) of the correct size to evenly distribute the gel coat. These considerations also apply when choosing a brush to apply gel coat. Three or four-inch chip brushes are commonly used (Figure 4-4). A chip brush is a brush with natural bristles with wood handles designed to be disposed of after one use. These brushes are occasionally cleaned in solvent and re-used, but care must be taken to ensure that the brush is thoroughly clean and thoroughly dry prior to use.

Figure 4-3. Examples of chemical resistant gel coat rollers.

Figure 4-4. Examples of chip brushes used for gel coat application.

Brushing a Part Designed for Brushing Alone

A typical application for a brushable gel coat would be a part that is smaller than ten square feet. Brushable enamels (air-drying gel coats) are often used to coat the laminate side of small parts and bilge areas in marine applications. This type of application will always have the total gel coat thickness applied at one time. Unlike a spray application, do not attempt to brush gel coat in multiple discrete passes.

The brushable gel coat is typically hand-catalyzed in a cylindrical container (pot, cup, etc.). The material is either poured onto a section of the area to be brushed and leveled with the brush, or the brush is saturated with gel coat and brushed onto the surface.

Brushing a Part that is Predominantly Sprayed

When gel coat is applied by brushing in conjunction with spray application, it is typically done to ensure even thickness in areas where it is difficult to obtain even thickness by spraying. Examples include narrow gunwales on boat decks or louvered covers on recreational vehicles.

Several techniques are commonly used, each with potential benefits and drawbacks: pre-brushing, post-brushing, and removal of over-applied gel coat. Some people prefer to pre-brush an area prior to spraying. Gel coat can be post-brushed over sprayed gel coat to ensure a total thickness of 18-22 mils. An additional technique relies on over-applying gel coat to an area to ensure coverage in difficult to reach areas and using a brush to smooth or remove the excess material. These are listed in Table 1 below.

Table 4-1. Benefits and drawbacks of brushing techniques.

Technique	Benefits	Drawbacks
Pre-brush (prior to spraying)	• Ensures coverage in known problem areas • Ensures sufficient millage to avoid alligatoring	• Potential for pinholes due to trapped air near the part's surface • Visible transfer of brush strokes to the part surface
Post-brush (after spraying)	• Less likely to show brush strokes on the finished part • Less likely to trap air against the mold surface	• Potential for curing at a different rate than the material previously sprayed into the mold, causing alligatoring
Remove over-applied	• Ensures coverage in difficult to reach areas	• Potential for sagging • Potential for trapping porosity in the thick areas • Potential pre-release

Techniques to Successfully Brush Gel Coat

- It is always critical to start with a clean and contaminant-free brush.
- When developing a plan to brush, always try to begin brushing at the farthest point from the operator and/or the lowest point on the part. Using this technique allows the operator to pull any excess material out of the mold or off the backside of a laminate.
- The use of mil gauges is highly recommended.
- In order to minimize the appearance of brush strokes, a light touch is required. Brush strokes may either telegraph to the front side of a molded part or create air voids during lamination.
- Typically, coarser bristles leave deeper brush strokes than softer bristles.
- When brushing gel coat in conjunction with spraying, it essential to weigh all of the variables related to gel coat cure. Improper timing of brushing and spraying leads to alligatoring, a condition caused by two films curing at different rates. When alligatoring occurs, the gel coat wrinkles (taking the appearance of alligator skin).
- When brushing from a container, always identify a safe area for any excess catalyzed material to exotherm and cool down prior to disposal.

4.6. Swimming Pool Recommendations

Overview

- **Introduction**
- **Material Selection**
- **Application**
- **Owner Maintenance**
- **Polycor® 960SW Series Gel Coat**
- **Shimmer® 946SW Series Gel Coat**
- **Patching Shimmer® 946SW Series**

4.6.1. Introduction

The look, feel, durability, and strength of fiberglass make this unique material an ideal candidate for the construction of swimming pools. With proper selection of materials, good workmanship by the manufacturer, and reasonable maintenance by the consumer, a fiberglass unit will provide many years of trouble-free service; however, if any of these criteria—material selection, workmanship, and maintenance—are not met, problems affecting the appearance of the fiberglass unit can be encountered. In fact, problems, such as blistering, staining, and color fading, can occur after a unit has been placed in service for only a short period of time.

Figure 4-5. Example of an inground fiberglass pool.

4.6.2. Material Selection

Swimming pools are exposed to continuous water contact of 50-100°F. This factor, coupled with the use of a variety of chemicals in the treatment of pool water, including salt and chlorine, provides for severe operating conditions. It is important to select the proper materials for these demanding applications.

To reduce and minimize potential problems, Polynt has formulated specific gel coats for making pools:

- Polycor® 960SW Series – available in four recommended colors.
- Shimmer® 946SW Series – available in 13 standard colors.

These products are MACT compliant for the swimming pool industry. Do not use any other products for a pool without consulting a Polynt representative.

These products are not recommended for spas or saunas or any application where the composites will be exposed to continuous moisture contact in excess of 100°F. These products also should not be used for any other MACT-compliant application.

Polynt does not recommend or sell any materials for the repair or refinishing of swimming pools to the post-coating markets. OEM's can use Polycor® 960SW and Shimmer® 946SW series gel coats to repair swimming pools fabricated with these gel coats as part of the manufacturing process.

Each of the materials used in constructing a fiberglass unit has an influence on the performance of the finished product. This includes the laminating resin, reinforcement glass, gel coat, and catalyst. The manufacturer should carefully select all materials and then test the entire system to determine if it is suitable for use. Key performance properties include but are not limited to:

- Mechanical properties
- Water resistance including blistering and color change
- Chemical resistance (pool chemicals)
- Weathering resistance

A focal point of proper material selection should be the avoidance of gel coat blistering. Blistering is a severe cosmetic problem which is expensive to repair. Blistering is best minimized by using ISO/NPG gel coats, high performance or vinyl ester barrier coats, and isophthalic or vinyl ester laminating resins. The gel coat must be applied to at least 20 mils wet film thickness and good spray procedures should be followed.

Blistering can also lead to another problem unique to pools. That problem is called Black Plague, a black or brown staining of the gel coat surface that forms around a blistered area. Chemically, the source of Black Plague is a reaction of the cobalt accelerator found in all room-temperature-cured polyester and the chlorine compounds used in treating pool water. To prevent Black Plague, eliminating blistering is essential. Refer to the Open Molding-Field Service: Blisters and Boil Tests section for more information.

Glass selection must also be carefully considered. Because of the wide variety of reinforcement glass available (i.e., the glass type, sizings, and binders used), a specific recommendation is not given here. Generally, a chopped glass laminate is superior to a mat laminate for blister resistance. Some surfacing veils can be used to improve a mat laminate's resistance to blistering. However, not all surfacing veils and glass mats (or even rovings) will give the same blistering resistance. Therefore, the manufacturer is encouraged to test the complete resin, glass, gel coat, and catalyst system before entering production.

4.6.3. Application

Proper application is necessary for good field performance of the finished unit. Even if the best materials are used, poor application techniques can result in an inferior unit. One important manufacturing concern is proper catalyzation. Improper catalyzation can lead to poor gloss, blistering, and color fading.

Figure 4-6 shows color change on a panel that was made in the field and then exposed in Polynt's lab.

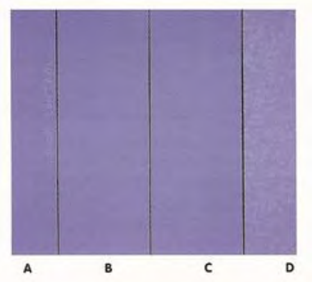


Figure 4-6. Color change on a panel. The panels are: A) Control—no exposure; B) Exposed in water at room temperature; C) Exposed in water at room temperature that contained pool chemicals; and D) Exposed in warm water that contained pool chemicals.

The white splotches are caused by excess catalyst or catalyst drops from poorly atomized catalyst. Poor catalyst/gel coat tip alignment also can cause this, which will be evidenced by a 'spray' pattern in the gel coat surface.

Gel coat color fading in particular can be extreme if the unit is exposed to unusual chemical treatment by the owner. Some color fading of the gel coat surface is expected over a period of time. Also, certain colors are more inclined to fading than others. Color fade is usually slow and not to a degree that is objectionable to the unit owner. However, this fade can be accelerated to the point of being objectionable when any two of three factors exist. These factors are:

- Overcatalyzation of the gel coat during application.
- Excessive use of chlorine compounds in water treatments.
- Elevated temperatures.

If all three factors are present, the fade will occur most rapidly.

Overcatalyzation is known to accelerate the gel coat color fading. The manufacturer can encounter units which have faded in spots, patches, or even stripes. These are usually symptoms of overcatalyzation.

Excessive use of chlorine compounds in water treatment can attack the gel coat even if it has been properly applied. But the discoloration will be increased if good manufacturing techniques are ignored.

4.6.4. Owner Maintenance

Owner care of the unit is the least controllable factor in assuring good field performance. Mistreatment by the owner may be the source of many field failures. A variety of chemicals are used in pool water treatment, including chlorine and salt, and in cleaning. When used in excess, especially the chlorine compounds or acid cleaners, color fade can result.

The manufacturer should select gel coat colors which resist fading in a chlorine environment. It is important to remember that chlorine is a bleaching agent and that no pigmentation system is completely resistant to chemical attack.

An expert on swimming pool chemicals should offer recommendations for water treatment. The guidelines listed on pool chemical containers quite often are standard for concrete pool construction and may not be applicable to fiberglass units.

Many conditions can influence the performance of FRP pools. Evaluation of all components together is the key to successfully servicing the finished product.

4.6.5. Polycor® 960SW Series Gel Coat

Polycor® 960SW Series gel coat is available in four recommended colors:

- 960LK171SW Medium Blue
- 960WK433SW White
- 960LF214SW Light ‘Baby’ Blue
- 960W016SW White

Polynt recommends only the products listed above for use in pools, water slides, and other products where continuous water contact is anticipated. Polynt requires that a disclaimer be signed by any and all parties who intend to use non-recommended products for these applications.

Polycor® 960SW Series gel coat offers many benefits, such as resistance to tearing and color separation, resistance to porosity, sag resistance, consistent liquid properties, blister resistance, and resistance to fading caused by swimming pool chemicals.

Polycor® 960SW Series gel coat meets the EPA’s National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reinforced Plastic Composites Production – Corrosion Resistant/High Strength or High Performance gel coat.

Polycor® 960SW Series gel coat is formulated for spray application. Brushing and rolling are not recommended. For the best overall end performance properties, a wet film thickness of 20-24 mils is recommended. The film should be applied in multiple passes, with each pass having a thickness of 6 mils. Maintain the recommended spray distance from the mold surface.

For training and educational purposes, we provide videos about setting up a fan pattern, spraying gel coat, and repairing gel coat.

Refer to the Open Molding-Conventional Gel Coat: Application section for more information about applying gel coat. Refer to the Open Molding-Field Service: Patching section for information on patching gel coat.

Polynt recommends that this gel coat be backed by IMEDGE® HPB 210LK292 high performance barrier coat, an ArmorGuard® vinyl ester barrier coat, or an ArmorStar® vinyl ester skin resin. Use of these materials will create a durable osmotic blister resistant composite that is ideal for swimming pool manufacture.

Additional information on swimming pool gel coats is available in MB-338 Performance of Swimming Pool Coatings.

4.6.6. Shimmer® 946SW Series Gel Coat

Shimmer® 946SW Series gel coat provides a deep, rich, sparkling finish that enhances swimming pool appearance. Shimmer® 946SW Series gel coat is available in 13 standard colors:

- 946AK339SW Stone
- 946AP241SW Electric Gray
- 946BP005SW Midnight Blue
- 946LK289SW Azure Blue
- 946LK290SW Persian Blue
- 946LP206SW Pacific Blue
- 946LP207SW Ocean Blue
- 946LP216SW California Blue
- 946LP220SW Aqua Marine
- 946LP288SW Maya Blue
- 946LP308SW Atlantic Blue
- 946NP273SW Sandstone
- 946WP274SW Artic White

Stone

Electric Gray

Atlantic Blue

Shimmer® 946SW Series gel coat is also available in other colors. A Polynt representative can provide more information on a specific formulation.

Figure 4-7. Example of Shimmer® gel coat.

Shimmer® 946SW Series gel coat offers many benefits, including blister resistance and blush or fade resistance caused by swimming pool chemicals and water exposure. Figure 4-8 includes pictures of panels after exposure to boiling water for 100 hours.

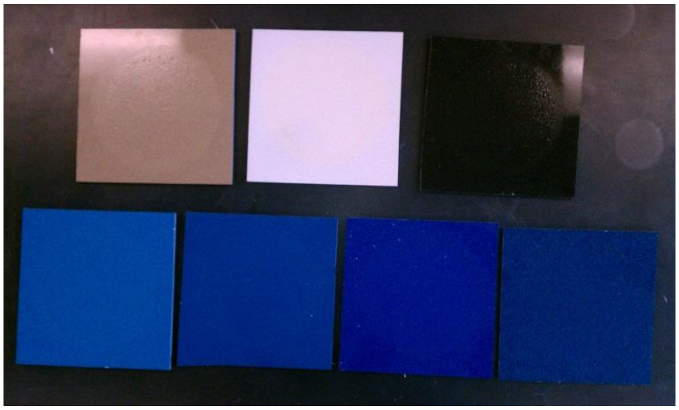


Figure 4-8. Panels after blush resistance testing. The following Shimmer® colors are shown: 946NP199SW Sandstone; 946LP206SW Pacific; 946LP207SW Ocean; 946LP216SW California; 946LP220SW Aqua Marine; 946BP005SW Midnight; and 946WP274SW Arctic White. All panels were sprayed at 30 mils and backed with 23 mils of ArmorGuard® 967BK150. Laminates were constructed using Stypol® LSPA2700.

Figures 4-9 and 4-10 show the gloss and total color change results for seven panels weathered in South Florida. The gel coat had good color and gloss retention for over 17 months.

Shimmer® 946SW Series gel coat meets the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reinforced Plastic Composites Production – Corrosion Resistant/High Strength or High Performance gel coat.

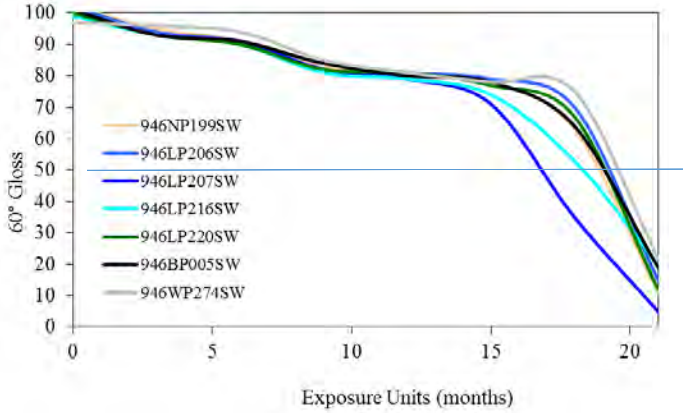


Figure 4-9. Gloss retention of seven Shimmer® colors during South Florida weathering.

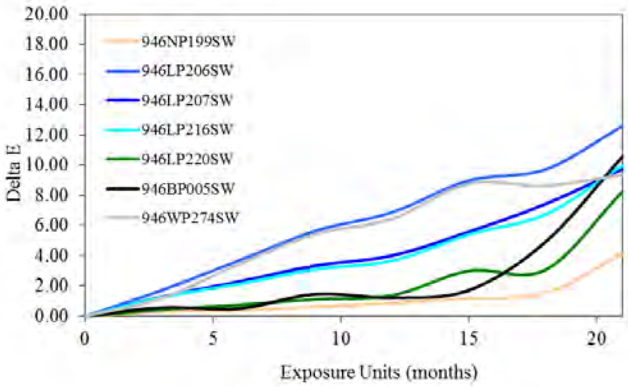


Figure 4-10. Color change of seven Shimmer® colors during South Florida weathering.

Shimmer® 946SW series gel coat is formulated for spray application. Brushing and rolling are not recommended. For the best overall end performance properties, a wet film thickness of 16-20 mils is recommended. The film should be applied in multiple passes of 8-10 mils per pass.

Shimmer® 946SW series gel coat is formulated with special effects pigments with particle sizes up to 18-mesh. To avoid plugging, Polynt recommends removing the filter (after the fluid section) from the equipment and using a tip with an orifice size of approximately 0.036 inches. The gel coat delivery rate will be approximately 6.8 lbs./minute, higher than recommended for spraying conventional gel coats. As a result, a spray distance of 36-40 inches is recommended to maintain thickness control.

For training and educational purposes, we provide videos about setting up a fan pattern, spraying gel coat, and repairing gel coat.

Refer to the Open Molding-Conventional Gel Coat:

Application section for more information about applying gel coat. Refer to the paragraphs below for information on patching Shimmer® 946SW Series gel coat.

Polynt recommends that this gel coat be backed by IMEDGE® HPB 210LK292 high performance barrier coat, an ArmorGuard® vinyl ester barrier coat, or an ArmorStar® vinyl ester skin resin. Use of these materials will create a durable osmotic blister resistant composite that is ideal for swimming pool manufacture.

Additional information on swimming pool gel coats is available in MB-338 Performance of Swimming Pool Coatings.

4.6.7. Patching Shimmer® 946SW Series

Required Materials

- Shimmer® 946SW gel coat
- ArmorFlex® 963CA220 clear patching thinner
- ArmorFlex® 963XK161 marine clear gel coat
- SprayCure™ 970C961
- MEKP
- 220, 800, 1000, and 1200-grit sandpaper
- DA (dual action) sander
- 3M™ Perfect-it™ III Compounding Pad with Imperial™ Compound and Finishing Material

Step 1

A. Prepare the patch area using a DA sander with 220-grit dry sandpaper. Feather the edge with 1000-grit wet sandpaper. The feathered area should extend two inches outside the 220-grit area.

B. Prepare the patch mix: 50:50 ratio of Shimmer® gel coat and ArmorFlex® 963CA220 patching thinner.

C. (Optional) Add up to 3% SprayCure™ 970C961 to improve sprayability.

D. Catalyze with 2% MEKP.

E. Spray the Shimmer® patch mix over the 220-grit sanded area. Feather the spray out into parts of the 1000-grit sanded area.

Step 2

A. Prepare the marine clear patch mix: 60:40 ratio of ArmorFlex® 963XK161 Marine Clear and ArmorFlex® 963CA220 clear patching thinner.

B. Catalyze with 2% MEKP.

C. Spray the marine clear patch mix over the Shimmer® color patch wet-on-wet. Feather the spray into the 1000-grit sanded area.

Step 3

A. Overspray the patch with SprayCure™ 970C961 wet-on-wet. SprayCure™ will not need to be catalyzed.

Step 4

A. Allow the patch to cure for 1-2 hours, depending on temperature.

B. Using a DA sander with 800-grit sandpaper (dry or wet), sand the orange peel off the patch carefully. Do not sand along the edge of the patch.

C. After removing all orange peel, wet sand the overall patch, including the patch edge, using a DA sander with 1200-grit wet.

D. Use medium grit 3M™ compound to polish the patch area.

Note: When using the 3M™ compound, you can remove more of the edge of patch to help blend in the patch.

Table 4-2. Patching Summary.

	STEP 1	STEP 2	STEP 3	STEP 4
Shimmer® Gel Coat	**50%**	--	--	--
Clear Patching Thinner ArmorFlex® 963CA220	**50%**	**40%**	--	--
Marine Clear ArmorFlex® 963XK161	**--**	**60%**	--	--
SprayCure™ 970C961 (1)	**3%**	**--**	**Overspray**	--
MEKP	**2%**	**2%**	--	--
Sanding prep	**220-grit**	--	--	--
Feathered edge	**1000-grit**	--	--	--
Cure	--	--	**--**	**1–2 hours**
Wet or dry sand (2)	--	--	--	**800-grit DA**
Wet sand	--	--	--	**1200-grit DA**
Compound	--	--	--	**3M™**

(1) Optional

(2) Only wet sand or dry sand the orange peel off from the patch. Do NOT sand along the edge of the patch.

5. VINYL ESTER BARRIER COATS

Overview

- **Introduction**
- **Materials**
- **Application**
- **Performance**

5.1. Introduction

Vinyl ester (VE) barrier coats are specialized gel coat formulations designed to enhance the performance of composite laminates. Barrier coats are primarily used in the marine industry, but can be used in any application where improved osmotic blister resistance and part cosmetics are desired. Use of barrier coats can also reduce production cycle times in some applications.

5.2. Materials

Barrier coats are formulated from the same types of materials used in gel coats. However, barrier coats are generally formulated with vinyl ester polymers. Other polymer types, such as isophthalic polyesters and isophthalic polyester/polyurethane hybrids, have been used in barrier coat formulations, but their usage is limited. Another difference between barrier coats and gel coats is that barrier coats are not formulated for use as an exterior coating. Barrier coats rapidly chalk and fade when used in this application.

5.3. Application

A barrier coat is applied directly behind the gel coat prior to application of the structural laminate. Application of vinyl ester barrier coats is similar to that of gel coats. Vinyl ester barrier coats should be mixed prior to application to ensure homogeneity of the material and to break down the viscosity in preparation for spraying. MACT compliant barrier coats are generally high in viscosity and should be at least 75°F (24°) when sprayed. In colder shops, in-line heaters may be necessary to raise the temperature of the material. Larger angle tips and larger diameter hoses may be required.

Vinyl ester barrier coats can be applied through conventional and low-emission spray equipment. The preferred method of spray application is conventional or air-atomized, air-assisted airless, or airless. Refer to the sections on Spray Equipment and Application in the Conventional Gel Coat chapter for additional application information. Always refer to the product data sheet for specific application information.

The vinyl ester barrier coat must be applied correctly to realize the performance benefits. In particular, the thickness of the vinyl ester barrier coat is critical. Thin application will result in under cure, causing poor cosmetics and osmotic blister resistance. Thick application can lead to increased cracking.

5.4. Performance

Composite parts fabricated with a correctly applied barrier coat will have significantly reduced blistering in comparison to parts fabricated without a barrier coat. The pictures in Figure 1 show the comparison of laminates that have been exposed to boiling water for a minimum of 100 hours. Each laminate was fabricated with two gel coat thicknesses.

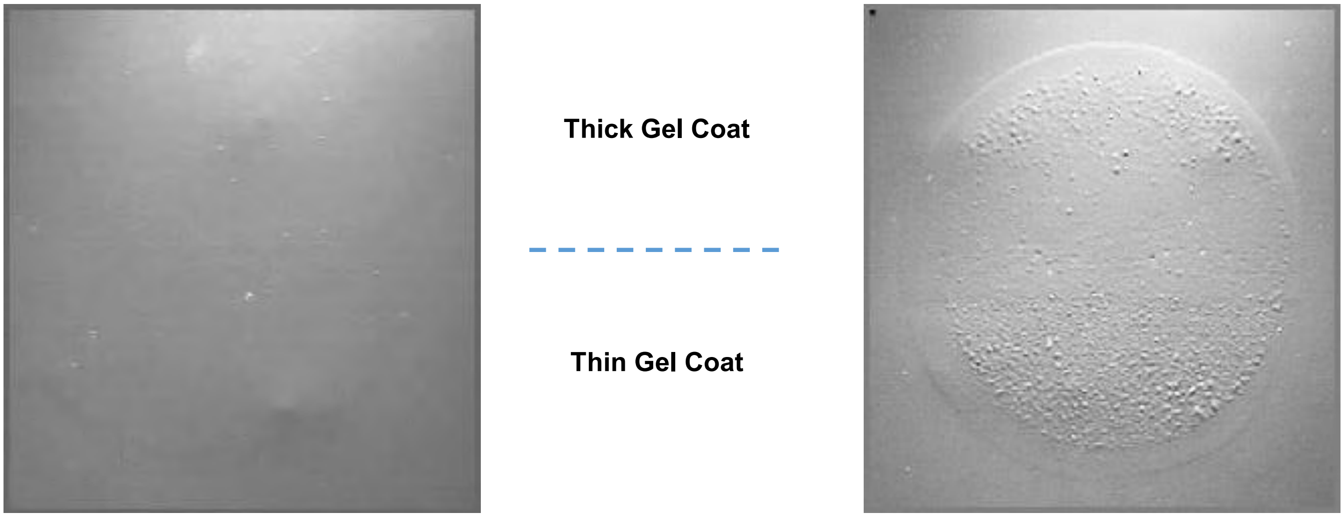
Reduction of osmotic blistering is accomplished by two mechanisms. First, the vinyl ester polymers used to formulate the barrier coat inherently have low water-absorption properties. Second, use of a barrier coat moves laminate porosity or air voids away from the gel coat. Laminate porosity at the gel coat-laminate interface is a source of blistering and cosmetic defects.

Vinyl ester barrier coats also improve laminate cosmetics by reducing fiber print-through and distortion. Use of a barrier coat increases the distance of the laminate's reinforcing fibers, balsa, and other structural parts from the gel-coated surface, reducing the impact of these features on laminate cosmetics.

Vinyl ester barrier coats also provide protection against dimensional changes (shrinkage) of the laminating resin during post-demold curing.

Vinyl ester barrier coats are two to three times tougher than typical pigmented gel coats, so the increased thickness can be added without increasing the risk of cracking associated with thick gel coat applications.

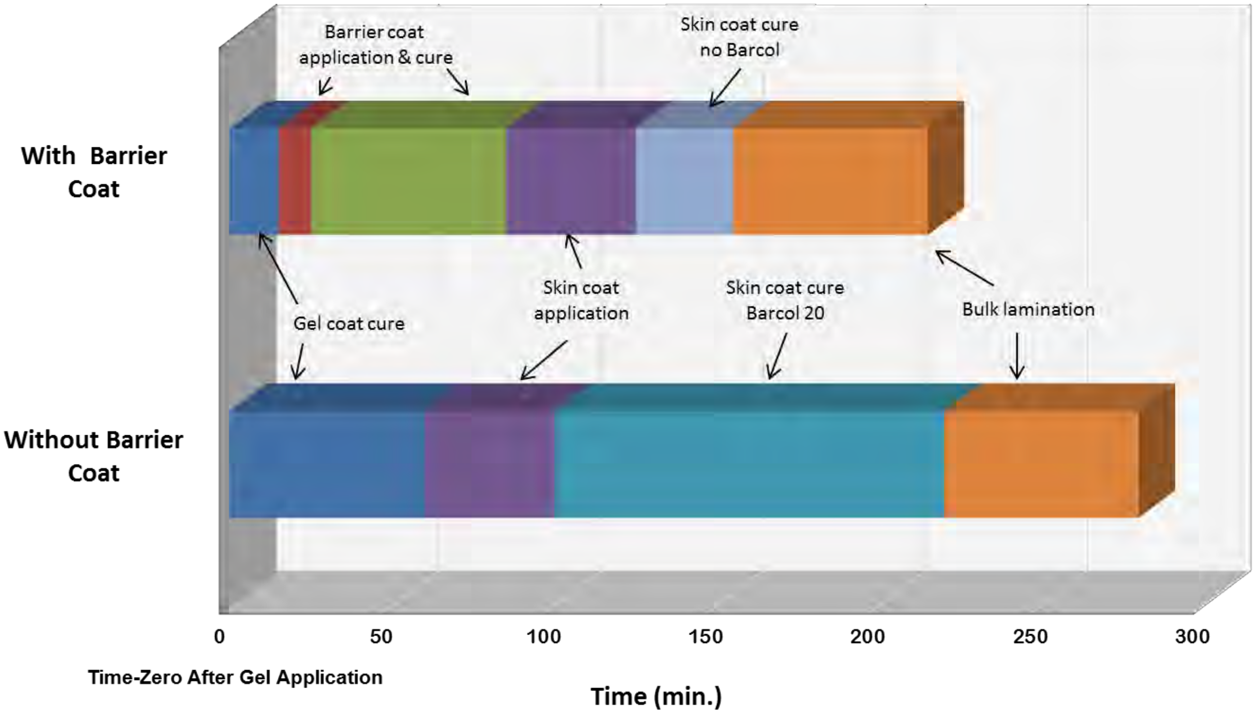
In addition to the performance benefits, fabricators have found that the use of a vinyl ester barrier coat accelerates the production cycle compared to laminates fabricated using a conventional skin coat. To realize the cosmetic benefits of a skin coat, it must be allowed to cure thoroughly prior to laminate application. However, a vinyl ester barrier coat needs only to cure to a tack-free condition prior to proceeding with lamination. The barrier coat reaches a tack-free condition much more quickly than the skin coat achieves a thorough cure. This cycle time savings is illustrated in Figure 2 for a high volume boat manufacturing operation.



Laminate with VE Barrier Coat (No blisters)

Laminate without VE Barrier Coat (Heavily blistered)

Figure 5-1. Laminates after 100 Hours Boiling Water Exposure.



***Over ONE HOUR time savings per unit using a barrier**

Figure 5-2. Cycle Time Comparison for Typical (High Volume) Boat Manufacturing.

6. OPEN MOLDING-LAMINATION

Overview

- **Laminating Resins**
- **Fiber Reinforcements**
- **Initiators**
- **Equipment and Application Methods**
- **Secondary Bonding**
- **Acrylic Bonding**
- **Troubleshooting**

6.1. Laminating Resins

Overview

- **Introduction**
- **Laminating Resin Formulation**
- **Laminating Resin Specifications**

6.1.1. Introduction

Laminating resins are polyester or vinyl ester resins that are formulated for use in open mold, spray-up or hand lay-up processes at ambient or room temperatures. These are the most versatile of the composite resins and can be used to manufacture a wide variety of finished products from boats to bathtubs. Laminating resins can be formulated for use in the neat form or filled with mineral fillers.

6.1.2. Laminating Resin Formulation

Laminating resins are formulated from several components, including the polymer, reactive monomer, thixotropic agents, promoters, inhibitors, and specialty additives. The specific components and amounts used are dictated by the end-user's processing requirements, requirements for finished part performance, and cost considerations. Emissions regulations also affect the resin formulation. Processing requirements typically include sprayability, wet-out, sag, working time, trim time, cure or Barcol development time, and peak exotherm temperature. Finished part performance requirements can include part appearance, physical properties, water resistance, weathering resistance, corrosion resistance, bond strength, and flame retardant among others.

Polymer

The polymer type and grade of laminating resin help define the finished properties of the composites as well as the processing and application characteristics. The polymer grade is the first consideration when selecting a laminating resin. Besides the mechanical strength and processing properties for each grade of resin, there are also cost differences between the various grades.

Historically, orthophthalic- and isophthalic-based resin chemistries were the dominate grades used for laminating resins. Both provide high mechanical strength and good secondary bonding. The isophthalic-based resins have slightly higher tensile properties and provide better chemical, heat, and moisture resistance than the orthophtalic resins. Both orthophthalic and isophthalic resins have been displaced in some applications by Dicyclopentadiene (DCPD) resins.

Three factors have contributed to the increasing use of DCPD grade resins in open molding products over the last 15 to 20 years. The first is the demand for improved surface smoothness on finished parts in consumer markets. Resins based on DCPD provide smooth finished surfaces with less print-through and distortion. The second factor is the increasingly restrictive regulatory rules on styrene emission. DCPD polymers can be formulated into usable laminating resins at much lower styrene levels. Typical styrene contents of an isophthalic-based resin are 45-50%, whereas the levels in DCPD laminating resins can be under 30%. The final reason for DCPD resins displacement of orthophthalic and isophthalic is cost. DCPD-based laminating resins historically have been more cost-effective than other resins while providing laminates with lower void content, less fiber-print, and compliance to environmental regulations.

Most laminating resins are a blend of DCPD and other resins. These other resin chemistries include orthophthalic, isophthalic, and vinyl ester type resins that modify the final blend in some way. Resins made with 100% DCPD polymer have lower tensile properties and provide short windows for secondary bonding. The use of blending resins imparts some of that resin's characteristics to the final blend. See the section on General Chemistry of FRP Composites Resins in Chapter 2 for more information.

All polyester polymers have an unsaturated acid component, typically maleic anhydride. The unsaturation in the polymer provides a site for reaction with the monomer, also known as cross-linking.

Monomer

The monomer fulfills two roles in the laminating resin. First, it is chemically reactive and cross-links with the reactive sites in the polymer to form the rigid thermoset material. All polymers used for laminating have an unsaturated acid component, typically maleic anhydride. This unsaturation in the polymer provides a site for reaction with the monomer, also known as cross-linking.

The second purpose for monomers is to reduce the viscosity of the polymer to workable levels for the laminating application. Without the addition of a diluent, unsaturated polyesters polymers in laminating resins are solid or very highly viscous materials at ambient temperatures. Therefore, laminating resins are actually solutions of polymers in a reactive diluent monomer.

Some common monomers used in laminating resins are styrene, vinyl toluene, methyl methacrylate (MMA), and alpha methyl styrene. The amount and combination of these monomers affect the glass fiber wetout, exotherm temperature reached during curing, cure rate, and mechanical, thermal, and electrical properties of the final laminate. Emissions regulations limit the type and/or amount of monomers that can be used in the laminating resin.

Thixotropic Agents

Laminating resins are formulated to be thixotropic or have a viscosity that is dependent on shear rate. A laminating resin should have a low viscosity during high shear operations such as pumping, spraying, and wetout. After these high shear operations are completed, the resin should recover to a high viscosity to prevent sag and/or draining.

This thixotropic behavior is obtained through use of thixotropic agents (fumed silica, Aerosil® from Degussa, Cabosil® from Cabot). These materials form a network with the polymer through hydrogen bonding. During high shear, this network breaks down and lowers the viscosity of the material. After the high shear is completed, the network reforms or recovers and the viscosity of the resin increases. The faster the rate of recovery, the lower the risk of sag or drainage.

The thixotropy of a resin is determined by measuring the low shear and high shear viscosity of the resin. The ratio of these two values is reported as the Thixotropic Index (TI). For unfilled laminating resins, the high shear viscosity generally ranges from 400-700 cps. TIs are typically 2-4. Filled laminating resins typically have lower TIs. In filled systems, the thixotropy not only helps prevent sag and draining but helps to hold fillers in suspension.

Promoters and Inhibitors

The types and levels of promoters and inhibitors used in laminating resins control the cure rate and, to some degree, the final properties of the composite. Most laminating resins are cured under ambient conditions (65-95°F (18-35°F)) with peroxide catalysts. Curing or cross-linking of a typical laminating resin includes the following:

- Gel time, or the working time before the resin solidifies.
- Peak exotherm temperature, or heat of the reaction.
- Hardness development rate measured by a Barcol impressor, which determines when a part can be trimmed and demolded.
- Final cure, when most of the composites properties are developed.

Promoters act to increase the reaction rate of the cure. Promoters, also called accelerators, split the peroxide catalyst into free radicals. These free radicals attack the unsaturation sites in the polymer, preparing them for reaction with the monomer.

The most common promoters used in laminating resins are salts of cobalt metal, such as cobalt octoate and cobalt napthenate. However, cobalt salts by themselves do not typically drive the cure to completion.

Other materials called co-promoters are used to modify the cure behavior and increase the degree of cure. Co-promoters enhance the ability of promoters to split the peroxide catalyst into free radicals. They are very effective in shortening the gel time and accelerating the cure or hardness development rate. Typical co-promoters are amines such as dimethyl aniline (DMA) or diethyl aniline (DEA).

Promoters and inhibitors can also affect the color of the cured resin. This effect must be considered when formulating low-color or pigmented systems.

Low peak exotherm temperatures can be a sign of undercure. High peak exotherm temperatures can result in mold damage.

Inhibitors have a converse or opposite effect from promoters on the cure of a laminating resin. Inhibitors lengthen the gel time, modify the cure, and stabilize the shelf life. Inhibitors used in laminating resins are effective at relatively low concentrations. The addition of 20-30 parts per million of certain inhibitors will double gel times in some laminating resins.

There are a variety of compounds that can be used to inhibit cure. Because of the low levels of inhibitors needed to affect cure, precautions should be taken to avoid contamination from potential sources of inhibiting compounds. These include water, phenolic compounds, copper, and even entrapped oxygen for air. Oxygen is a strong inhibitor and is the reason that the backside air-exposed surfaces in open molding remain tacky even after the laminate is cured. Surfacing agents can be added to resins to seal the air-exposed side to achieve a tack-free backside.

Specialty Additives

In addition to the above materials, a number of other additives can be used in laminating resin formulations to affect properties. These include processing aids such as air release agents, wetting agents, color change dyes to show catalyst addition, and odorants. Additives can also be used to affect final part performance, such as pigments and dyes, UV absorbers and light stabilizers for weathering performance and a variety of additives to impart flame-retardant properties.

6.1.3. Laminating Resin Specifications

When selecting a resin for an application, there are several specifications to consider based on the method of application, the part dimensions and the rate of production.

When producing laminating resins, resin manufacturers run a variety of quality control tests to ensure that the product being produced will meet the needs of end users. Final results of these tests are reported to the end user via the Certificate of Analysis (COA). Typical test results reported on a COA include:

- Brookfield® viscosity
- Thixotropic Index (TI)
- 100 gram mass cup gel time, time to peak exotherm and peak exotherm
- Laminate gel time and peak exotherm
- Laminate Barcol development

See Appendix A on Quality Control Lab and Test Methods for information on the equipment and procedures used to run these tests.

The 100 gram mass cup gel properties are a standard in the FRP industry for characterizing resin cure. These parameters are valuable to the resin manufacturer when producing the product, and to end users for verifying that the product will be suitable for use in their process. However, it is important to the fabricator to understand that 100 gram mass cup gel parameters will not necessarily correspond to those observed in the actual application. For example, the 100 gram mass cup gel time is generally faster than the gel time in a laminate, and the 100 gram mass cup peak exotherm is much higher than that of the laminate.

6.2. Fiber Reinforcements

Overview

- **Fiber Reinforcement**
- **Laminate Thickness vs. Layers of Glass Reinforcement**

6.2.1. Fiber Reinforcement

The lamination process uses a variety of reinforcements. The typical reinforcement is fiberglass. Fiberglass is the “F” in the FRP (Fiberglass Reinforced Plastic) acronym. Other types of reinforcements include fillers or flake glass and are used where specific properties are needed.

Various types of fiberglass grades are available. E-glass is the most widely used grade. E-glass, first developed for its good electrical properties (low conductivity), also provides good mechanical properties and some measure of corrosion and water resistance. This is the general-purpose grade of glass used in most open molding applications. C-glass, or Chemical glass, was developed specifically to improve resistance to chemical attack from acids. ECR-glass is another grade of glass that was developed to provide improved chemical resistance as well as higher mechanical properties than E-glass.

Fiberglass filaments are brittle if left untreated. Fiberglass manufacturers add a formulated protective coating around each individual filament. The coating is known as a sizing. The sizing acts to protect the dry glass during subsequent processes, such as weaving or knitting. It also includes chemistries to improve the bond strength between the resin and the glass filament. Different composite resins require specific sizing chemistries. Thermoplastics, such as polypropylene and PET, require different sizing chemistries than typical unsaturated polyester and vinyl ester resins used in open molded FRP. Indications of mismatched sizing chemistry in FRP include poor fiber wetout, “jack strawing,” or fiber burn and low laminate mechanical properties.

Reinforcement is not limited to fiberglass. Synthetic polymers in roving, mat, or entangled sheet form are available. Reinforcements can also be made from inorganic elements or compounds such as boron, carbon (graphite), minerals, or silica. This discussion will primarily refer to fiberglass because it is the most common reinforcement.

Surfacing Mat (Veil)

Veil is a thin (usually 10 mils (0.01 inches)) layer of fine, soft fiberglass or synthetic fiber that is used next to the gel coat. It is used to reduce the transfer of fiber pattern through the gel coat from the coarser glass mats. It is also used in corrosion work as the last layer next to exposed surfaces, where it yields a resin-rich surface.

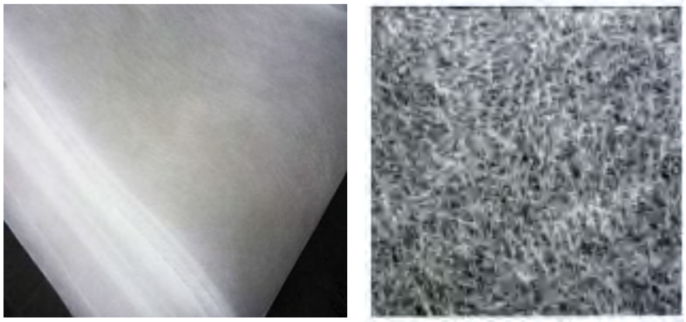


Figure 6-1. Surfacing mat (veil).

Chopped Strand Mat

Chopped strand mat (CSM) is delivered in rolls in widths of up to 120 inches. CSM is available in weights from ¾-3 ounces per square foot.

CSM is used to inexpensively to build up bulk and to increase strength and stiffness. Structurally, CSM has multidirectional strength because of the random orientation of the fibers. It is made up of chopped strands of roving up to 2 inches long. These strands are held together with a binder, which is soluble in the polyester resin. Normally, there is more binder on one side of the mat than the other. Some mats are made with an insoluble binder and cannot be used in the hand lay-up process. Excess binder can cause a dimpling of the gel coat surface.

New CSM lots should be inspected for particles (small and crystalline).

Make certain that the CSM is rated for use with polyester and vinyl ester resins.

Figure 6-2. Chopped strand mat (CSM).

Roving

Roving is a loose twine of glass fibers (usually 60) wound up into a cylindrical package weighing about 35 pounds. Roving is available with one red strand (out of 60) called a tracer to help gauge the uniformity of thickness and distribution. It is the least costly form of fiberglass.

Roving is used mostly in the spray-up process, where it is chopped and fed with converging streams of catalyzed resin onto the mold surface. Sometimes the continuous roving is used as a wrap-around (for circumferential strength) in special configurations such as tanks, pipes, and stiffening ribs. The glass fibers become transparent when wet with resin.

Figure 6-3. Roving and chopped fiberglass.

The ideal roving for use in spray-up has good compatibility with the resin, good cutting characteristics, easy rollout, fast wet-out, low water sensitivity, and minimal build-up of static electricity. Handling properties vary, notably to the extent that the sizing on the roving renders it ‘hard’ or ‘soft.’ Hard rovings cut well and have good strand integrity. Soft rovings tend to fray or open up when cut; however, they can be compacted into sharp corners, such as the strakes of boat hulls, without spring back.

Woven Roving (WR)

Woven roving (WR) costs about the same as or a little less than mat, but is twice as strong in tensile and flexural strength, so most structural laminates have some woven roving in their makeup. It is a coarse weave and is available in weights from 13-27 ounces per square yard; 18-24 ounces are most common.

The loose weave of WR conforms to contours better than mat or cloth. However, its coarse weave is sometimes problematic since the pockets formed by the warp and weft of the weave allow for localized resin-rich areas in the laminate. These pockets of resin shrink more on curing that the higher glass content rovings. This outline can be ‘telegraphed’ through the gel coat, leaving a checkerboard look to the finished side of the laminate. It is best when using woven roving to have at least 90-100 mils of mat or chopped roving between the woven roving and gel coat to minimize the print-through.

In most applications, alternating woven products with CSM is recommended to improve interlaminar shear and to better transfer any loading between the plies. Combo mats consisting of woven roving with a chopped strand mat adhered with a binder to one side are widely used as a way to ensure good bonding between plies of woven roving.

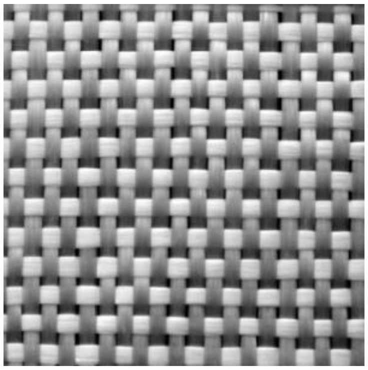


Figure 6-4. Woven roving.

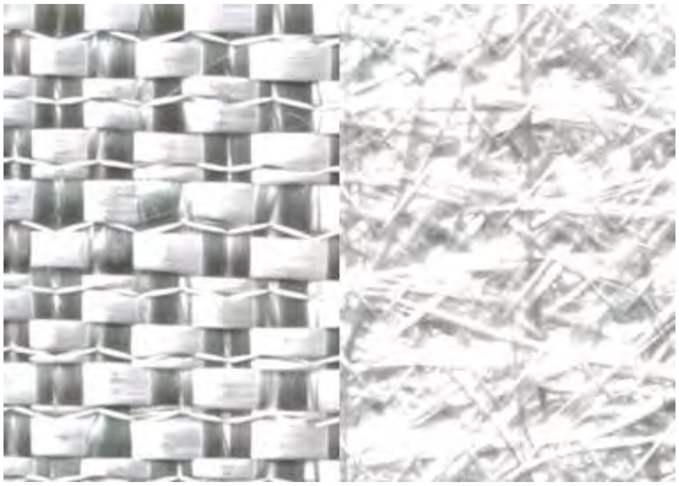


Figure 6-5. Combo mat with woven roving with a chopped strand mat adhered with a binder to one side.

Engineered Fabrics

Engineered fabrics align the reinforcements in a particular direction or bias. This gives laminate designers the ability to reinforce the composite for various loadings with less weight or thickness.

Typical examples of engineered fabrics are stitched mats. These come in a variety of multiaxial fabrics, including Unidirectional, Biaxial, Triaxial, and Quadaxial.

These fabrics can use other fibers, such as carbon or aramid along with glass fibers, to provide specific properties needed.

Fibers can be oriented in a variety of ways. Among some of the most unique engineered fabrics are those with a three-dimensional architecture. These fabrics not only have directional fiber placement in the X and Y coordinates but also a Z axis component.

Both the fabrication order and the type of fabrics used in a laminate design can affect the final composite properties. The selection of which engineered fabric to use should be based on the overall design and sample laminates tested under the usage conditions and loadings.

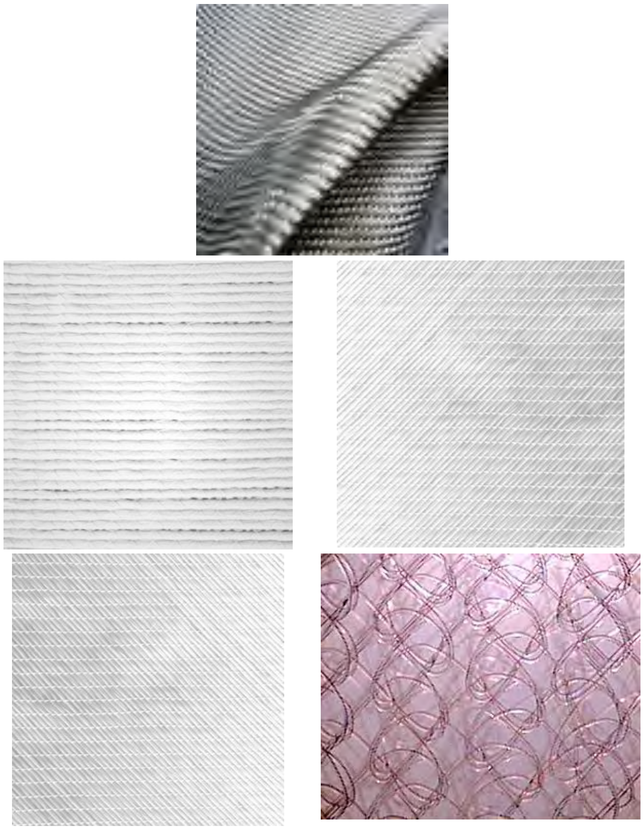


Figure 6-6. Examples of engineered fabrics (from top to bottom)-Stitched mat; Unidirectional; Biaxial; Triaxial; and 3D architecture of stitched mat.

Cloth (Hand Lay-up and Spray-up)

Cloth is the most expensive form of fiberglass and the strongest woven material on an equivalent weight basis. It is available in weights from 2-40 ounces per square yard. Although most production parts utilize 4-10 ounce material, the heavier weights, such as 40 ounce cloth, can be used in tooling to build up strength and thickness quickly.

It is available in different types of weaves, such as twill, crowfoot, and satin style. The satin is stronger and conforms more easily to compound curves.

Cloth is used principally as a finishing layer for better appearance or a skin layer (just behind the gel coat) for extra strength. It will 'telegraph' through the gel coat like woven roving, but with less 'profile.'

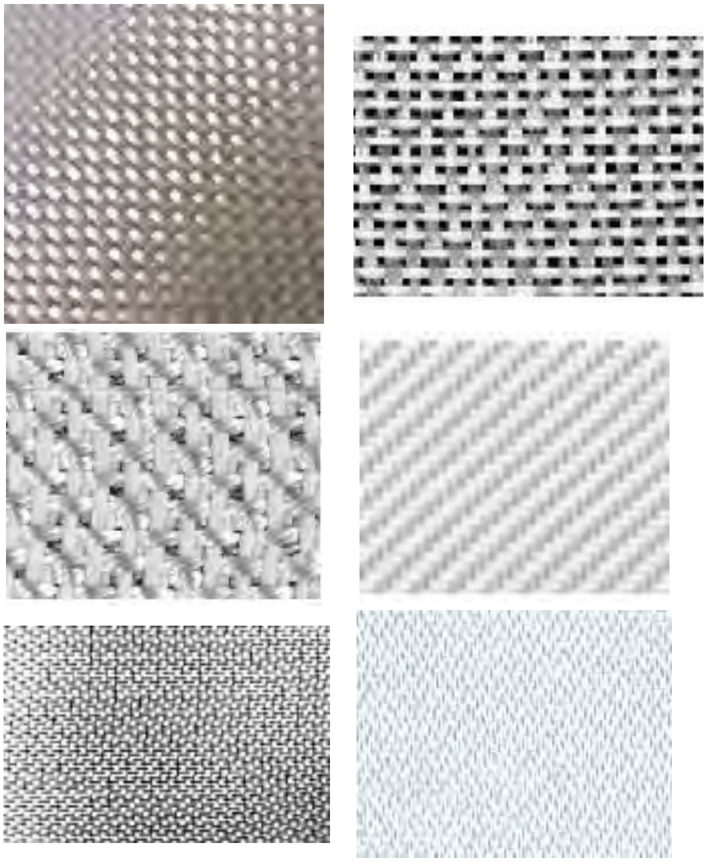


Figure 6-7. Examples of cloth (from top to bottom)-Cloth; Plain weave cloth; Double plain weave cloth; Twill weave cloth; Crowfoot weave cloth; and Satin weave cloth.

Core Materials

When the fabricator needs to build in stiffness and strength without significant increases in weight, core materials are sandwiched between layers of fiberglass. These core materials may be metal or paper honeycomb, cardboard, wood, foam, composites of hollow bubbles and fiberglass, or combinations thereof. Core material can also come in a sprayable form.

Consideration must be given to the resin demand of core materials and their impact on cure and on subsequent print/distortion. Their placement in order of construction must also be studied for optimum results. The angles, ribs, and tie-ins created during sandwiching add sturdiness, stiffness, strength and bulk to the FRP structure.

Reinforcement is usually specified by the type of material, number of ounces per unit area, and location in the laminate. The first layer is important in that it must reinforce the gel coat and be free of air pockets. Reinforcing is best ensured by a thin layer (skin coat) of binder-free glass.

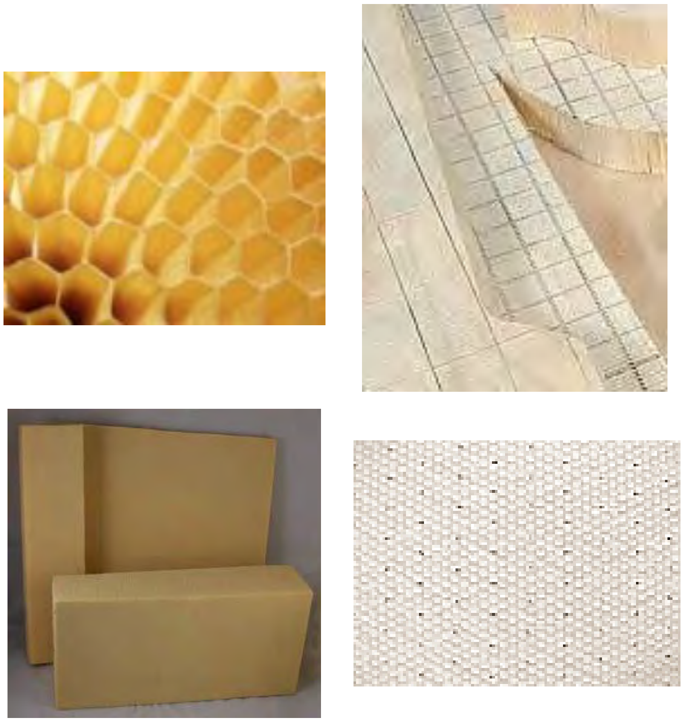


Figure 6-8. Examples of core materials (from top to bottom)-Honeycomb; Wood; Foam; and Core mat.

Studies have shown that laminate construction has an important effect on the performance of the gel coat. To reduce cracking, blisters, and crazing in gel coats, best results are obtained by using a thin coat of chopped glass and resin behind the gel coat; then, continuing with 1-1/2 ounces glass mat lay-up. Proper roll out of the skin coat is important to remove all air voids at the gel coat surface.

The next layer or two should be a heavier mat (1-1/2 ounces) or chopped roving, depending on the ultimate thickness desired. This provides for fast laminate build-up. Another advantage of starting the laminate with mat layers is that it positions the fabric layers, which show a greater fiber pattern, farther from the surface.

The third or fourth layer, if it is the final layer, can be woven roving or cloth. Woven roving should be used where strength is critical. Otherwise, 6-10 ounce cloth is used for a better finished surface (than the mat) and a little extra strength. Another advantage of cloth as a final layer is that the laminator can squeegee hard on the surface to remove trapped air bubbles and excess resin.

For best strength, succeeding layers should be alternating mat and woven roving (24 ounce standard). It is not usually good practice to face two woven layers because of poorer inter-laminate bond and a higher chance for porosity (air bubbles entrapped in the cloth or woven roving, usually extending the entire thickness of the fabric).

Nine total ounces of mat per square foot will result in a 1/4 inch laminate (at 30% glass content). Glass content is usually specified to prevent resin-rich areas (too low glass content), which crack and craze, or resin-starved areas (too high glass content), which cause porosity. An all-mat or chop laminate should have a tolerance of 30% glass (low) to 35% cent glass (maximum) for best results. When woven roving is used in conjunction with mat, the range of glass content can be as high as 80% for the ultimate in strength. Bag molded parts should have a glass content of 60-65%.

Figure 6-9. Layers in laminate construction to reduce cracking, blisters, and crazing in gel coats.

6.2.2. Laminate Thickness vs. Layers of Glass Reinforcement

The following table is offered as an aid toward estimating approximate laminate thickness of various glass reinforcing materials and typical laminating resins. The values given are averages and will vary according to application technique.

Table 6-1. Approximate laminate thickness of various glass reinforcing materials and typical laminating resins.

REINFORCEMENT TYPE	NUMBER OF LAYERS	LAMINATE THICKNESS (inches)	GLASS CONTENT (%)
1.5 oz. Chopped Strand Mat (CSM)(1)	1	0.035-0.040	37
	1	0.025-0.300	45
2 oz. Chopped Strand Mat (CSM)	1	0.045-0.055	37
	1	0.040-0.050	45
1808 Combo Biaxal Stitch/CSM Mat	1	0.070-0.075	37
	2	0.140-0.150	37
	3	0.215-0.225	37
18 oz. WOVEN ROVING (WR)	1	0.030-0.350	45
	2	0.065-0.070	45
	3	0.100-0.105	45
24 oz. WOVEN ROVING (WR)(2)	1	0.035-0.040	50
	2	0.075-0.080	50
	3	0.115-0.110	50
Alternating layers of 1.5 oz. Chopped Strand Mat (CSM) and 18 oz. Woven Roving	3 (CSM/WR/CSM)	0.130-0.135	WR @ 45, CSM @ 26
	5 (CSM/WR/CSM/WR/CSM)	0.215-0.220	WR @ 45, CSM @ 26
	7 (CSM/WR/CSM/WR/CSM/WR/CSM)	0.300-0.305	WR @ 45, CSM @ 26
Alternating layers of 1.5 oz. Chopped Strand Mat (CSM) and 24 oz. Woven Roving (WR)	3 (CSM/ WR/ CSM)	0.145 -0.0150	WR @ 45, CSM @ 26
	5 (CSM/WR/CSM/WR/CSM)	0.235-0.240	WR @ 45, CSM @ 26
	7 (CSM/WR/CSM/WR/CSM/WR/CSM)	0.330-0.335	WR @ 45, CSM @ 26

(1) Dry glass thickness: 1.5 oz. mat, 0.022 inch
(2) Dry glass thickness: 24 oz. woven roving, 0.024 inch

6.3. Initiators

Overview

- **Function and Types**
- **Usage Levels**

6.3.1. Function and Types

The function of a catalyst or initiator is to start the chemical reaction that cures or cross-links the resin. The most common type of catalyst used in open mold, ambient temperature lamination is called organic peroxide. For more general information on peroxide catalysts, refer to the FRP Composites: General Chemistry of FRP Composites Resins section. Laminators can choose from many types of organic peroxide catalysts. Each one affects the gel and cure behavior of the resin differently.

A. **Methyl ethyl ketone peroxide (MEKP)** catalysts are the most commonly used catalysts for ambient temperature, open mold lamination. These catalysts are actually solutions of various MEKP isomers and hydrogen peroxide in plasticizers. The plasticizer, also known as a phlegmatizer, serves to stabilize the peroxides. The same resin catalyzed with different MEKP catalysts may show significantly different gel and cure behavior due to differences in overall peroxide levels and peroxide combinations. The recommended MEKP catalyst usage level is 0.75-2.5% based on weight.

B. **Cumene hydroperoxide (CHP**)/ /MEKP blends are specialized catalysts that should be considered by laminators needing to reduce laminate peak exotherm temperatures in comparison to those obtained when using MEKP catalysts. Like MEKP catalysts, CHP/MEKP blends are solutions of peroxides (CHP, various MEKP isomers and hydrogen peroxide) in plasticizers.

   The overall peroxide content and the levels of the each of the various peroxides will affect the catalyst performance. In general, CHP/MEKP-blended catalysts result in longer gel times, longer cure times, lower peak exotherm temperatures, and slower initial Barcol hardness development. When used appropriately, the ultimate cure of laminates produced with CHP/MEKP blended catalysts is equivalent to or better than those produced with MEKP catalysts.

   CHP/MEKP-blended catalysts are not recommended for thin laminates or skin coats since reduced exotherm temperatures may not allow for complete cure.

   Use of MEKP/CHP catalyst blends in cooler temperatures should be carefully reviewed by the laminator and used only when required due to excessive peak exotherm temperatures.

   The recommended usage levels of CHP/MEKP-blended catalysts are typically higher than for MEKP catalysts, 1.5-2.75% by weight.

C. **Acetyl acetone peroxide** (AAP) or 2,4 Pentadione catalyst is another specialized catalyst that should be considered by laminators needing faster cure and demold times at similar gel times obtained with MEKP catalysts. AAP catalysts are solutions of 2,4 Pentadione peroxides in plasticizers. The use of AAP catalysts is somewhat limited since the faster cure rate also results in higher peak exotherm temperatures. The faster cure rate also results in a narrower trim window. The recommended usage levels of AAP catalysts are similar to MEKP catalysts, 0.75-2.25% by weight.

Many catalysts are available with a red dye. These red catalysts can be used in applications that are not sensitive to color to provide a visual indication of catalyst level and dispersion.

6.3.2. Usage Levels

The recommended usage levels for catalysts are generally expressed as a range. The starting point for a catalyst usage level is typically the level used by the resin manufacturer during quality control testing. Resin suppliers produce resins to meet gel and cure behavior specifications agreed to by the customer. An important part of these specifications is the catalyst type and level to be used during quality control testing as well as the test temperature. Unless directed otherwise by the customer, resin suppliers typically perform quality control tests using 1.25-1.5% by weight MEKP catalyst. The test temperature is typically 77°F (25°C).

Deviations from this usage level occur based on shop conditions and part geometry.

Shop Conditions

The most important shop condition factor affecting catalyst level is temperature. The higher the ambient temperature, the faster the gel and cure of the resin. In warmer conditions, it may be necessary to reduce the catalyst level to allow appropriate working time for the lamination operator. In cooler conditions, it may be necessary to increase the catalyst level to maintain desired production line speeds.

Part Geometry

The most important part geometry factor affecting catalyst level is thickness. When using the same resin and catalyst to fabricate parts having a variety of thicknesses, the laminator may need to adjust the catalyst level. Higher catalyst levels may be required in thinner parts to ensure complete cure. Lower catalyst levels may be required in thicker parts to limit the exotherm temperature.

When selecting a catalyst and determining a usage level, it is highly recommended that the laminator discuss options with their resin and catalyst suppliers.

6.4. Equipment and Application Methods

Overview

- **Introduction**
- **Process Overview**
- **Equipment**
- **Equipment Calibration**
- **Key Factors Affecting Quality**
- **Lamination Methods**
- **Equipment, Tools and Supplies**

6.4.1. Introduction

Lamination is the process of combining resin and reinforcing materials on an open mold. Use of proper lamination equipment and techniques is critical to producing structurally sound parts that meet design requirements as well as visually appealing parts that meet cosmetic requirements. Improperly applied laminates add cost to the part due to scrap and rework. Making the investment in proper equipment, equipment maintenance and calibration, and operator training can pay big dividends by reducing rework and scrap.

This section provides an overview of the lamination process, lamination equipment, equipment calibration procedures, key factors affecting laminate quality, and lamination methods. A list of equipment, tools, and supplies that should be available in the lamination shop is also provided.

6.4.2. Process Overview

Lamination of glass fiber reinforcements can be accomplished by hand lay-up or spray-up methods. In both methods, the glass is manually wet out and compacted with lamination rollers.

Hand lay-up is used when applying roll good reinforcements such as chopped strand mats and textile constructions that are stitched or woven. The roll good reinforcement is cut to the desired shape and manually placed in the mold. Brushes, rollers, or spray guns can be used to apply the resin.

Spray-up is used when the laminate reinforcement is chopped roving. Continuous strands of fiberglass roving are pulled through a chopper and cut into short lengths (¼"-1" lengths are typical) called chopped roving. Chopped roving and catalyzed resin are combined and applied onto the lamination surface with a spray gun or a flow chopper.

Selection of spray-up or hand lay-up methods for a particular part depends on the part configuration, mechanical property requirements, thickness tolerances, and cost considerations.

A. Complexity of shape often favors spray-up over hand lay-up since complex shapes require time-consuming and labor-intensive trimming and tailoring of roll goods plies. However, small and deep drafted parts cannot generally be produced by spray-up for economic reasons.

B. Hand lay-up laminates can be significantly stronger than spray-up laminates due to the higher glass content possible with some roll goods.

C. Laminate thickness is more easily controlled with hand lay-up than spray-up.

   - In hand lay-up, the laminate thickness is based on the type of roll goods used, the areal weight of the roll goods, and the number of layers of roll goods.
   - In spray-up, the laminate thickness is dependent on the operator's skill in evenly depositing the required amount of resin and glass over part surface.

D. The spray-up process is generally the lower cost process when compared to hand lay-up.

   - Roving is generally less expensive than roll goods.
   - Overspray will typically generate less waste than trimming roll goods, particularly when an experienced spray operator is used.
   - Labor costs are also generally lower for spray-up since no trimming or tailoring of roll goods plies is required. Resin and reinforcement can be deposited faster with spray-up than hand lay-up, particularly on contoured surfaces.
   - Spray-up or chopped parts also have the advantage in producing a cosmetically smooth outer surface. The random fiber placement and the lack of the binders that are in mat goods allow for a better surface quality.

Hand lay-up and spray-up are often combined within the same part or laminate to realize the advantages of both processes.

6.4.3. Equipment

Numerous types of lamination equipment are available to FRP fabricators. The equipment can be as simple as a paintbrush or as complex as a robotic unit programmed to select, meter, mix, and apply the reinforcements and resin. Several key features can categorize lamination equipment: catalyst metering and incorporation method, resin application method, and glass application method.

Catalyst Metering and Incorporation

Slave arm systems have become the industry standard for catalyst metering. The advantage of slave arm systems over other catalyst metering systems is that catalyst flow rate is tied to resin flow rate. This helps to ensure consistent catalyzation at the desired level. The catalyzation of the resin is critical for production speed, part cosmetics, and the final properties of the part.

In slave arm systems, the air motor for the resin is used to pump the catalyst, thus the resin and catalyst are connected to the same air motor (hence, slaved together). To prevent excess pressure from being put on the catalyst, a pressure relief valve is incorporated. The slave pump may be set either by specific intervals or on a dial-adjusted scale, generally ranging from 0.5-4%. The incorporation or mixing of the catalyst with the resin can either be accomplished internally or externally, depending on the specific type of equipment being used.

Other types of catalyst metering and incorporation systems include catalyst injection and split batch or dual nozzle spray gun system. In catalyst injection systems, a small pressure vessel with a flow meter is used to inject a metered quantity of catalyst into the resin stream. The catalyst is then mixed with resin either internally or externally. The control of the catalyst content is dictated by multiple variables including resin flow rate and air pressure to the catalyst pot.

Split batch or dual nozzle spray gun systems utilize two streams of resin. One stream is unpromoted but contains enough catalyst to cure both streams. The other stream is promoted but uncatalyzed. The two streams of resin are delivered to the spray gun so that the two streams intermix. The intermixing may occur internally or externally. These systems require the use of two separate resin systems. The catalyst/resin stream must be used within its pot life.

Neither system is in widespread use today.

Resin Application Method

Historically, atomized spray has been the most common method of resin application particularly in spray-up operations. EPA and OSHA requirements to reduce styrene emissions resulted in the emergence of new resin application techniques such as non-atomized spraying and non-spray methods.

A. **Atomized spray** involves the use of high fluid pressure or compressed air (up to 100 psi) to create a finely divided or atomized spray pattern. The small size of the particles in the spray pattern means large exposed surface area. Evaporation of monomers from this surface area creates high emissions. Catalyst incorporation can be either internal or external.

B. **Non-atomized spray**-Resin exits the gun in low-pressure streams. The impingement technique uses two low-pressure streams that cross each other. The collision of these streams creates a spray pattern. Non-atomized spray results in less exposed surface area than atomized spray, and therefore lower emissions. Catalyst incorporation can be either internal or external.

C. **Flow coaters** utilize internal catalyst mixing so the mixing chamber must be periodically flushed with a solvent to prevent the accumulation of gelled resin. Flow coaters use multiple, fine diameter orifices to produce parallel streams. Resin distribution with flow coaters is also not as even as with other spray techniques. This can lead to thickness and glass content variations, particularly in thin laminates.

D. **Pressure-fed rollers**, a non-spray technique, are used for hand lay-up applications. Pressure is used to push catalyzed resin out of a roller similar to a typical paint roller. Roller size and length can make resin application by this method difficult in tightly contoured areas. The roller system also utilizes internal catalyst mixing and must be periodically flushed with solvent.

Glass Application Method

Glass fiber reinforcements can be either hand laid or sprayed. For spray-up, an air-powered roving chopper is combined with the spray or flow coater resin application head. The resin application head and roving chopper are suspended from a carrying boom to allow the operator freedom of movement. One or more strands of roving are guided from spools along the boom to the chopper.

Ceramic guides are recommended to reduce fuzzing and static electricity generated by friction of the glass.

When the trigger on the chopper gun is pulled, two opposing rollers pull the rovings into the chopper, cut the rovings to the desired lengths and propel the chopped roving toward the mold surface. Razor-like blades mounted in one of the rollers chop the roving. Spacing of the razor blades determines the strand length (typically one inch). Shorter strands will be easier to roll out, but will reduce overall part strength. Longer strands increase strength, but may not conform to tight radii during rollout and cure. Outside the chopper, the glass fiber chop converges with the resin and is partially wet before reaching the mold surface.

6.4.4. Equipment Calibration

Calibration of equipment is important to ensure laminate quality. Equipment should be calibrated with each use, or at the very least daily. When calibrating spray-up equipment, the main areas of concern are resin flow rate, glass flow rate, resin-to-glass ratio, catalyst flow rate, and catalyst content. For hand lay-up, the resin-to-glass ratio is controlled by the operator; however, spray guns and pressure-fed flow rollers should be calibrated for resin flow rate, catalyst flow rate, and catalyst content. Always consult the equipment manufacturer for proper calibration of a particular type of equipment.

Resin Flow Rate, Glass Flow Rate, and Resin-to-Glass Ratio

For spray-up equipment, determine the resin and glass flow rates in pounds per minute as follows:

1. Adjust the pump to the desired pressure.
2. Weigh two containers individually in pounds.
3. Direct the resin head and glass head of the chopper gun into the separate containers.
4. Spray resin and glass into the containers for 10 seconds.
5. Individually weigh the containers in pounds.
6. Determine the resin weight by subtracting the empty weight of the resin container from the container weight with resin after spraying.
7. Determine the weight of glass by subtracting the empty weight of the glass container from the container with glass weight after spraying.
8. Calculate the resin flow rate by multiplying the resin weight by 6.

   For example, if the resin weight is 2.33 pounds, the resin flow rate will be 13.98 pounds per minute.
9. Calculate the glass flow rate by multiplying the glass weight by 6.

   For example, if the glass weight is one pound, the glass flow rate will be 6 pounds per minute.

Total laminate output or the sum of the resin and glass flow rates can vary, but are typically 6-30 pounds per minute. Some of the factors to consider when adjusting the total laminate output of a chopper gun are:

- Part size
- Available manpower for rollout
- Desired laminate thickness
- Gel time or working time of the resin

10. If the total laminate output or the resin or glass flow rates are not within the desired range, adjust the equipment per the supplier’s recommendations.
11. Calculate the resin content in percent by dividing the resin weight by the sum of the resin and glass weights and multiplying by 100.
12. Calculate the glass content in percent by dividing the glass weight by the sum of the resin and glass weights and multiplying by 100. The resin-to-glass ratio is then expressed as resin content (percent): to glass content (percent).

    For example, if the resin weight is 2.33 pounds and the glass weight is one pound, the resin content will be 70% and the glass content will be 30%. The resin-to-glass ratio is then 70:30.
13. If the resin-to-glass ratio is not within the part and process design requirements, adjust the equipment as necessary.

For hand lay-up processes using spray guns or flow coaters, follow the procedures above to determine resin flow rates. Resin-to-glass ratios are controlled by the operator.

Catalyst Flow Rate and Catalyst Content

A. **Catalyst Flow Rate**-Determine catalyst flow rate and resin flow rate in pounds per minute as follows:
   1. Attach a resin/catalyst splitter (available from the equipment manufacturer) to the spray equipment.
   2. Weigh two containers individually in pounds.

3. Spray the resin and catalyst streams into the separate containers for 30 seconds.
4. Individually weigh the containers in pounds.
5. Determine the resin weight by subtracting the empty weight of the resin container from the container with resin weight after spraying.
6. Determine the catalyst weight by subtracting the empty weight of the catalyst container from the container with catalyst weight after spraying.
7. Calculate the resin flow rate by multiplying the resin weight by 2.

   For example, if the resin weight is 7 pounds the resin flow rate will be 14 pounds per minute.
8. Calculate the catalyst flow rate by multiplying the catalyst weight by 2.

   For example, if the catalyst weight is 0.1 pound, the catalyst flow rate will be 0.2 pound per minute.
9. If the resin or catalyst flow rates are not within equipment supplier's recommendations, adjust the equipment as necessary.
10. Calculate the catalyst content in percent by dividing the catalyst weight by the sum of the resin and catalyst weights and multiplying by 100.

    For example, if the resin weight is 7 pounds and the catalyst weight 0.1 pound, the catalyst content will be 1.4%.

B. **Catalyst Content**-Catalyst content may also be checked by comparing the gel time of resin catalyzed with a known catalyst amount versus the gel time of catalyzed resin from the lamination equipment.

1. For the control sample, obtain 100 grams of uncatalyzed resin.
2. Weigh the appropriate amount of catalyst into the resin.

   For example, if a catalyst content of 1.5% is desired, weigh 1.5 grams of catalyst into the resin.
3. Start a timer and thoroughly mix the catalyst into the resin. Stop the timer when the resin reaches a physical gel.
4. Obtain catalyzed resin from the lamination equipment.
5. Pour 100 grams into a container similar to the one used for the control sample.
6. Start a timer at the time of catalyzation. Stop the timer when the resin reaches a physical gel.

The gel time of the material from the lamination equipment should be within ± 5% of the gel time of the control sample.

6.4.5. Key Factors Affecting Quality

The key factors affecting laminate quality are temperature, catalyst level, catalyst mixing, resin-to-glass ratio, thickness control, and laminate construction.

Temperature

Temperature during laminate fabrication is the most important process variable in open molding lamination shops. Many quality problems are traced to excessive temperature variations, which can further be complicated by variations in humidity and airflow. The resin and catalyst viscosity and the resin gel and cure times are all related to temperature. The temperature of the reinforcing materials, mold surface, and shop can affect the temperature of the resin and catalyst during application. Therefore, the temperature of the resin, catalyst, reinforcing materials, mold surface, and shop should all be regulated.

Most polyester and vinyl esters are formulated for use at temperatures between 60-95ºF (18-35ºC). Consult the product data sheet for the specific usage temperature range for each product.

Catalysts and resins increase in viscosity with decreasing temperature. Cold, high viscosity catalysts and resins are difficult to spray and distribute on the mold surface. Cold, high viscosity resins are slow to wet strands of glass and other reinforcements. Poor spray and wetting can result in increased void content that significantly lowers the mechanical properties of the laminate.

Catalysts and resins decrease in viscosity with increasing temperature. Use of hot, low viscosity resins can result in drain-out from reinforcements that can increase void content and reduce mechanical properties.

Resin gel time and cure rate increase with decreasing temperature. A good rule of thumb is that the gel time and cure rate will double with every 20°F (10°C) reduction in temperature and will be cut in half with every 20°F (10°C) increase in temperature. The slower gel and cure times of resins in cold conditions can lead to post-cure that can be seen as print-through and/or distortion. The faster gel and cure times in warm conditions may not allow enough working time for proper wetout.

Within the recommended temperature usage range, the catalyst level can be varied to adjust the gel and cure time of the resin to compensate for specific shop conditions. Higher catalyst levels are used at lower temperatures and lower catalyst levels are used at higher temperatures. Catalyst levels should be maintained within a range specified by the resin manufacturer. This range is typically between 0.75-2.5% for most laminating resins.

Use of unsaturated polyester and particularly vinyl ester laminating resins at temperatures below the specified minimum (typically 60°F (18°C)) can result in permanently under-cured parts. Under-cured parts will have poor physical properties and cosmetics.

Extremely high temperatures can also be detrimental to the cure of laminating resins. The monomer content may be lowered due to evaporation at elevated temperatures.

In colder weather, removing parts from the temperature-controlled application area too quickly after application can cause cure retardation. Even drafts of cold air should be avoided during application and until a sufficient degree of cure has been achieved.

To help compensate for seasonal temperature variances, the same resin can be supplied in summer and winter versions. Summer versions have longer gel times to allow for more working time in hot weather. Winter versions have shorter gel times to improve cure. Changes in viscosity can also be incorporated to provide the viscosity desired at the application temperature.

Catalyst Level

Low catalyst concentration and poor catalyst distribution are two more leading causes of problems in FRP composites. Peroxide catalysts initiate the cross-linking reactions in unsaturated polyesters or vinyl ester resins. All peroxide-initiated resins specify a minimum catalyst level, as well as a maximum. A typical range for a 9% active oxygen methyl ethyl ketone peroxide catalyst is 0.75-2.5%. Always consult the product datasheet for specific recommendations on catalyst type and usage range recommendations.

The minimum range limit is necessary to ensure that enough catalyst is available to achieve a suitable reaction rate and complete cure. Even small amounts of peroxides, or other free radical sources, will start the cross-linking reaction; however catalyst starved resin will be permanently under-cured and the resulting laminate will have poor mechanical properties and cosmetics. Another consideration for the minimum limit is the ability of catalyst metering equipment to meter lower volumes. Most commercial metering equipment also has lower volume limits.

The maximum limit is necessary due to the diluents used in the peroxide initiator products. These diluents are non-reactive and high levels can ‘plasticize’ the resin. ‘Plasticized’ resins have poor stiffness and hardness. This plasticizer is also transient in the polymer matrix and leeches out over time and with exposure water, leaving the remaining laminate embrittled. High catalyst levels can also cause an increase in the monomer-to-monomer side reactions that further weaken the laminate.

Catalyst Mixing

Even if an appropriate catalyst level is specified and equipment has been properly calibrated, faulty equipment may fail to mix the catalyst in the resin evenly or consistently. Parts made with poorly mixed catalyst may not show any symptoms during fabrication or at demold. In fact, parts with uneven catalyst may only present problems after the parts are put in service. Common indications of poorly mixed catalyst include print, distortion and delamination in laminates. Due to the severity of these problems, proper catalyst dispersion should be ensured.

Resin-to-Glass Ratio

The resin-to-glass ratio is the amount of resin (by weight) versus the amount of glass (by weight) in the total laminate. The appropriate resin to glass ratio depends on the type of glass fiber reinforcement used. For laminates fabricated with spray-up chopped roving, the resin-to-glass ratio is typically 70:30 to 60:40. For laminates fabricated with roll goods, the resin-to-glass ratio may be as low as 40:60. Always check the data sheet for the reinforcement used to determine the recommended glass content.

The resin-to-glass ratio affects the finished part’s mechanical properties, appearance, and weight. Resin-rich laminates, or laminates with high resin-to-glass ratios, have a glossy or wet appearance on the open side of the laminate. These laminates will have lower mechanical properties than laminates with appropriate glass contents and may crack or fail in service. Resin richness will result in additional shrinkage that may affect the finished part’s dimensions and cosmetics due to pre-release, distortion, and fiber print. Resin richness will result in higher laminate peak exotherms that can also contribute to pre-release. High peak exotherms can also damage tooling and degrade the cosmetics of subsequently produced parts. Resin-rich laminates are also heavier than laminates fabricated with proper glass contents.

Resin-poor or resin-starved laminates will have a dull, dry appearance on the open side and may have significant porosity. In extreme cases, resin-poor laminates will have dry fibers. These laminates will have lower mechanical properties than laminates with appropriate glass contents and may crack or fail in service. Resin-poor laminates may also be under-cured and print or distort.

Thickness Control

Laminate thickness control is required to ensure a quality laminate. Thick laminates will have higher peak exotherms during laminate cure than thin laminates. High exotherm temperatures can contribute to pre-release and can also damage tooling, resulting in degradation of cosmetics for subsequently produced parts. During spray-up, slow pass speeds and excessive overlap of strokes are two sources of excess laminate thickness. During hand lay-up, overlaps in roll goods can create excess laminate thickness.

Thin laminates can result in poor laminate quality. Thin laminates may not cure properly, resulting in poor cosmetics and mechanical properties. During spray-up, fast pass speeds and minimal overlap of strokes can result in thin laminates.

Laminate Construction

Laminate construction or design has a significant impact on the field performance of the end part. To reduce cracking, blisters, and crazing, the best results are obtained by using a barrier coat behind the gel coat. (See Vinyl Ester Barrier Coats chapter for more information.)

Skin laminates are also used for this purpose, although they are not as effective as a barrier coat. A skin laminate is a thin laminate applied directly behind the gel coat. Ideally, skin laminates are fabricated using chop and a high-performance laminating resin such as a vinyl ester, isophthalic polyester, or blends of these resins with DCPDs. Proper roll out of the skin coat is important to remove all air voids at the gel coat surface. The skin laminate must also be allowed to cure thoroughly prior to subsequent lamination to realize cosmetic benefits.

Print blockers can be used behind the barrier coat and/or skin coat to provide further protection against print through from subsequent layers. The next layer or two should be a heavier mat or chopped roving, depending on the ultimate thickness desired. This provides for fast laminate build-up. Another advantage of starting the laminate with mat versus woven roving or cloth is that it distances the fabric layers from the laminate surface, minimizing fiber pattern.

The next layers can be fabric layers such as woven roving or cloth. Woven roving should be used where strength is critical. Otherwise, 6-10 ounce cloth is used for a better-finished surface than roving. Use of fabric in the final layers of the laminate allows the operator to squeegee hard on the surface to remove trapped air bubbles and excess resin. For maximum strength, succeeding layers should alternate mat and woven roving. It is not usually good practice to use consecutive layers of woven material because of poor interlaminate bond and a higher chance for porosity.

6.4.6. Lamination Methods

General preparation for lamination is as follows:

- Check all equipment and lines for contamination such as flushing solvent, water, or oil.
- Check the temperature of the shop, mold, resin, catalyst, and reinforcing materials to ensure that they are within the appropriate range (typically 60-95°F).
- Completely calibrate the equipment as described previously in this section.
- Mix the resin as needed, according to the manufacturer’s direction.

When using spray equipment, it is recommended to make a test spray to check the spray pattern. When using spray-up equipment, a test spray should also be used to check glass dispersion and wetting.

Before laminating behind gel coat or barrier coat, check the film to make sure that it is ready for lamination by touching it. If no material transfers, it is ready for lamination. Due to its high vapor density, styrene vapors tend to accumulate in low portions of the mold. High styrene vapor concentration tends to retard the cure of a gel coat film. Monitor initial film curing by checking a well-ventilated area like the trim flange, but the final film cure should be checked in low areas.

When laminating behind a skin coat, check the skin coat to make sure that it is thoroughly cured. The skin coat must be thoroughly cured prior to subsequent lamination to realize cosmetic benefits. The approximate extent of cure can be measured with a Barcol impressor. The Barcol impressor measures the hardness of the resin. Resin hardness is related to cure. The further the cure progresses, the harder the resin becomes. Typically, skin laminate resins should reach a minimum Barcol hardness of 20 prior to subsequent lamination.

A. Spray-up Methods

1. Spray a thin mist coat of resin on the mold to help with fiber wetout at the surface.
2. Next, spray the first layer of chop. The layer should be sprayed in two passes with the second pass being at right angles to the initial pass.
    - Overlap strokes by approximately 50%.
    - Keep the gun perpendicular to the mold to ensure a uniform fan pattern.
    - Maintain a constant speed throughout the spraying to ensure even material distribution.
    - A quick rollout of material between passes may help prevent sagging or sliding on vertical surfaces.
3. After spraying, completely wet out and compact the glass with lamination rollers or brushes. Brushes often work best in corners or areas with complex geometry. Pay special attention to removal of air bubbles or voids, particularly at the gel coat surface. Voids at the gel coat surface can create cosmetic defects and lead to blistering.
4. After rollout, verify that the thickness of the laminate is within the design range by using a mil gauge.
5. Larger parts may need to be sprayed in sections. The size of each section will depend on the available working time and manpower. Sections should be sized so that they can be thoroughly wet out prior to resin gelation.

B. Hand Lay-up Methods

1. For best control of resin-to-glass ratio and for minimizing air voids, textile constructions should always be backwet. Resin is applied to the mold surface, the dry ply is placed in the liquid resin, and the ply is wetted by working the resin through from the bottom up. This ensures that the air is removed away from the surface.
2. Trim the required number of roll goods plies to the desired size and shape.
3. Wet the surface of the mold with a sufficient amount of resin.
4. Position the first ply on the mold. Trim the ply as required to fit the mold.
5. Wet out the glass and remove air bubbles with lamination rollers, brushes, or squeegees. Brushes often work best in corners or areas with complex geometry. Add additional resin as required to sufficiently wet out the ply.
6. Repeat this procedure until all plies are in place and wet.
7. Carefully inspect the laminate for wetting and air voids. Touch up with rollers or brushes as needed. Remove any excess resin with a paint roller or brush.
8. Some laminate designs utilize coring materials to increase the laminate stiffness while minimizing the additional weight. Coring materials can be incorporated into the laminate by bedding them prior to resin gelation. The bedding layer should be thick enough for adequate bonding, but thin enough to prevent print-through.
9. Laminate the bedding layer using the methods discussed above.
10. Wet the side of the core material that will be applied to the laminate with a thin coat of resin.
11. Position the core on the laminate and roll over the surface, applying pressure to ensure good surface contact.

After lamination is complete, the laminate must be allowed to cure adequately prior to demolding. The definition of adequate depends upon the part and process design criteria. The amount of time required to achieve adequate cure depends on the resin, the type and amount of catalyst used, and the temperature. Premature demolding of a laminate can lead to print or distortion as the laminate continues to cure outside the mold. As previously discussed, the Barcol hardness can be used as an indicator of cure.

After gelation and the peak exotherm temperature have occurred, it is possible to accelerate the remainder of the cure by exposing the part to elevated temperatures. This process is commonly known as postcuring. There are many benefits of postcuring composites. The ultimate mechanical properties are more easily achieved through postcure. If the postcure is done while the part is still in contact with the mold surface, the parts will be more dimensionally stable and resistant to print and distortion during service. Postcuring can also drive off unreacted monomer to reduce odors in the finished part.

6.4.7. Equipment, Tools and Supplies

The following is a list of equipment, tools, and supplies that should be readily available in the lamination shop.

Equipment Needed

- Spray booth with filter, exhaust fan, metal-lined sliding doors, ample walking space around molds, good lighting.
- Air compressor (don't skimp on size—specify an air dryer; use accumulators with large water extractors). It is recommended that all hand tools be air operated for operating costs and for safety reasons (non-sparking).
- Cutting table for glass reinforcement (not needed for spray-up), 60-inch wide rack on one end for mounting rolls of glass, two rolls.
- Lamination equipment (as discussed earlier in this chapter and per manufacturers' guidelines).
- Monorail and hoists for heavy parts, boats and shower stalls.
- Dollies or conveyor track for moving molds around plant.
- Air hose, additional water traps, connectors, air regulators.
- Air-powered, gear-driven mixer for mixing resin.
- Storage bin—heated or dehumidified for glass materials.
- Fire extinguishers around plant; consult insurance carrier and local safety officials for proper type and location.
- Scales for weighing ingredients (ounces and grams).

Tools Needed

- Large scissors for cutting roll goods and smaller ones for individual tailoring during lay-up.
- Paint brushes—3" and 4", solvent-resistant.
- Rollers—plastic and aluminum, such as 1" by 3" and 2" by 12", and corner rollers. Nap rollers are used to redistribute resin.
- Squeegee material.
- Hand grinders for smoothing exposed surface and edges.
- Buffers for applying rubbing compound, cleaner, and glaze.
- Putty knives for bonding, filling, repairing.
- Air-powered drills for hardware, trim, other attachments.
- Linoleum knives for trimming edges of part in mold.
- Wrenches for bolting molds together.
- Clamps for holding inserts to wet laminate while curing.
- Measuring container for measuring catalyst.

Auxiliary Supplies

- Sandpaper—80 to 600-grit, wet or dry.
- Solvent for cleanup.
- Covering for floors under laminating area.
- Cans—1 gallon and 5 gallon, for resin and solvent of appropriate type.
- Sponges for washing molds.
- Mold cleaner, mold sealer, and mold wax.
- Wash basins—for cleanup.
- Solvent dispenser can.
- Rags.

6.5. Secondary Bonding

Overview

- **Introduction**
- **Conditions Affecting Secondary Bonding**
- **Resin Chemistry and Secondary Bonding**
- **Surface Preparation**
- **Secondary Bond Evaluation**

6.5.1. Introduction

Secondary bonding is defined as fabrication of a new laminate (secondary laminate) onto a previously cured laminate (primary laminate). The term secondary bond refers to the chemical and/or mechanical interaction between the primary and secondary laminates. Although chemical bonds are stronger than mechanical bonds, both types of bonds are necessary to optimize secondary bond strength.

A chemical bond is formed when the resin from the secondary laminate reacts with available chemical sites on resin of the primary laminate. Available (or unreacted) sites on the surface of the primary laminate can result from an under-cured laminate surface, otherwise known as an air inhibited surface. The amount of chemical bonding that occurs depends upon the number of these available sites.

A mechanical bond is formed when resin from the secondary laminate flows into and cures in rough areas on the primary laminate's surface. This interaction creates an interlocking force mechanically holding the two laminates together. The open sides of most open molded laminates have some roughness that will allow mechanical bonding. Surface roughness can be created by mechanical abrasion.

Generally, shops with slower turnover of parts have the greatest concern with secondary bond adhesion. Examples of shops with long process times include large custom yacht builders or shops making smaller, more intricate FRP parts that are laminated over extended periods.

6.5.2. Conditions Affecting Secondary Bonding

There are many conditions that can affect the ability of a secondary laminate to form a strong bond with the primary laminate. These conditions include:

A. **Temperature**—Exposing a cured laminate to elevated temperatures allows the laminate to obtain a greater degree of cure. This greater degree of cure is good for the overall properties of the laminate, but not good for secondary bonding. This greater degree of cure reduces the number of unreacted sites on the surface of the primary laminate thus limiting the amount of chemical bonding that could occur with the secondary laminate.

B. **Humidity**—High relative humidity has the opposite effect on the primary laminate. Humidity slows down the surface cure and increases the number of unreacted sites. These unreacted sites are then available to form secondary chemical bonds.

C. **Surface Contamination**—On the primary laminate, surface contamination can affect both chemical and mechanical bond strength. If the primary laminate is not cleaned properly, the secondary bond can be compromised, and the secondary laminate cure could be affected as well. Common contaminants that detract from secondary bonds include grinding dust, compressor oil, water droplets from dew, and cleaning solvents.

D. **Ultraviolet (UV) Radiation or Exposure to Sunlight**—Exposure to sunlight has the same effect as exposure to elevated temperatures. Exposure to UV rays helps to speed the cure rate at the resin surface and reduces the number of bonding sites available. If laminates made with DCPD-based resins are exposed to sunlight at any time before a secondary bond is formed, the bonding surfaces must be ground to remove all visible gloss.

E. **Time**—The time between cure of the primary laminate and application of the secondary laminate also affects secondary bonding. In general, the shorter the time between these steps the better. The more time that elapses between primary laminate cure and secondary laminate application, the further the cure of the primary laminate will progress. Extended time prior to application of the secondary laminate also increases the chance of exposure to elevated temperatures, contamination, and sunlight.

6.5.3. Resin Chemistry and Secondary Bonding

The type of resin used by the fabricator significantly influences the degree of secondary bonding that can be obtained. As mentioned in the previous section, there are numerous conditions that can affect secondary bonding regardless of resin type. However, resin type plays a major role and must be considered. For the purpose of this discussion, the resin types that will be compared for secondary bonding are orthophthalic and DCPD resins.

Orthophthalic Resins

Orthophthalic resins have proven to be very forgiving in secondary bonding applications. Orthophthalic resins are air-inhibited, which means that they have poor cure in the presence of oxygen. The poor cure is manifested as tackiness on the open side of a laminate. Poor surface cure is a benefit for secondary bonding since there are a relatively large number of unreacted sites on the primary laminate that are available to react with the secondary laminate. In addition, the poor surface cure characteristics of orthophthalic resins means that the degree of surface cure will not progress as quickly with time or exposure to heat and sunlight as for other resin types.

Primary laminates made with orthophthalic resins that are stored in a cool, dark location and kept free from contamination can be used successfully in secondary bonding applications without extensive surface preparation for several weeks.

Fabricators need to be aware that some orthophthalic resins contain additives to reduce the surface tack. These additives form a film on the open side surface of the laminate and can be detrimental to secondary bonding. The most common additive used is paraffin wax.

DCPD Resins

DCPD resins have been widely accepted by FRP composites fabricators for reasons such as tack-free cure, good cosmetics, low shrink, low costs, and emissions compliance. However, the tack-free cure means that DCPD resins are not air inhibited and have poor secondary bonding characteristics since there are relatively few unreacted sites on the open side of the laminate. Exposure to heat and sunlight further cure the surface, resulting in even fewer unreacted sites for secondary bonding.

Primary laminates made with DCPD—containing resins that are stored in a cool, dark location and kept free from contamination — can be used successfully in secondary bonding applications without extensive surface preparation for only one to three days. After this time period, the primary laminate must be mechanically abraded, and use of structural adhesives is recommended to achieve a good secondary bond.

Vinyl Ester Resins

VE resins offer the best secondary bonding capabilities. The VE resins are best for three reasons. First, the VE chemistry itself provides several bonding sites that remain active even in a fully cured laminate. Second, VE resins are more susceptible to air inhibitions than other resins, offering an uncured layer in which the secondary laminate resin can co-mingle. Third, VE resins can be as much as three times stronger that many polyester laminating resins. For these reasons, VE resins are often selected for repairing aged laminates of various or even unknown constructions.

6.5.4. Surface Preparation

Mechanical abrasion of the primary laminate surface is the best approach to ensuring a good secondary bond. Primary laminates meeting the following conditions should always be mechanically abraded prior to application of the secondary laminate:

Need abrasion of primary laminate prior to second if....	Laminates made using resins containing wax or most other additives to reduce surface tack
	Laminates that have been exposed to elevated temperatures
	Laminates that have been exposed to UV light
	Laminates made using DCPD-containing resins that have been cured > 3 days
	Laminates with glossy resin-rich surfaces

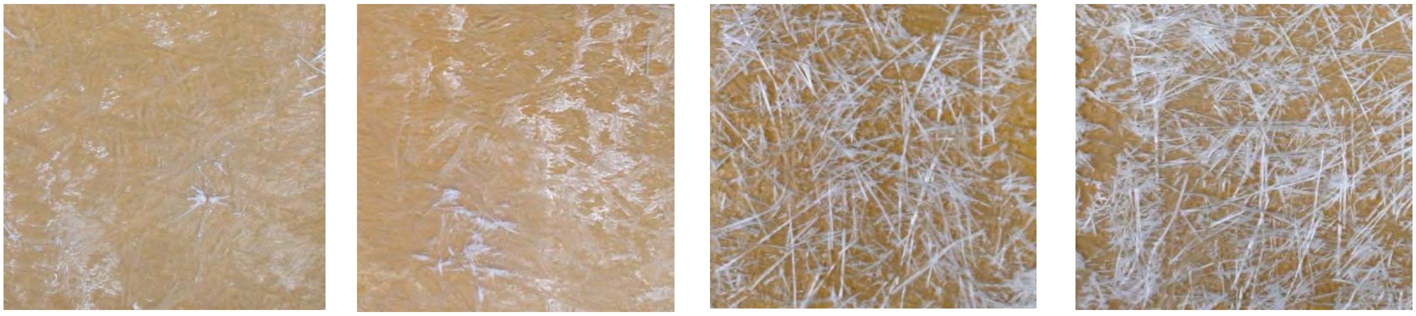
Mechanical abrasion by sanding or grinding should remove all visible gloss and expose a fresh laminate surface. It is advisable to sand down to expose some fiberglass.

6.5.5. Secondary Bond Evaluation

It is recommended that each fabricator experiment with secondary bonding using their materials and specific shop conditions. The most common method for evaluating secondary bonding is to perform a pull test. This type of testing does not quantify secondary bond strength, but allows for assessment of secondary bond integrity by evaluation of the failure location and failure mode. Users may want to perform several pull tests to evaluate various materials, storage conditions, storage times and/or surface preparation procedures. Testing should be repeated when changing any materials (e.g., glass, resin, or catalyst). The testing procedure is outlined below.

1. Fabricate a primary laminate and store it under the desired conditions and for the desired time frame.
2. Prepare the surface of the primary laminate. Place a strip of Mylar® film or other release material at one edge of the laminate to act as a failure initiation point.
3. Apply the secondary laminate. The secondary laminate should have the same dimensions as the primary laminate. Allow the secondary laminate to cure for at least 24 hours.
4. Using the Mylar® film location as a failure initiation point, pull the two laminates apart.

If the failure occurs between the two laminates without fiber tear, the secondary bond is considered poor. If the failure mode is within either of the two laminates as evidenced by fiber tear, then the secondary bond is considered acceptable. See the pictures below for examples of poor and acceptable secondary bonds.



Primary Laminate Secondary Laminate Primary Laminate Secondary Laminate

Poor Secondary Bonding **Acceptable Secondary Bonding**

Figure 6-10. Examples of poor and acceptable secondary bonds.

The following are some general guidelines that will help to provide the best secondary bonds possible.

Table 6-2. Guidelines for best secondary bonds possible.

DO	DON’T
Do test secondary bonding when changing any materials (i.e., glass, resin, catalyst).	Don’t expose parts to direct or indirect sunlight.
Do sand or grind to improve adhesion to primary laminate if laminating after 72 hours.	Don’t allow shop dust to coat the part.
Do use structural adhesives on parts being made outside of the acceptable secondary bonding window.	Don’t allow contaminates to come in contact with the part.

6.6. Acrylic Bonding

Overview

- **Introduction**
- **Acrylic Thermoforming Process**
- **Resin Matrix Material Selection**
- **General Application Guidelines**
- **Adhesion Testing**

6.6.1. Introduction

Acrylic plastics were introduced in 1936 and because of some distinguishing properties, have become a widely accepted liner material for the fabrication of tubs, showers and spas. Acrylic plastics offer the fabricator a variety of colors, and outstanding weathering characteristics, chemical resistance, and a durable, easy-to-clean surface for both the fabricator and end-user. Acrylic liners are typically backed with FRP laminates made with polyester or vinyl ester resins. These laminates, when properly bonded to the acrylic liner, provide strength and stiffness to the finished part.

6.6.2. Acrylic Thermoforming Process

The process for creating the desired acrylic part shape is called ‘thermoforming.’ Thermoforming is the shaping of a polymer sheet by the use of heat. This process can be broken down into three stages: heating, forming, and cooling.

Heating

The first stage of the thermoforming process (i.e., heating) varies, depending on the specific type of acrylic sheet being used. In general, a source of heat is applied to the acrylic sheet. After the heat application at a predetermined temperature and length of time, the sheet becomes soft, and can then be molded into the desired shape.

Forming

Forming creates the desired shape. This is accomplished by taking the heated acrylic sheet, laying the sheet over the mold, and by some mechanical and/or pneumatic means, molding the acrylic into the desired shape.

Cooling

The process of cooling returns the acrylic sheet back to its original stiffness but now in the desired part shape and dimensions. For specific details regarding the thermoforming process, the fabricator should contact one of many suppliers of thermoforming machines. The suppliers of these machines can thoroughly discuss all parameters and options related to the thermoforming process.

6.6.3. Resin Matrix Material Selection

Numerous options for backing thermoformed acrylic sheeting are now available from resin suppliers. The resin types typically used for backing up acrylic are either polyester or vinyl ester resins.

Polyester Resins

The majority of acrylic backup laminates are fabricated with polyester resins. Orthophthalic resins are common, but other types of resins can be used as well. Not all polyester resins adhere to all types of acrylics. Resins selection is significantly influenced by adhesion considerations.

Polyester resins can be used unfilled or filled. Unfilled or neat resin application generally provides better adhesion than filled application, but is also more expensive.

A. **Neat Resin**-Neat resin is defined as applying only the pure resin and fiberglass behind the acrylic. Better adhesion properties are one advantage to applying a neat resin layer behind the acrylic. A disadvantage to using neat resin is cost to the fabricator.

B. **Filled Resin**-Filled resin systems use inorganic materials such as, alumina trihydrate, calcium sulfate and/or calcium carbonate added to the resin. There are many advantages to using a filled resin system such as lower matrix cost, increased flame retardancy and reduced volatile organic emissions. However, fillers can detract from the adhesion of the resin to the acrylic substrate. Because fillers vary, the type and amount used (typically 30-60%) can affect the resin viscosity and cure characteristics. Fabricators should work with the resin supplier in order to develop a resin system suitable for the fabricator’s specific process.

   Another parameter that must be considered when using a filled resin system is the type and amount of fiberglass reinforcement applied to the part. Typical glass contents range from 15-30% and can be chopped roving applied by sprayup, or chopped strand mat applied by hand layup. The type and amount of glass reinforcement directly affects mechanical properties of the finished part. The fabricator is ultimately responsible for determining the amount of reinforcement required to obtain the desired end use engineering design.

Vinyl Ester Resins

Vinyl ester resins are typically used as acrylic backup resins when improved water resistance or thermal properties are required. Spas and hot tubs are examples of such a requirement. The vinyl ester resins are typically applied as a thin laminate next to the acrylic, and the remainder of the backup laminate thickness is built with a more economical polyester resin. As with polyester resins, not all vinyl ester resins adhere to all acrylics. The value of the vinyl ester resin is lost if the product does not adhere to the acrylic.

6.6.4. General Application Guidelines

Once the acrylic shell has been properly clamped and supported to the laminating stand, the acrylic should be cleaned to remove contaminants such as dust, moisture and other liquid materials. These contaminants can interfere with the resin's ability to adhere to the acrylic or affect the curing characteristics of the resin matrix. Possible methods for cleaning the acrylic include:

- Use of compressed air to remove unwanted dust.
- Use of an approved cleaner (recommended by the acrylic sheet supplier to remove moisture and/or other liquid contaminants).

Before any resin matrix material is applied to the acrylic shell, the fabricator should make sure all manufacturing process parameters have been checked. These parameters include but are not limited to:

- Filler is mixed properly into resin.
- Resin and shop temperatures are within the resin supplier's recommended guidelines.
- If using a chopper gun, the gun is in proper working condition.

When the fabricator is ready to apply the resin matrix, a good recommendation is to either spray or brush on a thin layer or mist coat of resin directly to the acrylic shell. The mist coat helps to ensure that there is sufficient resin next to the acrylic to provide adhesion.

After application of the mist coat, the first layer of resin and glass reinforcement can be applied. This layer needs to be completely and carefully wet and rolled out. All air voids must be removed to ensure a complete bond between the laminate and the acrylic. At this point, the fabricator can continue with the next layer of reinforcement or allow this layer to cure before continuing.

Each fabricator must determine a preferred specific lamination sequence. Some factors to consider are:

- Resin cure characteristics
- Filler loading
- Acrylic draw thickness

All of these factors affect the laminate exotherm temperature. Low exotherm temperatures can be an indicator of poor cure. Poorly cured laminates will have low physical properties and poor adhesion. High exotherm temperatures can cause cosmetic issues, especially in areas where the acrylic is relatively thin.

The final stage of the process is the trimming and addition of any plumbing or external hardware. It is recommended that the resin matrix be allowed to properly cure and cool down before any such work is performed. A good indicator of resin cure is to check the Barcol hardness of the backup resin. Ideal Barcol hardness is a minimum of 20 HB. Performing such work before the resin has been allowed to cure properly can result in stress fractures in the part and minimize the resin's adhesion properties to the acrylic. It is the sole responsibility of the fabricator to determine when these types of operations can be performed (see the following paragraphs on Adhesion Testing).

This testing should be repeated on a regular basis to ensure that proper fabrication procedures are being followed. This testing should also be done when any material change is made, including changes in cleaners, acrylic, resin, filler, catalyst, and glass fiber.

6.6.5. Adhesion Testing

Before Polynt Composites makes a resin recommendation for an acrylic backup application, Polynt offers to perform adhesion testing for the fabricator. However, Polynt cannot duplicate all of a fabricator's conditions. Each fabricator should design a suitable internal method to periodically check adhesion, using their specific materials and conditions.

The perfect time for the fabricator to check adhesion is when the part is trimmed. The excess flange material can be observed for proper laminate rollout and wetting. Good adhesion can be determined by breaking a piece in half. Good adhesion is characterized by the appearance of resin and fiberglass left behind on the acrylic. This indicates laminate failure and not failure at the acrylic and laminate interface. Caution should be taken if using this method because the flange acrylic area is typically thicker than the remainder of the part. It is easier to obtain a good bond over a thick acrylic than over thinly drawn sections of acrylic, partly because less change occurs to the acrylic polymer structure during the thermoforming process.

The most common method for evaluating acrylic bonding is to perform a pull test. This type of testing does not quantify secondary bond strength, but allows for assessment of secondary bond integrity by evaluating the failure location and mode. The testing procedure is:

1. **Prepare a thermoformed section of acrylic** per standard production procedures. It is important to use thermoformed acrylic since the thermoforming operation influences adhesion. Place a strip of Mylar® film or other release material at one edge of the laminate to act as a failure initiation point.
2. **Apply the backup laminate** per standard production procedures.
3. **Allow the backup laminate** to cure to a Barcol hardness of at least 20.
4. **Physically separate the laminates** at the failure initiation point.

If the failure occurs between the acrylic and laminate with little or no fiber tear or pullout, the adhesion is considered poor. If the failure occurs within the laminate with significant fiber tear or pullout, the adhesion is considered acceptable. Refer to the pictures in Figure 1 for examples of poor and acceptable acrylic adhesion.

Finally, fabricators have the option of quantifying the adhesion by performing ASTM C297 for flatwise tensile strength. For more information on this type of testing, please contact a third party mechanical testing facility or Polynt representative.

Figure 6-11. Examples of poor and acceptable acrylic adhesion.

6.7. Troubleshooting

Overview

- **Lamination Troubleshooting**
- **Equipment Troubleshooting**

6.7.1. Lamination Troubleshooting

Even under the best of conditions, problems can occur due to accidents, mistakes, and unanticipated events.

Listed on the following pages are some of the more common laminate problems, although other problems can occur. It is impossible to anticipate every plant circumstance that can cause problems.

Table 6-3. Common laminate problems, causes, and solutions

Problem	Cause	Solution or Items to Check for
Color variation in the laminate	• Hot/cold laminate • Uneven laminate	• Mix in catalyst well; reduce percentage of catalyst; resin puddles; moisture contaminated glass. • Check spray pattern.
Cure time—long or short	• Various	• Check percentage of catalyst and type; temperature; laminate thickness; gel time; contamination.
Delamination • From gel coat • Between laminates	• Contamination • Undercured/overcured • Application • Resin • Cloth against cloth • Uncured	• Dust on gel coat; mold release build-up dissolved by gel coat; gel coat with surfacing agent (wax). • Lay-up too soon/too late. • Poor impregnation, resin-rich. • Too much wax in resin; weak resin; check grade and physicals. • Use mat or chopped glass between plies. • Check percentage of catalyst; temperature; pulling green.
Dimples in gel coat	• Particles in laminate	• Check for excessive binder on mat (one side may be worse than the other); trash or dust between gel coat and laminate; gel particles in resin.
Drainout • No dry glass • Dry glass	• Resin-rich • Resin too thin • Long gel time	• Reduce resin-to-glass ratio; avoid excess resin application. • Use a higher thixotropy resin. • Increase catalyst where allowed; check temperature.
Gel time—too long or short	• Various	• Check percentage of catalyst and type; temperature; laminate thickness; gel time; contamination.

Table 6-3. Common laminate problems, causes, and solutions (cont.)

Problem	Cause	Solution or Items to Check for
Glass pattern or waviness found in gel coat • When part is pulled	• Resin shrinkage or heat • Thin gel coat • Undercured gel coat • Laminating process	• Check catalyst level, temperature; use lower exotherm resin; avoid resin puddling; thin gel coat; undercured gel coat. • Use a minimum of 18 mils. • Use a minimum of 1.2% MEKP; temperature should be at least 60°F (18°C). • Too much laminate at one time (use a skin coat); woven roving or cloth too close to gel coat.
• After part is pulled	• Post cure	• Catalyst level too low; temperature too low; liquid contaminated; resin exotherm too low; demolding too soon; gel coat too thin.
Glass pickup on roller	• Rolling near gelation • Styrene evaporation • Rolling too fast • Glass percentage too high • Dirty rollers	• Adjust gel time. • Dip roller in styrene or fresh catalyzed resin. Keep air movement across laminate to a minimum. • More deliberate rolling. • Increase resin. • Change solvent.
Hot spots	• Overcatalyzing • Resin-rich areas • Unbalanced laminate	• Check equipment, catalyst, and resin sides for clogs, surging, drips; purge catalyst line. • Reduce resin content. • Check thickness of different areas.
Resin crack	• Pulling too soon • Too hot	• Do not pull undercured parts. • Resin puddles; excessive catalyst; resin too high in exotherm.
Strength (low impact) or cracking	• Insufficient glass • Demolding • Part too thin; weak resin	• Check glass-to-resin ratio. • Rough demolding; too much twisting and flexing. • Increase thickness; check grade and physicals.
Soft spots	• Unmixed catalyst • Water, solvent or oil (may appear as whitish areas)	• Check equipment, catalyst and resin sides for clogs, surging, drips; purge catalyst line. • Check air lines and solvent; rollers must be free of solvent.
Voids (air bubbles)	• Entrapped air	• Poor rollout; slow wetting glass; resin-starved areas; resin viscosity high; filler level high; resin drainout.
Warpage of parts	• Unbalanced laminate	• Use symmetrical layup; back spray laminate with gel coat or enamel.

Table 6-3. Common laminate problems, causes, and solutions (cont.)

Problem	Cause	Solution or Items to Check for
Wetting (poor)	• Viscosity too high	• Check viscosity; cold resin; moisture contamination;. high resin solids.
	• Glass type or wetting properties	• Check type and grade of glass.

6.7.2. Equipment Troubleshooting

The majority of lamination today utilizes semi-automatic equipment. The care and operation of this equipment will determine whether or not the laminate achieves its maximum properties and performance.

Fabrication equipment operators must be trained to use and maintain their equipment.

Anyone who uses spray equipment should have (and should read) all the literature available from the manufacturer of the equipment. This includes parts diagrams, setup instructions, operating instructions, maintenance requirements, and safety and troubleshooting guides. If this information has not been obtained or if a question arises, call or write both the company from which the equipment has been purchased and the manufacturer. They will be happy to help because they want the equipment used efficiently, correctly, and safely.

Also, they will have general literature on spraying and technical service people to provide assistance.

Always remember the investment in the equipment and that it was purchased to do an important job. If it is not maintained and if worn parts are not replaced, the investment will be lost and the equipment will not do the job for which it was selected and purchased.

One method that can be used to determine if a cure-related problem is caused by material or equipment is to make a small test part where the catalyst is mixed directly in the resin. If this part does not exhibit the problem, then the cause is more likely with the equipment or operator. Another way to check is to run a different batch of material through the equipment; however, this could generate bad parts, making the first test method preferred.

A list of common problems that can occur with lamination equipment follows. Since there are numerous types of equipment in use, it is impossible to cover each one individually or list all possible problems or solutions. See manufacturer's literature for the type of equipment in use, or contact the manufacturer.

Table 6-4. Equipment troubleshooting - suggested causes and remedies

Problem—Resin/Chopper/Laminate	Suggested Causes and Remedies
Atomization poor (large droplets)	Check air pressure, length of hose, hose diameter (which may be too small); clogged or worn nozzle or air cap; stuck check valves; too much fluid flow; regulator not working properly.
Balls in the catalyst flow meter drop	Bottom needle valve almost closed and vibrates; filter plugged; not enough CFMs (cubic feet per minute).
Balls in the catalyst flow meter overshoot	Top valve wide open-turn 1-1/2 turns in (Binks Injector).
Catalyst injector balls fluctuating	Catalyst needle valve vibrating or too close to seat; open or tighten packing; not enough or fluctuating CFMs; dirty catalyst filter.

Table 6-4. Equipment troubleshooting - suggested causes and remedies (cont.)

Problem—Resin/Chopper/Laminate	Suggested Causes and Remedies
Catalyst valve—burst of catalyst	Weak spring due to aging. If Binks, use Plug Groove valve at the gun. If hose within a hose, check for broken catalyst line.
Cavitating pump—sucks air	Remove siphon tube, put pump directly into resin. If it pumps okay, cavitation is due to the siphon system leak, pump too small, cold or high viscosity.
Check ball stuck	Residue after flushing, vapor lock. Use piece of wood to free ball or tap side of pump.
Chopper will not run or runs slowly	Loss of air, check CFMs; regulator not on; rubber roller adjusted too tight.
Drips (Gun): • Fluid • Catalyst • Solvent	 • Worn, clogged, or bent needle; seating adjustment of needle; overspray on gun; worn packings or seals; loose connection. • Worn seat or seals; damaged air valve; trigger out of adjustment; overspray on gun; loose connection; clogged valve or seat; gun head not aligned to gun body; fan control may trap catalyst in dead air space and drip catalyst out of air horns. • Clogged or worn valve; worn seals; sticking needle or button.
Gelled hose	Bad fluid nozzle; bad seat.
Glass (chopped) not uniform in length	Worn or damaged blades; worn rubber roller; incorrect roller adjustment.
Glass pattern narrow	Chopper angle wrong; chopper air too low.
Glass off to one side	Chopper out of alignment; fluid nozzle worn or clogged.
Glass-to-resin ratio varies	Chopper air not regulated; pressure dropping before compressor kicks on—install regulator and set below the compressor’s kick-on pressure; prewetting and extra wetting not accounted for.
Hot spots	Uneven laminate thickness; catalyst or resin surging-purge catalyst line before starting; catalyst drops.
Shaft of pump drops an inch or two—shudders	Starved pump—check filters or worn internal packings. Check for worn packing by stopping pump at top of stroke—if with no material flow shaft creeps down, packing is worn.
Shaft of pump (material coming up around)	Loose or worn seal—clean and tighten; stop pump in down position when system not in use; worn shaft.
Siphon kit jumps	Dirt on check ball in pump.
Slow gel time and/or cure	Check catalyst and material flow, oil, or water contamination; check gun trigger for proper activation; if slave pump, check for air bubbles.

Table 6-4. Equipment troubleshooting - suggested causes and remedies (cont.)

Problem—Resin/Chopper/Laminate	Suggested Causes and Remedies
Surging: • Material • Catalyst	 • Inconsistent or low air pressure on pump; worn or loose pump packing; out of material; sucking air through loose connection; balls not seating in pump (dives on down stroke—bottom ball; fast upward stroke—top ball; flush pump); filter plugged; siphon line has air leak; screens plugged; too much material flow; cold or high viscosity; plugged surge chamber. • Inconsistent or low air pressure; out of catalyst; check valve sticking in gun or catalyzer; loose connection; screen plugged; if Binks equipment, install Plug Groove valve at the gun; keep hoses straight rather than coiled.
Fingers in pattern (airless): • Material • Catalyst	 • Pump pressure too low; worn tip; too large of tip; viscosity too high. • Worn tip; low pressure; wrong tip; viscosity too high; too large a fan.
Tips spitting or trigger will not shut off	Worn seat, needle or weak spring-check packing.
Trigger stiff	Bent needle, bent trigger, worn needle guide.
Water in air lines	No extractor; extractor too close to compressor—should be no closer than 25 feet; all take-offs from main line should come off the top.
Worn packings	Pump overheating from being undersized; high pressure or pumping without any material; do not let pumps jackhammer—no more than one cycle (both strokes) per second—use glass reinforced Teflon® packings; keep idle pump shaft in down position to keep dried material from damaging packings.

7. OPEN MOLDING – PAINTING POLYESTER GEL COATS

Overview

- **Description**
- **Surface Preparation**
- **Baking**
- **Other Systems**

7.1. Description

If painting of a gel coat part is desired, the most durable paint system to employ is a catalyzed urethane.

In general, two-component acrylic urethane or polyester urethane enamels maintain very good gloss and color retention when subjected to prolonged and severe atmospheric conditions. They will normally cure at ambient temperatures to a very tough, abrasion-resistant film with exceptionally high gloss.

Reputable sources for quality coatings include:

- DuPont
  www.dupontrefinish.com
- Sherwin-Williams Co.
  www.sherwin-automotive.com
- U.S. Paint Corporation (AWL Grip)
  www.uspaint.com

7.2. Surface Preparation

When recoating (painting) a polyester gel coat, it is very important that the surface be clean and free from mold release agents, oil, grease, and other surface contaminants.

Follow the coatings manufacturer’s directions for surface preparation, mixing, reducing, sweat-in, pot life, application coverage, film thickness, drying time, cleanup, physical data, precaution and safety, and other aspects.

If using for water immersion service (boats, tubs, showers, pools, spas, etc.), be sure that the paint is recommended for such use.

1. **In the absence of surface preparation instructions**, a minimum surface preparation includes washing thoroughly prior to and after sanding with clean rags and VM&P Naphtha (or coatings manufacturer’s recommendations) to remove all contaminants.
2. **Sand all gel coat surfaces** with a medium grit sandpaper such as 120, 220, or 320 to roughen the surface. Follow with an overall fine sanding to a smooth surface using 400-grit sandpaper.

7.3. Baking

Customer experience has demonstrated that gel coated laminates can be post-baked at temperatures up to 285°F for as long as two hours.

NOTE: If the fiberglass part is not completely cured before baking, distortion can occur during the bake cycle. It is better to prebake the part for one hour at the baking temperature before sanding. Then sand and bake.

7.4. Other Systems

Other paint systems can be used but may not have the exterior durability of catalyzed urethane. Match desired durability with paint quality. See paint manufacturer’s recommendations

8. OPEN MOLDING-FIELD SERVICE

Overview

- **Cosmetics**
- **Gel Goat Weathering**
- **Cracking**
- **Blisters and Boil Tests**
- **Patching**

8.1. Cosmetics

Overview

- **Defining Cosmetic Surface Quality for FRP**
- **Sources of Cosmetic Flaws and Strategies for Preventing Print and Distortion**

8.1.1. Defining Cosmetic Surface Quality for FRP

Cosmetic surface flaws go by many different names: print-through, distortion, heat lines, orange peel, dimples, waviness, glass print, pock marks, puckered, poor profile, glass pattern, balsa print, woven roving checks, rough surface, and heat distortion.

There are various types of surface distortions that are caused by different mechanisms. While not all types can be neatly classified, all print distortion can be grouped grossly into two sets:

- Small-term distortion (less than 0.05 mm).
- Long-term distortion (greater than 0.5 mm).

Small-term distortions (orange peel, fish eyes, etc.) are generally found in the coating film thickness (paint or gel coat) but also include distortions that show through the individual fibers of the layer of reinforcement directly behind the film.

Long-term distortions are those flaws that are larger and may even disrupt the surface enough to be felt. Larger flaws seen during the application of the coating film such as sag lines or curtaining are long-term distortions. Other common examples are the transfer to the surface of patterns of the reinforcing fabrics and cores.

8.1.2. Sources of Cosmetic Flaws and Strategies for Preventing Print and Distortion

Tooling

The quality of the mold surface is the primary source for print. A smooth, flawless part cannot be made from a distorted tooling surface. The surface quality of the part is only as good as the surface quality of the mold. Every copy fabricated in a flawed tool will cost more in labor to restore than fixing the tooling surface (see the chapter on Polyester Tooling for more information).

Gel Coat

While gel coat is only designed to provide color and gloss, distortions also occur in the gel coat film. Most gel coat cosmetic flaws are due to application mistakes. Heavy or uneven application can cause the ripples and sags that show through to the finished surface. Undercatalyzed (less than 1.2%) gel coats do not cure properly and have low heat distortion temperatures. Poorly cured gel coats are easily distorted by the substrate laminate and by exposure to high temperatures.

Along with undercure, thin gel coat application is the leading cause of small-term fiber print-through. Because the fiber bundles of the glass are closer to the surface, the shrinkage of the laminate around the fiber also pulls on the gel coat film.

Thicker films of gel coat are more resistant to showing the fiber print-through. There are trade-offs with thicker application of gel coat. Problems such as sagging, porosity, cracking, and reduced weathering resistance are more likely to occur.

Barrier Coats

The use of a barrier coat is an effective method of increasing the distance of the reinforcing materials from the surface of the gel coat without the problems associated with thicker gel coat. Barrier coats such as Polynt's IMEDGE® High Performance Barrier (HPB) and ArmorGuard® vinyl ester barrier add an unreinforced layer behind the gel coat to block fiber print and distortion. These barrier coats are tougher and more crack resistant than standard gel coats. They also offer increased resistance to osmotic blistering.

Print Blockers

The use of a print blocker is another method of distancing reinforcing materials from the gel coat surface. Sprayable print blockers that are formulated with high-grade resins will thermally insulate the gel coat from the shrinkage of bulk lamination layers.

Reinforcement

Fibers used for reinforcing FRP must have the correct sizing for the matrix resin used. Fiber sizing for epoxy does not dissolve in styrene-based polyester and vinyl ester resins. If the fiber is not compatible with the resin, the resultant composite will have prominent fiber print. When the fibers are not thoroughly wetted by the matrix resin, micro voids along the fiber axis are left behind. During cure, these voids expand and cause the fiber print pattern to be enhanced.

The type of reinforcement architecture also influences cosmetics. Laminates made with woven, stitched cloth, continuous roving reinforcements or coring materials close to the gel coat surface show pronounced long-term print. Laminates made with coring materials close to the gel coat surface without bedding into a random fiber layer or veil also show pronounced long-term print. The resin rich areas between fibers and bundles shrink more than fiber rich areas. The pattern of this shrinkage transfers through to the surface.

The laminate sequence and cure cycle can also influence surface cosmetics. The heat of exotherm of each lamination step must be controlled to prevent distortion caused by excessive shrinkage at high temperatures.

Resins

Polyester and vinyl resins generate heat as they cure. This heat of reaction is mass sensitive, meaning the larger the volume cured, the higher the exothermic temperature.

There are several strategies for controlling the exotherm in a laminate. The most basic is to control the thickness applied during one cure cycle. This is the time it takes for the resin in the laminated layer to gel and exotherm. The best example of controlling exotherm by ply thickness is in the traditional mold-building process. Using a conventional polyester resin to build a tool, thin layers (less than 90 mils) are laminated over several days. This process allows the shrinkage to occur in small, controlled steps while very little exotherm is generated, resulting in a distortion-free surface. Most production schedules do not allow for this extended cure time.

Other strategies for exotherm control include:

A. **Resins formulated to suppress exotherm** are designed to moderate the peak exotherm of the reaction by extending the duration of the exotherm phase of reaction. This results in a longer time to reach the ultimate cure. There is some penalty on speed of cure in thin sections with these versions.

B. **Catalyst level and types** can be used to control exotherm of each ply. Lowering the catalyst to the minimum limit for the specific resin can help moderate exotherm. Lower catalyst levels lower exotherm, but also extend gel time and cure and may be detrimental to surface cosmetics.

C. **Methyl ethyl ketone peroxide (MEKP) catalysts blended with cumene hydroperoxide (CHP)** are available from most organic peroxide suppliers. These catalysts provide exotherm control by diluting the MEKP with an alternative peroxide initiator. The CHP and resin have a lower heat reaction. Used properly, these systems can provide exotherm control with negligible delay of the final cure.

Process Factors

Faster production rates in an FRP fabrication process can be detrimental to good surface cosmetics. Faster gel and cure cycles increase the percentage of shrinkage. A part spending less time in contact with the mold increases the chance for shrinkage to happen after the part is demolded (commonly referred to as postcure). Parts that are demolded earlier in the cure cycle are also at risk for other problems, such as cracking and dull finishes.

Hot, cold, or uneven temperatures in the fabrication shop can cause a host of cosmetic issues.

- If the temperature is too high (more than 95-100°F (35-38°C), parts may demold in sections during lamination. This is known as secondary pre-release and leaves the areas of smooth finish where the part remained in contact with the mold adjacent to areas of fiber print.
- Uneven temperatures, such as one side of the part near a heat source and the other side near an open door, can also cause secondary pre-release.
- Lamination in cold temperatures (less than 60-65°F [16-18°C]) risks retarding the cure of the laminate. On demold, these parts may distort as they warm and finish curing later, producing a warped distorted surface.

- If the temperature is too low, the cure may be permanently retarded. In this case, the undercured part will have a low heat distortion temperature. Depending on the color the exposed surface, sunlight may be enough to distort the surface.

8.2. Gel Coat Weathering

Overview

- **Introduction**
- **Weathering Forces**
- **Weathering Effects**
- **Influences on Weathering**
- **Weathering Tests**
- **Additional Reading**

8.2.1. Introduction

Gel-coated FRP parts are used in a number of outdoor applications where they will be exposed to a variety of elements. Gel coats provide durable surfaces that are resistant to degradation from the elements. However, all gel coat surfaces will show wear and tear over time. This wear and tear is typically referred to as weathering. It is important to note that weathering of a gel-coated surface can be minimized through regular preventive maintenance just as the painted surface of a car will last longer with regular washing and waxing. A program of regular preventive maintenance is always more cost-effective than allowing the gel-coated surface to deteriorate and then undertaking a major restoration effort to restore the surface to its original appearance.

This section includes an explanation of weathering forces, the effects of these forces on the gel coat surface, how weathering can be prevented or minimized, and how the gel coat surface can be restored if weathering occurs.

8.2.2. Weathering Forces

Once a part is made, it begins to change because it is immediately and inevitably attacked by the environment. The attack is from:

- Light
- Water
- Pollutants
- Temperature

These are strong forces which cause wooden boat owners to repaint and recaulk almost every year, and which cause cars to rust, vinyl to crack, and virtually every synthetic material to need repainting.

Light

Light is a form of energy. The energy in light is made up of different components or wavelengths. A rainbow displays light separated into its individual wavelengths. Some of these components are stronger than others. Ultraviolet (UV) is considered to be the most destructive wavelength when it comes to weathering, but the others cannot be ignored.

The energy in light attacks materials by breaking down their molecular or polymer structure (degradation). This energy can cause a chemical reaction to take place. This reaction is oxidation and is noticed as color change (yellowing, chalking, or bleach fading).

Water

Water is called the universal solvent. It will dissolve more things than any other chemical.

Water attacks gel coats by dissolving or reacting with them. It penetrates materials and leeches out impurities or degraded materials. It can also contribute predissolved chemicals which can cause stains or degradation. It can change a noncorrosive material into a corrosive material. As water penetrates, it can also cause blistering.

Pollutants

The environment is not sterile. The atmosphere contains many foreign materials. Some of these are natural: pollen, mold spores, dust, aquatic grasses, organisms, and dirt. Others are man-made: smog, acids, oxides, etc., as in exhaust from manufacturing plants. Some are harmless, some stain, and some attack whatever they land on.

Temperature

Sunlight generates heat and will raise the temperature of a part. How much the temperature will escalate depends on color. White reflects most of the sunlight and warms up only slightly (e.g., in 100°F (38°C) air; white can reach 120-130°F [49-54°C]). Dark colors absorb more sunlight and warm up more (e.g., in 100°F (38°C) air; black can reach 150-170°F [66-77°]).

As the part warms up, three things happen:

- The material softens slightly.
- Additional cure can take place.
- Chemical attack and water penetration rates are increased (see Table 1 below).

Table 8-1. Effect of color choice on surface temperature under sunlight.

Surface Temperature °F (ºC)		
Panel Color [1]	**No Backing**	**Foam Backed**
White	120°F (49°C)	127°F (53°C)
Light Blue	127°F (53°C)	137°F (58°C)
Medium Blue	137°F (58°C)	157°F (69°C)
Dark Blue	144°F (62°C)	174°F (79°C)
Medium Red	128°F (53°C)	142°F (61°C)
Dark Red	137°F (58°C)	169°F (76°C)
Black	148°F (64°C)	173°F (78°C)

[1] These panels were exposed to outdoor sunlight with unrestricted ventilation of 100°F (38°C) air.

8.2.3. Weathering Effects

The effects of the weathering forces described above can be characterized as follows: chalking, fading, yellowing, loss of gloss, and fiber bloom. Most of these changes are cosmetic. They appear on the surface of the gel coat and do not affect its strength. The surface is sound, but does not look as it did originally.

Chalking

Chalking is the development of a fine power on the gel coat surface. Chalking occurs when the thin resin rich layer at the surface of the gel coat breaks down. The accumulation of this fine powder decreases the gloss of the part and also results in the color appearing lighter. The chalk is strictly on the surface and can be removed. Most house paints are designed to chalk and then wash clean when it rains. Gel coat chalk, however, does not simply wash off.

Fading

Fading is a uniform color change that cannot be recovered. A faded surface has less brightness and intensity, resulting in a washed-out appearance. Fade can be measured as changes in hue (red, blue, yellow), chroma (brightness or intensity), and value (lightness and darkness). Since chalking causes a color to appear lighter, it can mistakenly be interpreted as fade; however, chalk can be removed and the surface appearance recovered.

Different grades of gel coat will show varying degrees of fade. The type of polymer and pigments used in the gel coat affects the rate and amount of fading. When pigment fade occurs, the part typically retains its gloss, but will become lighter in color. Fading can also be the result of chemical exposure with the chemical staining or bleaching the part surface.

Yellowing

As you would guess from the term, yellowing is the change of the surface from its original color to a yellower shade. Yellowing is typically seen only in lighter colors. Darker colors typically fade when weathered. Yellowing is caused by the reaction of light, water, air pollutants, and heat with any reactive sites in the gel coat, which can include aromatic structures, unpolymerized maleic or styrene, or byproducts. Some of these sites always exist. Achieving a good cure is necessary to reduce these to a minimum.

Yellowing can be uniform or nonuniform across the part surface. Usually nonuniform yellowing can be attributed to application. Streaks can be caused by chemical stains, residues, or by a covering that was left on the gel-coated surface which, therefore, shielded the surface from the environment.

Loss of Gloss

Gloss refers to the gel coat's shine or how it reflects light. A surface that is high in gloss will appear shinier and reflect more light than a low-gloss surface. Any change in the surface (be it a light sanding, chalking, or dirt) will alter the gloss. Polynt has found that parts restored after weathering will lose gloss faster upon re-exposure than a new surface weathered for the first time.

Fiber Bloom

Non-gel coated fiberglass laminates can experience all the effects described above, but can also be susceptible to fiber bloom. Fiber bloom is the protrusion of the laminate’s reinforcing fibers through the part surface. This occurs when the resin rich layer on the surface of the part breaks down, allowing the reinforcing fibers to “bloom” through the surface. Gel coat provides excellent protection against fiber bloom.

8.2.4. Influences on Weathering

Gel Coat Types

A. General

1. **Resins**—The weather and water resistance of gel coats can be related to the resin type used. For polyesters, certain glycols and acids impart better yellowing, chalking, and blister resistance to a polymer than others do. Vinyl esters typically have poor weathering resistance.

2. **Other Ingredients**—The other ingredients used in gel coats can improve or reduce the weathering characteristics of the base resin. Application, weathering, and blister resistance have to be balanced. These ingredients are:

   - Fillers—type and amount
   - Pigments
   - Additives

   Two types of additives that can significantly affect the weathering performance of gel coats are UV absorbers and stabilizers. UV or light absorbers work by absorbing the harmful sunlight and converting it into nondestructive energy. Light absorbers eventually are used up. They only slow down and even out yellowing. The part will change in color with time. Light stabilizers work by scavenging free radicals formed in the photo-oxidation process and inhibit degradation. Light stabilizers are not used up, but instead are regenerated in a cyclic process.

   The effectiveness of UV absorbers and UV stabilizers is dependent on pigmentation and product series. For instance, UV absorbers are of significant benefit in clear or non-pigmented gel coats. However, UV absorbers do not generally improve the weatherability of white-pigmented gel coats. UV absorbers can be of significant value in certain colors. Light stabilizers (HALS) can be effective in improving the weatherability of pigmented gel coats.

   Certain end-use specifications may require that UV absorbers be specifically added to the gel coat. In these cases, UV inhibitors and/or UV stabilizers are added to the gel coat products upon the customer’s written request. Since the effectiveness of such additives is not always known in a particular circumstance, Polynt cannot make any claims or warranties as to their effectiveness in a particular product or with a particular color.

B. **Clears-**Clear gel coats are the most susceptible to yellowing because of the absence of pigment. Because of this, UV light absorbers are useful in clears. The use of light absorbers in clears is a compromise. They add to the initial yellow color of the clear (since the better light stabilizers are yellow themselves) but this is balanced against slower yellowing upon aging.

   Clears have greater gloss retention than standard gel coats due to the absence of pigments and fillers.

C. **Metal Flakes-**A metal flake system is a clear backed by the metal flake in clear. The weathering on the surface is the same as a clear, but now the effect of environment on the flake itself must be considered. Some metal flake is made by coating an aluminum foil or aluminized Mylar® sheet with a dyed epoxy. The aluminum reflects the light back through the dyed epoxy coating, giving it the color of the dye. If the epoxy is not properly cured and the gel coat is not cured, the aluminum can be corroded and the color is changed.

D. **White and Off-White Gel Coats-**The weathering of whites and off-whites is partly controlled by the amount and grade of titanium dioxide (TiO_2) used. High exterior durability grades of TiO_2 are the best and also the most expensive. Whites are very forgiving since they do not show changes in gloss easily, but will yellow. White gel coats are highly pigmented and will chalk more than clears. The chalking is not as noticeable because it is white on white, but gloss will suffer. Chalking is more noticeable on dark colors.

E. **Colored Gel Coats-**A wide variety of pigment types are used to make colors. All pigments do not weather equally. Normally, medium to dark colors do not yellow, but will chalk and fade. Color pigment must be checked out carefully. Colors that weather well in paints may not work in polyesters. Polynt uses pigments with proven weatherability in gel coat applications.

   Accelerated weathering must be compared against actual outdoor exposure (i.e., some colors look good in the weatherometer, but after six months in Florida will have faded badly). Many pigments will bleach out when subjected to either acids or bases. Blues and greens fade in color, while yellows and reds turn brown or go darker.

   EPA regulations limit the types of pigments that can be used. At Polynt, lead, chromate, and other heavy metal pigments have been discontinued.

F. **Deep-Colored Gel Coats-**Blacks, blues, reds, burgundies, and greens chalk as they weather. They may do so at the same rate as other colors, but the whitish chalking is more visible. This is because deep colors highlight any chalking, making it stand out. Some colors absorb more sunlight, becoming hotter and weathering faster. In general, as they weather, clears, whites, and off-whites will yellow; colors will fade; and black and deep colors will chalk.

   Colored gel coats, whether lighter or darker, have a greater tendency to discolor (lighten) and develop osmotic blisters when exposed to water than white or off-white gel coats. The severity of water-spotting or blushing will depend on the length of time of the exposure, the temperature of the water, chemical makeup of the water, the darkness of the color, degree of cure, etc. Also note that continuous use is more detrimental than intermittent use. For example, boats stored on trailers or in dry dock are less likely to display the problem than boats left in the water continuously.

Fabrication

The durability of a part is related to the care that is taken in making it. Good materials used poorly will produce a poor part. Today's increased production rates leave very little margin for error. Training and tight controls are a must.

Beware of making parts rapidly with the intention of fixing them later. Repairs are costly and take away from the ultimate quality of the part. Sanding and buffing can hasten the chalking and loss of gloss of gel coats. The ideal approach is to build quality in, rather than add it on (by patching).

Patches will not weather (chalk and change color) at the same rate as the original gel coat. This phenomenon may be most noticeable with bright whites, but is not necessarily limited to just this color. Because of the different weathering characteristics of a patch versus original gel coat, it is advised that patches be taken to a break point on the part, such as an edge, tapeline, or where hardware may be attached later, etc. If a patch must be made in a flat area with no break line, the customer is advised to determine if the different weathering characteristics of the patch versus the original gel coat are a significant cosmetic problem. To make this determination, perform an exposure test on parts made and patched in the production area, using the exact patching technique and materials proposed.

Molds and equipment will get dirty and wear quickly; good maintenance is a must to assure production of a quality part.

A. **Molds**—Weathering takes place at the surface of the part, which mirrors the mold. If a mold has any dirt, dust, or a build up on it, some will be transferred to the part. For example, polystyrene slowly builds up on the molds. Polystyrene yellows badly. If the molds are not properly cleaned, the polystyrene is transferred to the part and will yellow. Do not use styrene to clean a mold for three reasons:

   1. Fumes can cause more polystyrene to form.
   2. It can leave a thin residue of polystyrene on the mold.
   3. The styrene may contain polystyrene, leaving it on the mold. Pure styrene starts to form

polystyrene after only 30 days. Styrene, as it ages, will turn yellow, thicken, and eventually gel.

Excessive wax left on the molds can also be transferred to the part, which may yellow later.

B. **Additions to Gel Coat**—If the gel coat is modified before spraying, its weathering properties can be changed.

Do not thin the gel coat without authorization from the gel coat supplier.

Do not add anything except catalyst without the supplier's permission, as the initial color and resistance to weathering may suffer.

C. **Calibration**—Inadequate calibration of spray equipment will affect the weathering of parts. Catalyst levels that are too high (or too low) can cause parts to prematurely yellow or chalk. If the catalyst is not well mixed with the gel coat, inconsistent weathering can occur. Refer to gel coat product data sheets provided by the manufacturer for catalyst type and amount. Poorly atomized gel coat will retain more monomer, resulting in more yellowing.

D. **Technique**—The gel coat must be applied as evenly as possible because inconsistent film thicknesses will cause non-uniform weathering.

Also, apply in at least two passes. One-pass spraying of thicker films will cause yellowing. Thinner films yellow less than thicker films. For high-visibility areas such as boat decks, 12-16 mils might be considered; however, resistance to print-through and blistering would be reduced.

E. **Cure**—Poorly mixed catalyst will make various sections of a part weather differently. Overcatalyzed parts or areas will bleach, fade, and chalk worse than an undercatalyzed part. Ambient and mold temperatures in the plant must be 60°F (15ºC) or above to ensure proper cure.

Part Maintenance

Weathering can be influenced by the care the finished part receives. Weathering starts immediately. It does not depend on if the part is immediately sold or if it sits at a dealer.

FRP parts need to be washed, waxed, and taken care of like a car. They do not need repainting and caulking each year like wooden boats, but they do need care. A car dealer will wash his cars once a week to keep them looking good. A professional FRP dealer should do the same.

Chemicals and dirt can collect during storage. The gel coat can be attacked or stained when chemicals combine with rain or dew. They then can attack or stain the gel coat.

Following are some general instructions for keeping fiberglass parts looking almost like new. For further information, contact the manufacturer or suppliers of cleaning materials.

- Wash monthly or more frequently, if needed. Wash with mild soap such as dishwashing soap; avoid strong alkaline cleaners or abrasives.
- Wax the part with a good grade paste wax formulated for gel coat surfaces. Waxing frequency depends on the level of exposure of the gel coated part. Water will bead on a freshly waxed, gel coated surface. When water no longer beads, waxing is needed. Once or twice per year is generally sufficient.
- Cover the surface with an appropriate breathable material or shelter from sunlight when not in use.

For parts that have weathered and chalked:

- Wash the gel coated surface.
- Try a little wax in one area to see if this is sufficient to restore luster. If not, use a fine glaze or rubbing compound, followed by wax.

If the part has weathered for some time and has developed a very severe chalk, rubbing compound alone may not be strong enough to remove the chalking. Sand lightly with 600 (or finer) 3M™ Wetordry™ paper, then follow with a fine rubbing compound, glaze, and wax. Use finer paper, or preferably use the finest obtainable compound/glaze, to remove less severe chalking.

A. **Cleaners**—Polyester gel coats are very resistant to water and other chemicals, but the number of overly harsh cleaners that are available on the market is alarming. Avoid any strong alkaline (such as trisodium phosphate) or highly acidic cleaners. Avoid bleach and ammonia. These materials, if left in contact with polyester, may attack or change the color. Any cleaner that is used should be in contact with the polyester the minimum amount of time required to do the job. All cleaners are meant to attack dirt and remove it. The longer they remain in contact, the more they attack the dirt and the finish.

   It is best to use mild detergents such as hand dishwashing soap, which will work for a majority of stains and dirt accumulations. If you are unsure about using a cleaner, do two things:

   1. Read the label and follow the manufacturer's instructions. Use cleaners only on surfaces recommended by the manufacturer. Use of cleaners on other surfaces could be damaging. Cleaners normally used for wood or teak also may not be appropriate for fiberglass.
   2. Run a test spot. Try it in an inconspicuous spot. If it discolors or dulls this area, do not use it.

B. **Sanding and Buffing**—The process of sanding and buffing a new part surface can cost three to six months of finish life. For weatherability's sake, it is advantageous to operate with defect-free, high-gloss molds (and good procedures) so that minimal finishing is required on the part. The reason sanding and buffing causes a reduction in weatherability is that sanding and compounding remove the thin, resin, rich surface which protects the part's surface and imparts higher gloss.

   Glazes give gel coats a glossy appearance when first applied. This is a temporary shine that may disappear as it wears or evaporates. It is easy to be deceived with this false gloss and fooled into thinking the gel coat is rapidly losing gloss when it is really fugitive glaze. Again, the best approach is to build the gloss into the part through the mold surface finish.

C. **Rubbing Compounds**—A rubbing compound is a fine, gritty material that is used to take off part of the top surface. Compounds come in a number of different types of grits, such as sandpaper. Some are faster cutting (more abrasive); some are slower.

   The coarser grits are faster cutting compounds, which have larger particles and remove more of the surface more quickly. Stay with the fine grits. These grits are carried in a variety of liquids (lacquer, mineral spirits, water, and other vehicles). General tips are:

   - Read directions on use.
   - Do not use in direct sunlight. This makes the rubbing compound dry out.
   - Use clean pads to apply. Apply rubbing compound liberally.
   - Do a small area, (usually 3 feet by 3 feet) at a time.
   - If using a power buffer, use low RPM (1,700-3,000 RPM range).
   - Keep the buffer moving at all times.
   - Do not apply heavy pressure. Heavy pressure will make the rubbing compound cut quicker, but will also leave gouges, pits, scratches, and swirl marks, and will produce heat.
   - If using the power buffer, keep the buffing pad wet with material. Do not allow the pad to dry out. If the pad dries out, coarser particles scratch rather than cut.
   - Gradually lighten up on pressure as a high gloss appears. Several applications may be necessary.
   - After a rubbing compound has been used, apply a 'glaze,' then wax the part.

D. **Waxes**—There are a number of waxes on the market. Try to use one specifically designed for fiberglass. Apply a thin coat of wax. Do not leave a large residue because excess wax can yellow, causing a streaking pattern later.

   General instructions on waxes:

   - Read the directions on the can.

- Do not use in direct sunlight.
- Use clean cloths.
- Work a small area (about 3 feet by 3 feet) at a time.

Normally, the harder the wax in the can, the higher the wax content. Softer waxes have a higher proportion of silicones and solvents in them. If a power buffer is used, use a low RPM with light pressure. Keep it moving at all times to prevent heat build-up.

Waxes formulated specifically for gel coat/fiberglass surfaces are handled by many boat dealers, shower stall dealers, and automotive retail stores.

E. **Sealants**—While sealants may provide a wet luster or slick surface when applied to a new or sanded and/or compounded/exposed gel coat surface, Polynt has not found them to significantly extend the gloss or color retention life of that surface. If applied frequently during the use of the FRP item, a sealant will make the surface look better during that use; however, a one-time application will not protect or add durability to the gloss or color of the surface. Waxes designed for exterior surfaces perform similar benefits as sealants. One system may last longer than another before reapplication is needed to achieve a slick feel and luster. Again, neither has been found to be a one-time application solution to weathering.

F. **Stains**—Many fiberglass parts, as they age and are used, eventually pick up stains. These stains can come from dust, dirt accumulation, road tar, plant sap and pollen, rust from fittings, material that has leaked from caulking or sealing compounds, covers, other fittings, and accessory parts.

Stains can be difficult to remove. It requires a lot of trial and error to determine the fastest and easiest method to remove the stain. The best practice is to begin with the easiest method and then work up to the more complicated. Before trying to remove stains, materials used should be pretested in an inconspicuous area. Some materials not only remove the stain, but also deteriorate the gel coat or change its color.

Materials that stain gel coat can be broken down into two very general types of substances: soluble and nonsoluble in water. The majority of stains will be caused by water-soluble materials.

1. Pre-wet the area and wash with a mild detergent. If the soap and water solution does not remove the stains, a solvent might be necessary.
2. Beginning with a small portion of the stain, apply the cleaner, making sure it is no more than a fine abrasive since it will also remove some of the surface.
3. It may be necessary to come back with rubbing compound and wax to restore the luster.

Water insoluble materials are often organic-based substances. There are two general classes. One is called aliphatic and the other is aromatic. It is a general rule in chemistry that ‘like dissolves like.’ Before using any solvent, read directions and the warning label.

CAUTION: If using cleaning solvents, contact must be limited. Leaving a solvent-soaked rag on the part can cause deterioration of the gel coat.

CAUTION: Many solvents are flammable.

Different types of solvents can be used; test areas are recommended. The accepted procedure is:

1. Apply a small amount of solvent to the area that is being cleaned.
2. Promptly wipe it dry.
3. Repeat if necessary, but do not soak an area.

The most common removers for aliphatics are acetone, methyl ethyl ketone (not catalyst, which is methyl ethyl ketone peroxide), ethyl acetate, and rubbing alcohol. Acetone is a principal ingredient in fingernail polish remover and is also found in lacquer thinners. Lacquer thinners also contain some alcohols and other solvents.

To remove aromatics, try xylene or toluene. These are commonly used as paint thinners.

If these materials do not remove the stains, or if the stain has gone deeper into the material, then surface abrasion will be necessary. In mild cases, rubbing compound works for a small spot. If this does not remove the stain, then use 400 to 600-grit sandpaper, followed by rubbing compound, glaze, then waxing.

G. **Scratches and Nicks**—Scratches can occur with normal use. To repair scratches, try the simplest method first.

1. Work on a small area of the surface (as small as possible).
2. First try a little rubbing compound. This may not completely remove the scratch, but may make it hardly noticeable.
3. Wax to retrieve the original sheen.
4. If rubbing compound does not do a satisfactory job, move on to wet sandpaper.
5. Waxing to retrieve the original sheen.

If the scratch has penetrated the gel coat, a repair will have to be done. For instructions on repairs, see the section on Patching in this chapter or contact the manufacturer of the part.

Minor repairs can be done easily with the knowledge of how to work with polyesters. A good repair is almost invisible. Major repairs should be done by a professional.

In cases where there is extensive damage, it may be necessary to paint or refinish the fiberglass part. In all cases, read the coatings manufacturer's literature and directions on the container. Recommendations should be read and followed. Two-component polyester or acrylic urethanes find best acceptance.

H. **Shrink Wrap**—Boat manufacturers, marinas, and dealers are being encouraged to 'shrink-wrap' boats by those who sell the wrap and heat guns. This practice is suggested to keep boats clean during storage and transit. As a manufacturer of gel coats for the marine and fiberglass industry, Polynt believes it is important to alert our customers to the complications and risks associated with this practice.

Of course, a clean boat is preferable to a dirty boat. However, those who choose to shrink-wrap boats need to consider the possible adverse side effects as well as viable alternatives. Polynt's concern centers on two primary issues:

- Heat applied to the laminate
- Moisture trapped next to the gel coat

Shrink wrapping involves heat being applied against a plastic film. The heat causes a reaction and the film 'shrinks to fit.' This heat, if/when applied to a laminate, can have an adverse effect. Heat can bring about fiber print and postcure distortion.

These wraps may not 'breathe.' If these films trap water or condensed moisture next to the gel coat surface for prolonged periods, the possibility of blistering or color fading is likely. Boats are obviously constructed to sit in water. However, lakes, rivers, oceans, etc. have moderate temperatures compared to heat trapped inside plastic. It is somewhat analogous to rolling up the windows of a car on a hot day; it is hotter in the car with the sun beating through the window than on the outside. The length of time and the temperature at which the FRP article is stored in the plastic wrap, as well as the color of the gel coat and the shrink wrap, are major factors influencing the severity of this possible problem.

Breathable materials which would allow moisture to escape are preferred. Less heat is preferred to more heat, and no heat is the best option when covering a fiberglass part.

If it is the customer's decision to continue the shrink wrap practice with the full knowledge of the risk involved, then Polynt encourages adoption of certain techniques which can reduce the severity of these potential problems:

1. Use white or light-colored shrink wrap for less heat generation.
2. Taping of shrink wrap to rails or to the white or off-white gel coat surface or an area not affected by the moisture will place the condensed moisture in an area less sensitive to these problems.
3. Seal or tape the shrink wrap to the hull in such a way that collected moisture does not rest against an area that is highly visible.

4. Place a barrier of foam or fabric between the plastic film tape and the gel coat surface to prevent heat-released plasticizers from reacting with the gel coat surface.

Removal of the discoloration depends on severity. Mild cases have been removed to a limited extent by use of a heat gun. The procedures must be conducted cautiously and at lower heat settings to avoid heat discoloration as well as laminate print.

Proactive Minimization

Now that the causes of weathering have been addressed, the next question is: What can be done to minimize these effects of weathering?

Here are 10 tips that have been shown to positively influence the problem of weathering:

- Keep the molds in good condition.
  - Do not let polystyrene, wax, or dirt accumulate on them, and pay particular attention to radii and nonskid areas.
  - Do not clean molds with styrene.
- Choose a gel coat optimized for durability and application.
- Choose colors with weathering in mind.
- Do not thin gel coats.
- Contact the gel coat manufacturer before adding anything (except catalyst) to the gel coat.
- Calibrate the gel coat equipment.
- Use the proper type and amount of catalyst with complete mixing.
- Keep film thickness as uniform as possible and not excessively thick.
- Clean and wax the finished part at least twice per year.
- Ship a ‘care package’ of instructions with the manufactured part.

8.2.5. Weathering Tests

The principal environmental elements causing the deterioration of gel coat include light energy, heat, and moisture. The only way to evaluate the weathering characteristics of a gel coat is to test it.

Outdoor Exposure

The best test is outdoor exposure. The ideal location should have lots of sun, moisture, and warm temperature, (e.g., southern Florida). The only problem is time; usually it takes one year or more to achieve results.

Several configurations for outdoor testing are currently in operation, primarily in Florida. Test options include open or closed back samples. The test panels are placed at 5, 26, or 45 degrees facing south. The panel angle affects the amount of UV radiation striking the surface. Integrated energy taken from Florida readings is presented in the chart that follows.

Table 8-2. Variation in radiation with panel angle.

Panel Angle	Total Radiation (MJ/M^2)*	UV Radiation (MJ/M^2)*
5 degrees	6453	300
26 degrees	6480	271
45 degrees	6458	260

* Mega joules per meter^2

Artificial Weathering

The brief chronology that follows details the significant milestones in artificial weathering technology:

- 1918—First enclosed carbon arc (used to test fabrics for the Navy)—Atlas Electric.
- 1930s—Introduction of the source for the open flame Sunshine carbon arc.
- Late 1950s—First xenon arc source—Heraus (Atlas quickly followed).

- 1968—The 6500 W xenon power source currently in use became available; a quartz/borosilicate filter combination was widely used by the automotive industry.
- 1970—FS40 fluorescent bulb (B bulb) weatherometer introduced.
- 1984—The 313 B fluorescent bulb, a more powerful version of the FS40 bulb is introduced.
- 1987—The 340 A fluorescent bulb is introduced; more realistic UV cut-on frequency.
- 1980s-90s—Enhanced filter technology to provide better spectral simulation of sunlight (xenon units); feedback/data acquisition technology to control the irradiance intensity (all units).

There are two fundamental issues which must be considered when selecting an accelerated weathering method. These two issues, which must be considered in sequence, are:

- Correlation-The term correlation refers to the ability of the accelerated test to produce results that agree with real-time outdoor test results.
- Acceleration-Acceleration is a measure of how rapidly the test can be conducted using an accelerated weathering device compared with outdoor weathering. If agreement exists with outdoor results, it is valid to estimate the acceleration of the laboratory test.

The single most significant component of simulated weather is the nature of the light (radiation). Light energy varies in intensity throughout the ultraviolet, visible, and infrared components of the spectrum. The most energetic, and therefore most damaging, portion of the spectrum is the ultraviolet region, with wavelength less than 400 nanometer (nm). The ultraviolet portion of the spectrum has been further divided by ASTM (G113) into three regions, UV-A, UV-B, and UV-C.

The UV-A region consists of wavelengths of 400-315 nm. This type of light causes polymer damage. The UV-A light will transmit through window glass and is therefore relevant to interior materials.

The UV-B region consists of wavelengths of 315-280 nm. UV-B light is highly energetic and will result in polymer deterioration. UV-B light is the shortest wavelength of light reaching the Earth's surface. UV-B light is filtered by common window glass and is therefore relevant for components used outdoors.

The most energetic section of the ultraviolet region is UV-C light with wavelengths below 280 nm. This region of the solar ultraviolet spectrum is filtered by the atmosphere and is found only in outer space.

Testing protocols have been established by several standards organizations, including ASTM (American Society for Testing and Materials), SAE (Society of Automotive Engineers), ISO (International Organization for Standardization), as well as other groups (DIN, GM, AATCC, FLTM, NSF, VW, Ford, Renault).

The four basic options to accelerated weathering of exterior materials are:

1. Light source based on electrified xenon gas (modified via optical filters).
2. Light source based on the arc produced between carbon rods (filtered).
3. Light produced by fluorescent bulbs.
4. Sunlight concentrated using a Fresnel (outdoor) reflector.

Weathering Instruments

A. **Xenon Arc Weatherometer**—The xenon lamps are the closest match to solar power distribution throughout the UV/visible/IR spectrum. The Ci65 xenon unit fitted with a quartz inner filter and borosilicate outer filter has been the industry standard. Recently, data has been published comparing other filter combinations. The borosilicate inner/borosilicate outer filter combination has been shown to provide higher correlation with Florida exposure results than the quartz/borosilicate combination.

   The Xenon exposure is based on kilojoules of energy per meter area (kJ/m^2). Polynt's unit yields 200 kJ/m^2 per week. A 1400 kJ/m^2 test (equal to about one year south Florida exposure) will take seven weeks to run. This method of expressing exposure (kJ/m^2) allows for accurate comparison of one test series to another. Measurements in just 'hours' do not compensate for variation in lamp intensity as the bulb ages.

B. **Carbon Arc Weatherometer**—Graphing of the spectral power distribution for the carbon arc weatherometer shows the Sunshine carbon arc to be an improvement over the older enclosed carbon arc. The spectral cut-on (appreciable energy) frequency of the Sunshine unit approximates sunlight near 300 nm. Neither the Sunshine nor enclosed carbon arc provides a good representation of sunlight over the entire UV/visible spectrum.

C. **Fluorescent Bulb Unit (QUV or UVCON)**—The older FS40 B bulb and the UVA-313 bulb produce significant irradiance in the UV light region. These bulbs are particularly harmful to aromatic unsaturated polyester, which have light sensitivity in the spectral region emitted. The UVA-340 bulb has a peak irradiance wavelength much closer to sunlight. The UVA-351 bulb is intended for testing interior materials. The fluorescent bulbs do not contain significant levels of infrared radiation, which is responsible for the different temperature reached by different colored panels in sunlight.

D. **Fresnel Reflector**—Fresnel-type reflectors, such as the EMMAQUA (DSET Laboratories) and SUN10 (Atlas Electric Devices), use multiple flat mirrors to concentrate the sunlight onto samples mounted on a target plane. The radiant light concentration varies with wavelength, but is approximately equal to 'eight suns.' An air blower is used to control the specimen surface temperature.

The Atlas Ci65 weatherometer (Type 'S' borosilicate/borosilicate inner and outer filters) consistently produces relatively high correlation with Florida exposure over a range of colors and appearance characteristics. The EMMAQUA device provides good overall correlation for gloss retention, but it does not fare quite as well at correlating with Florida on some important color change characteristics. The smaller xenon unit (DSET CPS) and the carbon arc weatherometer perform similarly, showing high correlation in some respects and low correlation in others. The UVA-313 bulb consistently exhibits poor gloss and overall color change correlation with the Florida data set. The UVA-340 bulb produces a significant improvement in correlation at the expense of time (acceleration factor of approximately 3). Issues of correlation and acceleration must be considered sequentially.

The Atlas Ci65 xenon arc weatherometer and the EMMAQUA+NTW device provided the highest level of correlation with high acceleration. The UVA-340 bulb unit represents a significant improvement in correlation over the UVA-313 bulb although the test is significantly slower than the Ci65 or the EMMAQUA+NTW.

Significant differences exist in purchase price, operational cost, and capacity among the weathering devices.

Table 8-3. Features of Weathering Devices

Device	Light Source	Moisture	Max. Temp.
QUV B 313 bulb	Unrealistic—UV below that of sun	Dew cycle	60°C
QUV A 340	UV component only	Dew cycle	60°C
Carbon Arc	UV/Visible—poor match	Water spray	63°
DSET CPS Xenon	UV/Visible—good match	None	44°
Atlas Ci65 Xenon	UV/Visible—excellent match	Water spray	70°C
EMMAQUA+ NTW*	Magnification of sunlight	Water spray	—

*Night Time Wetting

Methods to Assess a Material's Response to Weather

The traditional methods to monitor deterioration due to weathering focus on the changes in appearance. The gloss meter and color computer form the basis to evaluate appearance changes.

- **Gloss Meter**-Measures the specular reflection (shine) of the gel coat on a scale of zero to 100 (zero = dull and 100 = perfect reflection).

- **Color Computer**-Quantifies the color-related changes such as yellowing, fading, and milkiness of the gel coat.
- **Wave Scan Unit**-Measure long- and short-range surface attributes such as fiber print or surface distortion.
- **Haze Meter**-Measures haze (light diffusion) rather than gloss.

Changes in appearance of the gel coat during exposure include gradual reduction in gloss as well as potential change in color. When the part is demolded, the gloss will register in the high 80s to low 90s depending on the gloss of the mold surface. The part continues to be visually acceptable until the gloss reaches a value at or below 50. As the gloss value continues to drop, the surface appears increasingly dull, and eventually chalking is evident. Changes in color of the gel coat are highly system dependent, being influenced by initial color. Light colors (white, off-white) are generally evaluated for yellowing or overall color change. Medium and darker colors are frequently evaluated for fading or overall color change. The surface may have more print-through and distortion as well as a haze.

A. **Gloss Change**—Gloss is determined by measuring the amount of specular light reflected from a surface. Typically, the measurements are taken at 20, 60 and/or 85 degree angles from the light source. The 20 and 60 degree angles show the most change and the 85 degree angle the least.

B. **Color**—Refer to the Instrumentation and Color Determination subsections in the Conventional Gel Coat: Color section.

   NOTE: As the degree of gloss drops during the weathering process, the gloss influence on color measurement will increase.

C. **Surface Profile**—The Wave Scan Unit can measure print-through and distortion. It measures long-term as well as short-term waviness. Long-term waviness typically can still be seen at distances of 6-10 feet. Short-term waviness is most obvious at a close distance of about 20 inches.

D. **Haze**—Diffusely scattered light (haze) can be caused by long- and short-term waviness. Surfaces that exhibit haze will have a sharp reflected surface that is surrounded by a halo. For measurement with the Byk-Gardner haze-gloss reflectometer, two additional apertures are used on either side of the 20 degree aperture, which allows for the measurement of the diffusely scattered light.

8.2.6. Additional Reading

For a complete review of gel coat weathering correlation, ask a Polynt representative for a copy of ‘Evaluating the Durability of Gel Coats Using Outdoor and Accelerated Weathering Techniques: A Correlation Study,’ L. Scott Crump, Cook Composites and Polymers Co., Reinforced Plastics/Composites Institute SPI, 51st Annual Conference, 1996.

8.3. Cracking

Overview

- **Overview of Gel Coat Cracking**
- **In-Plant Sources of Gel Coat Cracking**
- **Post-Production Sources of Gel Coat Cracking**

8.3.1. Overview of Gel Coat Cracking

A gel coat acts as a thin (less than 30/1000 of an inch) cosmetic shell to protect the composite and add color to fiberglass parts. However, gel coats are not designed to contribute any structure to a fiberglass part. In designing laminates, mechanical strength of the gel coat is usually not included in the composite's strength calculation.

Gel coat cracks are always caused by movement due to stresses upon the laminate. The sources and reasons for gel coat cracking are complex and can involve every element of a fiberglass part's life cycle, from design to production to usage. An analysis of some of the typical sources for these stresses on fiberglass parts can be helpful in determining the root causes of gel coat cracking.

During the life of a fiberglass part, cracking can occur in two places:

- **In-Plant**-The fabrication or production of the part can introduce cracks in a variety of ways that involve the composite materials, and/or stresses that involve the handling of the parts.
- **Post-Production**-The end use or final destination of a fiberglass composite part can introduce stresses that might exceed the design and production quality of the parts.

8.3.2. In-Plant Sources of Gel Coat Cracking

Possible sources and contributing factors for gel coat cracking that can occur during typical production of fiberglass parts are:

A. **Gel Coat Thickness**—Over-application of gel coat is the number one reason for gel coat cracking. Gel coats, like all coatings, are designed to be used in a narrow range of thicknesses. If the gel coat is applied too thin, the part could have cure and coverage issues. If the gel coat is applied too thick, yellowing or cracking could occur.

B. **Demolding**—The process of demolding a fiberglass part can generate, in most parts, greater stresses than the part will encounter throughout the rest of its life cycle.

C. **Handling before Assembly**—A fiberglass part without its structural support elements (ribs, stiffeners, etc.) is extremely fragile. Even small mishaps in handling these parts can stress the laminate beyond its design parameters and thereby initiate cracks that may not appear until later in the part's life.

D. **Design of the Part**—The design of a fiberglass part is critical to the short-term and long-term durability of any gel-coated part. Marginal designs that do not consider the range of possible stresses are likely to produce cracks.

E. **Complex Part Geometry**—While fiberglass fabrication does offer the versatility to combine many complicated shapes into one larger part, there are practical limits to these unitized designs. Complex part shapes are more difficult for gel coat application (deep draws are hard to gel coat with a consistent thickness), for lamination layout and especially for demold.

F. **Cure/Green Strength**—Undercure at the point of demold of any of the polymeric materials in a fiberglass composite can lead to cracking. The mechanical strength of a fiberglass composite builds with time as the thermoset polymers in the resins, gel coats, cores, and putties cure. If the cure is slowed either by low temperatures or incorrect catalyst levels, or if the part is demolded too quickly, cracking can occur because the 'green strength' of the part is not sufficient to protect the part from stresses at demold.

G. **Glass Content**—The fiberglass adds the stiffness to a composite part. Cracks can occur if the glass content is too low, too high or inconsistent, or if the glass reinforcements are oriented incorrectly.

H. **Joining/Fitting Parts/Pinning Boat Decks**—Fitting fiberglass parts together is a great source of stress on the laminate. While composite parts will flex to some degree to allow for fitting and joining, stresses will be built into the parts that may later produce cracks while relieving the stresses.

I. **Metallic Pins or Screws**—Use of metallic pins or screws to join fiberglass parts can also be a source of cracking due to differences in thermal expansion coefficients between the metallic material and the composite. Drilling and countersinking pilot holes can significantly reduce cracking at fastener locations.

J. **Jigging Stresses**—Using jigs while bonding structural elements such as ribs and stiffeners can deform fiberglass parts beyond their designed limits. Cracking can arise from placing the part in the jigs or from shrinkage during the cure of the adhesives or putties.

K. **Voids in Laminate**—Voids left in the laminate can cause cracking by allowing parts of the laminate to move more than the designed limits or by causing separations in the laminate cross-section.

L. **Temperature**—The temperatures that fiberglass parts are exposed to can lead to cracking during processing. Temperature not only affects the cure of the laminate but low temperatures can also contribute to cracking in ‘fully’ cured parts. The stiffness of fiberglass parts increases as the temperature decreases. Uneven heating or cold-shock can also cause cracking in FRP structures.

8.3.3. Post-Production Sources of Gel Coat Cracking

Among factors that affect gel coat cracking after parts are assembled and have left the production plant are:

A. **Handling during Shipping**—Proper cradling and use of supports are critical when transporting all types of fiberglass composite products. It is relatively easy to over-stress a composite part during shipping (i.e., boat hulls are designed to be supported by water on all sides, not by two fork lift tongues, and storage tanks are designed to carry a static load, not swing from a crane, etc.).

B. **Misuse in Final Application**—Unintended usage, misuse, and abuse are often the sources for cracking once the fiberglass part is put in service.

C. **Environmental**—Temperature extremes and other weather-related issues are often determined to be causes for gel coat cracking.

D. **Design Flaws**—Repeated cracking in the same area on multiple copies of a composite part might be an indication of either a laminate construction deficiency or a design flaw that is concentrating stresses in that area. Parts can also be under-engineered for stresses in ‘normal’ usage, leading to gel coat cracking.

8.4. Blisters and Boil Tests

Overview

- **Introduction**
- **Causes of Blistering**
- **Troubleshooting Blisters**
- **Boil Tests (ANSI Water Resistance Test)**

8.4.1. Introduction

A blister is a raised surface area behind which there is either a hollow area (generally referred to as an air bubble) or a liquid area (swelling).

The appearance of blisters in the surface coating of a part is often an indication of issues in the substrate underneath. For example, the cause of blisters in the paint of an old car may be rusting of the metal underneath. When looking for the source of blisters, it is important to consider not only the coating, but all the components of the part.

8.4.2. Causes of Blistering

Air Pockets

Air pockets beneath gel coat can cause a blister to form when the surface is heated enough to cause the entrapped air to expand. A part in sunlight can reach temperatures greater than 150°F. The darker the color of the part, the higher the temperature. If the surface above the air void is weaker than the force generated by expansion, a blister will form. These voids can also serve as a collecting point for liquids, such as water or residues.

An air pocket is a common cause of blistering and can be easily located by tapping the part with a plastic or wooden stick. Air voids generally are indicated by a difference in sound; usually that sound will be dead or muffled. Air pockets such as these are generally detected and repaired in the plant. They will vary in size and are more commonly found in radii (corners).

Most of these air pockets are caused by poor rollout, too much glass and/or filler, poor wetout of the glass or glass springback. Some air pockets are caused by debris that has fallen into a mold, trapping air or affecting bonding between layers due to contamination. These voids, however they are formed, will also cause the gel coat to crack more easily.

Figure 8-1. Example of blister caused by an air pocket.

Entrapped Liquids

Entrapped liquids are another common cause of blisters. Just like entrapped air, an entrapped liquid can expand with heat. Heat can cause some liquids to form gas or to become a reactive/corrosive liquid. These blisters will normally show up a few hours after the part is pulled and placed in the sun. Some will take longer to appear. Bubbles of entrapped liquids are generally random and about the size of a quarter or smaller. If punctured, they are sticky and contain fluid.

Catalyst droplets are one type of entrapped liquid that occurs in composites. Catalyst can cause a blister by simple expansion, or by breaking down to form gasses and/or solvent-like material that slowly weakens the surrounding area.

An entrapped solvent can also expand, change into a gas, and then weaken the area around it.

Uncatalyzed resin entrapped between cured layers can cause blisters.

Attack by Chemical

Chemical attack occurs when a corrosive agent literally breaks up the part from the outside or from within. When polyesters are attacked by a chemical, the first signs are swelling and blisters.

The general types of materials than can break up polyesters are: alkaline (such as lye, caustic, trisodium phosphate); certain solvents (such as acetone, ethyl acetate, or methyl ethyl ketone, if in contact long enough before evaporation); or chlorinated liquids (such as methylene chloride). Typically, these solvents will also cause delamination of the gel coat.

If chemical attack is suspected, it is important to check for signs of attack on metal fittings, trim, and wood attachments.

Figure 8-2. Example of blister caused by catalyst.

Creation of an Osmotic Pressure Cell

Osmosis is a very common phenomenon. This mechanism involves a membrane and liquids or liquid mixtures that can or cannot pass through that membrane. In the case of laminates, the gel coat acts as a membrane. Water permeates through the gel coat to saturate it, but also to saturate the laminate behind it. The hydrolysis of the laminating resin (i.e., the depolymerization of the unsaturated polyester polymer) generates decomposing molecules. Those molecules are dissolved in the water, saturating the laminate and the osmotic pressure cell is created. On one side of the gel coat (i.e., the membrane) is water, and on the other side is a blend of water and decomposition products that are too large to pass through the gel coat. When the pressure created becomes higher than the critical stresses the materials can withstand (e.g., when the water attack of the laminating resin has been extensive and the concentration of decomposition products has become very high), the structure weakens and blisters are formed.

The blister resistance is therefore affected by all the parameters that affect the overall hydrolytic stabilities (i.e., the chemical resistance to water) of the components (gel coat, laminating resin), and the strength of each of the components in the laminate (geometry, degree of cure) as well as the presence of impurities such as unreacted species (unreacted catalyst, synergist, etc.).

The ability of a laminate to resist osmotic blistering can be greatly improved through the use of a water resistant barrier coat such as Polynt's IMEDGE® HPB or ArmorGuard® or a vinyl ester skin laminate. Of course, the degree of improvement is dependent on the quality of the materials and the application techniques used. A water resistant barrier coat or vinyl ester skin laminate is recommended for fiberglass parts that will be exposed to continuous moisture, such as boat hulls, swimming pools, waterslides, etc.

Figure 8-3. Example of osmotic blisters.

8.4.3. Troubleshooting Blisters

When blisters are encountered, do not assume a particular cause. Do the following:

1. **Examine the Blistered Part**
   - Where does the blister occur on the part?
   - How many blisters? What is the size of each blister?
   - Were water and/or heat involved?
   - How soon did the blister develop after demold?
2. **Puncture and Observe the Blister**—Make a cross-section cut and note the following:
   - How deep is the blister, or where did it occur (gel coat, skin coat, bulk laminate, or between layers)?
   - Does it contain fluid, or is it dry?
   - Does it have a different color?
   - Does it have an odor?

     NOTE: Decomposed catalyst will not smell like pure catalyst.
   - Is there any discoloration around or near the blister on wood or fittings? What color is the discoloration?

3. **Select the Most Probable Blister Mechanism**—Select the most probable mechanism and list materials, equipment and procedures that are involved.

Now comes the hard part.

4. Try to **determine what material, process, or combination caused the blister**. Sometimes the cause will be obvious. In other instances, testing will be required.

It is impossible to guarantee that even one of the parts will never develop blisters. Too many materials, types of equipment, and people are involved. However, Polynt can provide guidance on the best methods to reduce the occurrence of blisters. These strategies are:

- Apply proper types of gel coat; refer to data sheets.

  NOTE: Some gel coats, such as orthophthalics and some ORTHO/NPG's, develop blisters within themselves that cause failure regardless of laminate construction.

- Apply the proper type of gel coat. Polynt's isophthalic or ISO/NPG gel coats are recommended.
- Use proper equipment and procedures to apply; refer to the Conventional Gel Coat: Spray Equipment section. If catalyst injection equipment is used, make sure it is properly calibrated.
- Make sure temperature is above 60°F.
- Avoid contamination in any part of the system.
- Use a high-quality laminating resin.
- Use the right catalyst and its proper amount in all polymer portions of the composites. See data sheets.
- Assure that the laminate is applied and cured properly, especially the skin coat.
- Choose a suitable glass; refer to the data sheet on that glass.

8.4.4. Boil Tests (ANSI Water Resistance Test)

One method for testing the blister and overall water resistance of composite laminates is the ANSI-Z124 test. This test is a material standard for showers and tubs and has been adopted by other industries including marine. In this test, the gel-coated surface of a laminate is exposed to boiling (212°F or 100°C) water for 100 hours. After the exposure, panels are visually rated.

Figure 8-4. Boil test.

The rating applies to five separate areas:

- Blister (size and number)
- Change in surface profile (fiber prominence)
- Cracks
- Loss of visible gloss
- Color change

The rating scale for each area is subjective. The scale is 'zero to five' with 'zero' being no change and 'five' being the maximum change possible. Refer to the Troubleshooting Guide section of the Conventional Gel Coat chapter for examples of these changes.

Values one, two, three, and four are increasing gradations of change. A panel is independently rated by three experienced people. A panel is failed if any one area has a rating of four or over, or the total of all area averages is over nine. The ANSI standard also lowers the severity of the test for thermoplastic sheet material by lowering the test temperature to 82°C. It is important to note that blisters do not necessarily mean failure by themselves; rather, it is the combination of all factors.

The question has been posed as to whether the boil test can be related to actual use. Several factors have instigated such questioning:

- Different test temperatures are used for different materials.

- The thickness of gel coat and type of substrate is not specified, but both are major influences on the success or failure of the specimen.
- Test conditions are extremely severe and are not found in normal field application.
- Some materials which fail this test have been used successfully for years in certain field applications.
- Test results are very dependent on types of glass and resin and their application.

However, it is important to remember that in the production of shower stalls, which must meet FHA requirements, these criteria must be met, as well as the other requirements listed in ANSI-Z124.

This test, if performed with proper controls, can be helpful in choosing or comparing materials.

Since the boil test is required by the shower stall industry and is referred to by other segments of the FRP industry, a good understanding of what affects this test is a must.

The purpose of the boil test is to create conditions that will accelerate the attack of the water and therefore obtain results much quicker than at room temperature. The following factors will affect the performance of gel coats on boil tests:

A. **Type of Resin Used in the Gel Coat**—The more resistance the gel coat has to the attack of water and to permitting water to pass through it, the better the test results. In general, gel coat systems rank as follows:
   1. Orthophthalic systems (fair)
   2. ORTHO/NPG systems (fair to good)
   3. Straight isophthalic systems (good)
   4. ISO/NPG systems (best)

B. Water Resistance of Other Gel Coat Components

C. **Cure of the Gel Coat**—If the gel coat is undercured, it will have poorer water resistance. Major factors affecting cure are:
   1. **Temperature**—If parts are made below 60°F (16°C), poor cure will result.
   2. **Percent Catalyst**—If the catalyst is too low or too high, undercure can occur. Too high appears to be a greater problem than too low because excess catalyst remains that can act as an osmotic agent. It can simultaneously chemically attack the gel coat and weaken it further.
   3. **Type and grade of catalyst**—Different brands and types of catalyst will have different ratios of ingredients and produce different cures.
   4. **Thickness**—If a gel coat is less than 12 mils, the possibility of undercure is increased due to insufficient mass and to excessive styrene loss due to surface evaporation.

      NOTE: A thin film (or overspray) sprayed onto cured gel coat will cause water blisters. Areas that receive extended water immersion (boat hulls, swimming pools) should not be backsprayed with a thin film/overspray onto cured gel coat.
   5. **Contaminants**—These consist of agents such as water, solvent, and intentionally or unintentionally introduced materials.

D. **Thickness of Gel Coat**—The thicker the gel coat, the better the results will be. This is because a thicker gel coat can withstand a higher pressure and slows water penetration.

E. **Barrier Coat**—Use of a properly applied barrier coat such as Polynt's IMEDGE® HPB or ArmorGuard® will reduce blistering.

F. **Quality of the Laminating Resin**—In general, orthophthalic resin yields poorer results than isophthalic resin or vinyl esters.

G. **Fillers**—Certain fillers can increase or decrease blistering and color change.

H. **Laminate Cure**—The cure of the laminate is important because it is more susceptible to attack if under-cured. The factors involved in laminate cure are the same as gel coat.

I. **Type and Sizing of Glass (Layer Next to Gel Coat)**
   1. A **layer of surfacing veil** yields good results when used as a skin coat for either chopped glass or mat.
   2. **Cloth** yields better results than mat or chopped glass.

      NOTE: Layers of cloth next to each other show sporadic large blisters due to poor bonding between layers.
   3. **Roving (chopped laminate)**, in general, yields better results than chopped mat.

NOTE: There is a difference between types and brands of roving. Some yield poorer results than mat, others better. This may be related to the type of glass binder and sizing.

4. **Mat** is generally a worse choice than any other type of fiberglass due to binder deposits.

J. **Lay-up Time**—The more time that passes beyond lay-up readiness, the poorer the boil/blister resistance will be due to weaker bonding between gel coat and laminate.

Clearly, there are many factors that affect the boil test. If this test is used to compare gel coats or other materials used in making a part, it is important to make sure that nothing else overrides the material being tested. For example, in comparing two gel coats, the following should occur:

- Proper fabricating temperature should be maintained above 60°F (16°C), preferably 77°F (25°C). Maintain proper cure.
- Proper amount and type of catalyst should be used. Refer to the data sheet for each product.
- Uniform thickness is desirable. Strive for a normal film thickness (18 mils ± 2) and a higher film thickness (25-30 mils). Side-by-side draw-down comparison is most accurate.

Use the same gel coat, laminating resin, glass and amount of proper catalyst consistently throughout all systems to be compared, allowing for only one variable at a time.

8.5. Patching

Overview

- **Introduction**
- **General Working Conditions**
- **Cure**
- **Repair Procedures**
- **Minor Surface Repairs - Spot Patching**
- **Spray Patching - Area Patching**
- **Putty Patch - Holes or Cracks in Gel Coat**
- **Gel Coat and Laminate Repair - Holes, Punctures or Breaks in the Laminate**
- **Finishing Techniques**
- **Helpful Hints**
- **Troubleshooting Guide**
- **Associated Data**
- **Patching Guide - Wall Chart**

8.5.1. Introduction

Repairs are needed for a number of reasons, such as:

Common causes:	Usage
	Storage
	Impact during handling
	Defects in the mold
	Contamination
	Processing issues (material, operator)
	Rough demolding

It is important to determine the cause of a defect so that steps can be taken to correct the cause. Then, the type of defect and extent of damage are analyzed (Figure 8-5) to decide the best repair procedure.

There are five basic steps for patching gel coat (Table 1). This includes: prepping the area; accurately measuring the catalyst, patch aids and gel coat; thoroughly mixing spray patch materials; applying gel coat and/or laminating resin; and finishing—sanding, buffing and polishing.

In order to maximize gel coat patching success, it is important to:

- Look at the work environment, including safety.
- Use materials within their shelf-life and from the same batch as the part if possible.
- Follow all repair instructions.

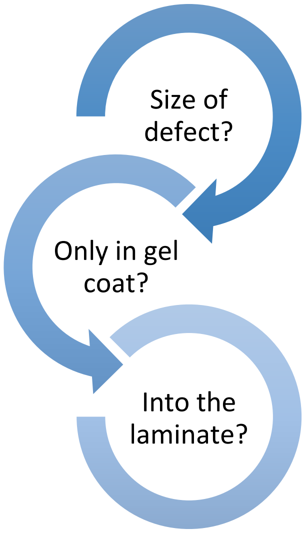


Figure 8-5. Evaluate the defect

Table 8-4. Five basic steps to patching gel coat.

Step	Procedures	Example
1	**PREPARE**	Clean surface, mask off areas, sand defect using correct grit size, and use proper equipment.
2	**MIX**	Use material from original batch. Transfer material from the larger container, if applicable, and mix thoroughly before use.
3	**MEASURE**	Accurately measure gel coat, catalyst, and Patchaid®.
4	**APPLICATION**	Depends on size of repair, from minor surface repairs to patching large holes.
5	**FINISH**	Sand (coarse to fine grit), clean, and buff patch using appropriate materials.

8.5.2. General Working Conditions

Consideration of safety and lighting are critical to achieving a good patch repair.

Safety

Many of the materials used in fiberglass repairs can be hazardous. Therefore, before starting a repair, read all safety data sheets (SDS), technical data sheets and other instructions for all materials to be used in the repair, such as gel coat, resin, catalyst, solvents and so on.

NOTE: Most of these materials are flammable. Peroxides (catalysts) are corrosive and can ignite or explode if not handled properly.

Follow all local, state and federal regulations concerning the use and disposal of these materials.

Make sure all safety requirements are met before proceeding.

Lighting

It is very important to have a well-lit area for the repair process. Ample lighting ensures the most success for identifying and removing defects as well as making certain the repair is acceptable.

8.5.3. Cure

Consideration of temperature, catalyst levels, and calibration (measurement) are also critical to achieving a good patch repair.

Temperature

Repairs should not be attempted when materials, the part and the work area temperatures are below 60°F (16°C) since poor cure may result. Poor cure can cause the repair to dull, change color, and/or prematurely fail. At 60°F (16°C), repairs will be slow and have long cure times.

It is best to have temperatures above 75°F (25°C) since small amounts of materials (thin films of gel coat) are being used. Air and part temperatures are critical since cold air, or draft, and cold parts will greatly influence small amounts of materials. If this happens, poor cure can result.

It is important to avoid working in direct sunlight since it will heat materials, which shortens working time.

Catalyst

Since small amounts of gel coats are used and additional heat from the laminate is not available, the catalyst levels should be kept on the high side, normally 2-3%. Refer to Polynt product data sheets for catalyst recommendations.

To achieve good cure, the ratio of catalyst to material should be measured (calibrated) carefully. Mixtures must be measured accurately, by mass, in grams (g), or volume, in milliliters (ml), or cubic centimeters (cc).

Measure (Calibrate)

Many repairs are small and require small amounts of patching materials. Measuring gel coat and catalyst quantities is critical for successful patching. The smallest amount of gel coat that can be accurately measured is 50 grams (ml or cc). Even if 95% of the catalyzed material is discarded, it is cheaper to make 50 grams of gel coat patch material than having to redo a repair because of inaccurate measurement of materials. It is less costly in the long run if the materials are accurately measured.

The next best method is to measure by volume (50 ml or cc of gel coat, 1 ml or cc of catalyst).

Low-cost measuring devices can be purchased from local pharmacies, laboratory/hospital supply firms or scientific apparatus suppliers.

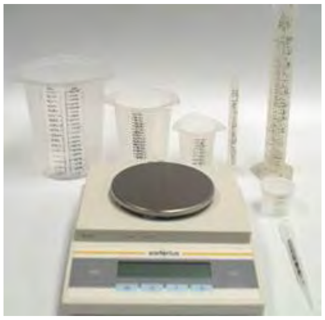


Figure 8-6. Measurement equipment.

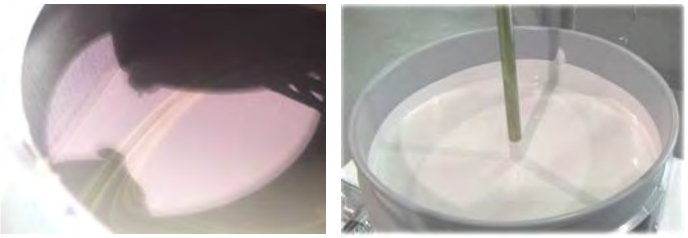
Materials

Fiberglass repairs should be made with the same gel coat and/or laminating resin used to make the original part. The same chemical reactions taking place during cure of the original part also takes place during repair. Ideally, it is best to use product from the same batch number that was originally used to make the part.

Mixing

To assure patch uniformity, all materials must be mixed thoroughly before use. This is important since gel coat settles over time and materials separate.

Gel coat components separate over time (like paint). In general, solvent and promoters move to the top, polymer resin to the middle, and pigments, fillers and thixotropes settle to the bottom (Figure 8-7).



Unmixed Gel Coat

Mixed Gel Coat

Figure 8-7. Examples of how unmixed and mixed gel coat appear.

NOTE: Material used for repair should be taken from the larger production container. This container must be mixed prior to taking any gel coat for repairs.

8.5.4. Repair Procedures

When doing a repair, keep the patch area as small as possible and only do the necessary steps. There will be less work and make the repair harder to detect. Stand three (3) feet away from the part. If the defect can't be seen from more than three (3) feet away, repair may not be needed.

If an area is stained or discolored, the area should be washed with soap and water first. If not sufficient, wash with a solvent. If it still appears stained or discolored, use rubbing compound. The final option is sanding.

If the defect is still visible after washing or buffing, repair is needed. The repair process depends on the size and type of defect.

SPOT PATCH

- Minor surface repair

SPRAY PATCH

- Large area repair

PUTTY PATCH

- Holes or cracks in gel coat

GEL COAT AND LAMINATE PATCH

- Holes, breaks, or punctures in gel coat and laminate

The repair process may call for some of the following actions:

- Mask off area for repair
- Sand[1] before and after patch spray
- Grind out debris
- Apply gel coat (dab or spray)
- Apply putty
- Laminate
- Buff surface
- Wax surface

[1] All sandpaper grit numbers described here meet ANSI standards (non-ANSI grit numbers are different coarseness)

8.5.5. Minor Surface Repairs—Spot Patching

The following procedure is recommended for the following:

- Small areas that have damage to the gel coat only (Figure 8-8).
- Small areas that have a blemish (hole, gouge, or scratch) that is deep enough to penetrate through the gel coat to the fiberglass but not deep enough to go completely through the laminate (less than 1/32" or 30 mils deep).

Figure 8-8. Examples of minor gel coat scratches.

A. Preparation

1. Roughen the surface of the defect using coarse sandpaper, or a router, depending on the type of damage.
    - Sand the surface by hand using a sanding block or sand with a Dual Action (DA) sander.
    - For small defects in the gel coat, sand the surface with 220-grit sandpaper.
2. Wipe away sanding dust with a clean shop rag, then sand with 320-grit sandpaper.
3. Feather the edge surrounding the blemish with finer grit sandpaper (1000-grit). Do not undercut this edge.

    Note: The sanding marks should be close to the size of the defect.
4. If the defect goes through the gel coat into the laminate, grind out material with a router or pencil grinder or use with coarser sandpaper (50-80-grit).
5. Try to keep the area round/oval with beveled edges.
6. Clean the patch area, removing all dust, oils, wax or other contaminants.
7. Clean the surface with a no rinse cleaner. Solvents such as ethyl acetate and methyl ethyl ketone are suitable. See warnings in solvent SDS before use.

B. Mix and Measure

Always make the patch with material from the same batch of gel coat that was used to make the original part. Failure to comply with this rule will almost certainly result in an off-color patch. Material for repair should be taken from larger production containers. Refer to the paragraphs on Helpful Hints in this section.

1. Thoroughly mix the gel coat before removing from container.
2. Measure 50 grams (ml or cc) of gel coat into a suitable container such as an eight (8) ounce cup (not paraffin lined or styrofoam).
3. Add 5% (2.5 g, ml, or cc) of Polycor® 970C940 2% wax solution to the gel coat to obtain good surface cure.
4. Thoroughly mix the proper amount of MEKP into the mix. The addition of 2% (one g, ml, or cc) catalyst to the mix should give approximately the same gel time as the gel coat itself.

Table 8-5. Amount of material required.

Material	Amount (g, ml or cc)[1]
Gel coat	50 g
Polycor® 970C940 (2% wax solution)[2]	2.5 g (5%)
Peroxide	1 g (2%)

[1] Can use g or ml (cc) to measure, i.e. 50 g or 50 ml

[2] Wax solution is optional

C. Application

1. Work the catalyzed gel coat into the damaged area with a knife or spatula (dab).
2. Slightly overfill the blemish, including the area around and above, to allow for shrinkage (Figure 8-9).
3. Puncture and eliminate any air bubbles that may be trapped within the gel coat.
4. If wax solution is not added to the gel coat, cover the repaired area with cellophane, waxed paper, or parting film (PVA) while the patch cures (Figure 8-9).

    NOTE: PVA can be difficult to spray. In order for it to provide an efficient barrier, it must be sprayed as a film rather than a dust coat. Do not flood it on or spray it too thick.

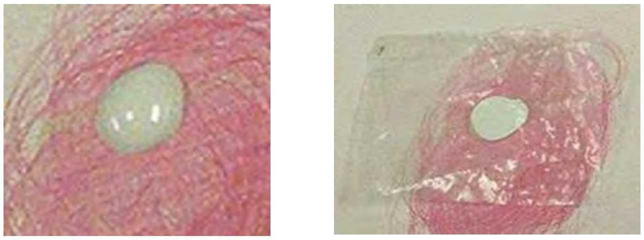

Dabbed Patch
Covered Dab

Figure 8-9. A dabbed patch on a minor repair and the dab covered with plastic while the patch cures.

5. Allow the patch to cure thoroughly before any further action is taken. Cure time should be approximately two to three hours. The patch has not cured sufficiently if a thumbnail leaves an impression in the gel coat.

D. Finishing

1. Sand the patched area with 220/320-grit (wet or dry) sandpaper. Do not sand down the patch completely with the 1st sanding. Subsequent sanding steps remove material and help when feathering the hard edge.
2. Remove sanding dust. Always remove dust and debris by washing or wiping the area between sanding steps.
3. Sand the patch wet or dry with 400/600-grit sandpaper. If using a DA sander, use 320, 500 and then 800-grit.
4. Remove all dust.
5. If the patch shrinks to a point where the surface is not level with the adjoining areas, repeat the preceding steps (apply material again).
6. Complete the finishing process by buffing with buffing compound to a smooth surface.
7. Wax and buff the surface to a high gloss. Refer to the paragraphs on Finishing Technique in this section.
8. If the spot patch does not match the part in color, verify that the same batch of gel coat was used for the patch as was used for the original part.
9. It may be necessary to make a spray patch (see next paragraphs) over this spot patch or over an entire section. As with bodywork on automobiles, it is sometimes necessary to spray patch an entire section at a time, using edges or corners as boundaries for difficult-to-match situations.

8.5.6. Spray Patching—Area Patching

Spray application is used when there is a larger area to repair (Figure 8-10). The sanding area will be slightly larger than the repair.

Figure 8-10. Example of multiple holes in the gel coat surface needing repair.

A. Preparation

The first step to patching is preparation. Preparation involves sanding the damaged area, removing debris, and masking off, or isolating the defective area in preparation for spray. The defect can be sanded first and then masked-off or masked-off first, followed by sanding.

When masking first:

1. Mask off the area around the defect with tape. Cover surrounding areas to protect the surface from overspray (Figures 8-11 and 8-12). Keep the repair area as small as possible.
2. Sand the patch area with 220-grit sandpaper by hand (sanding block) and/or with a DA sander (Figure 8-13). Feather the edges, using finer grit (1000-grit) paper in hard-to-match situations. Use clean rags to remove sanding dust.
3. Place a second layer of tape about 1/16"-⅛" inside the first tape edge (Figure 8-14).
4. Clean the patch area. Remove all sanding dust with a clean rag, and then use a suitable solvent as described in the previous section.

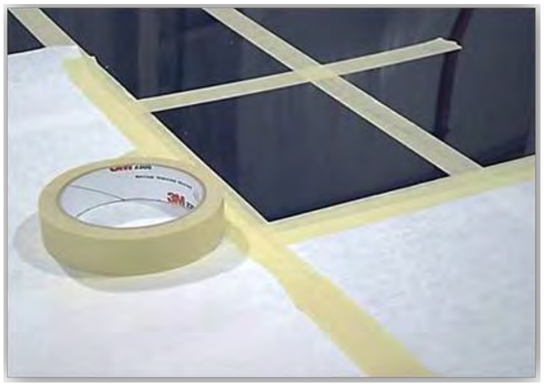


Figure 8-11. The area around the defect is masked off with masking tape.

Figure 8-12. Protected part is ready for spray patch application.

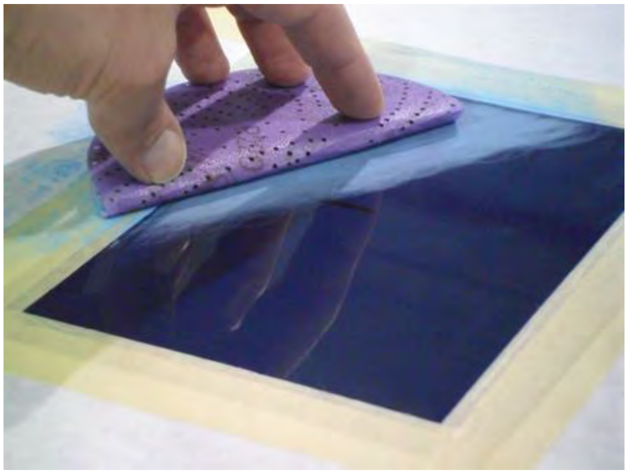


Figure 8-13. The damaged area is being sanded with 220-grit (P220) sandpaper.

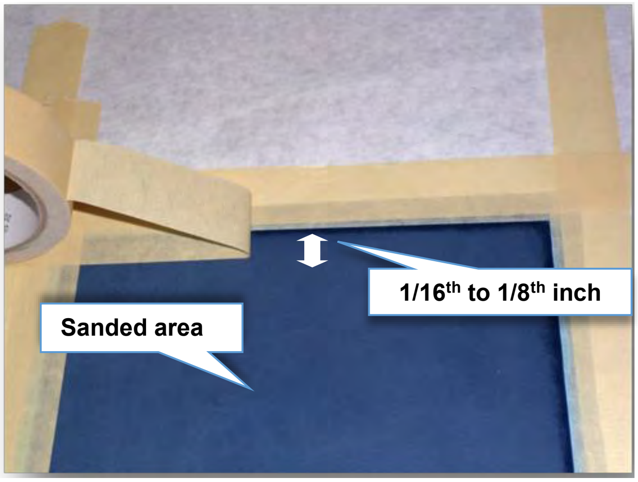


Figure 8-14. Apply making tape inside the prepped area.

When sanding first:

1. Sand the patch area with 220-grit sandpaper by hand (sanding block) and/or with a DA sander (Figure 8-13). Feather the edges, using finer grit (1000-grit) paper in hard-to-match situations. Use clean rags to remove sanding dust.
2. Mask off the area around the defect with tape. Cover surrounding areas to protect the surface from overspray (Figures 8-11 and 8-12). Keep the repair area as small as possible.
3. Place a second layer of tape about 1/16"-⅛" inside the first tape edge (Figure 8-14).
4. Clean the patch area. Remove all sanding dust with a clean rag, and then use a suitable solvent as described in the previous section.

B. Mix and Measure

Use material from the same batch that was used to make the original part (Figure 8-15). Failure to use the same batch will almost certainly result in an off-color patch. Refer to the paragraphs on Helpful Hints in this section.

Figure 8-15. Use same batch or lot number material for repair.

For best color match and weathering considerations, it is best to use a method where the material is used without diluents or additions except catalyst. Polynt does not recommend solvents (acetone, MEK, ethyl acetate, or any of the replacement solvents or cleaners) for diluting gel coat.

Solvents are more flammable and reduce the flash point of the gel coat. Always use high purity solvents.

Use high atomization and do not spray too close to the part, or too quickly. Do not apply too thick.

Retained solvent in the patch will deteriorate patch quality by retarding cure, creating porosity, changing the color, lowering gloss, reducing hardness, and compromising weatherability.

Polynt offers several Patchaid® products (Table 3) for:

- Reducing the viscosity for better spray characteristics and leveling (less orange peel).
- Accelerating patch cure time for quicker sanding.

Table 8-6. Polynt's Patchaid® products

970X900 Speed Patchaid®
Used for reducing viscosity and when repairs need to be sanded quickly. Typically, the patch can be sanded in 45 minutes depending on catalyst, temperatures and air movement.
970X901 Slow Patchaid®
Used to lower the viscosity and when repairs do not need to be sanded quickly, such as mold resurfacing and when initial gel times are already very short. Also, Patchaid® 970X901 is formulated to yield better dilution; therefore, it works better when using aerosol cans or air brushes.
970XJ037 Patchaid®
This is a fast Patchaid® version of 970X901.
3-5% of 8% Wax Solution
Can be used as a diluent. Typically, the patch can be sanded approximately two hours after catalyzation.

When using Patchaid®, use two (2) parts gel coat, one (1) part Patchaid® and catalyze with 2% MEKP.

Example

70 cc gel coat

30 cc Patchaid®

2 cc MEKP

See individual data sheets for mixing and application instructions.

C. Spray - Application

Use a precision touch-up spray gun for spraying the patch (e.g. Binks Model 115).

1. Spray the catalyzed gel coat over the entire sanded and feathered area. Thickness should be approximately 8-12 mils for good cure. If spraying an area where gel coat has been completely removed, thickness must be at least 12 mils for good hide.
2. After spraying, follow-up with a film coat of Patchaid® Spraycure™ 970C961 to seal the open side of the patch and enhance cure (Figure 8-16). Apply while the patch is still wet, within 5-10 minutes of spraying the patch. For an efficient seal, Patchaid® 970C961 must be sprayed as a film rather than a dust coat. Do not flood it on or spray it too thick.

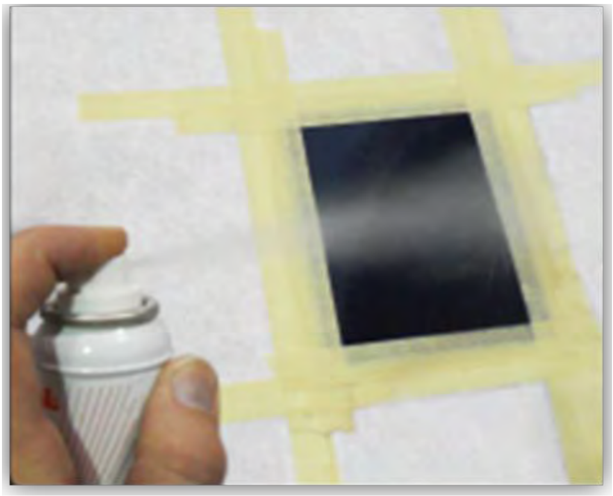


Figure 8-16. Applying a film coat of Patchaid® Spraycure™ 970C961.

3. After the Patchaid® 970C961 has been applied, remove all tape and masking materials.
4. Allow the patch to cure thoroughly. If time allows, the patch should be allowed to cure overnight.

D. Finishing

1. Sand with coarse grit sandpaper, followed by a succession of several finer grit sandpapers. Follow the order of sanding shown below in Figure 8-17. Increase grit number from 400 to 1000-grit sandpaper. Always remove dust/debris between grit sizes.

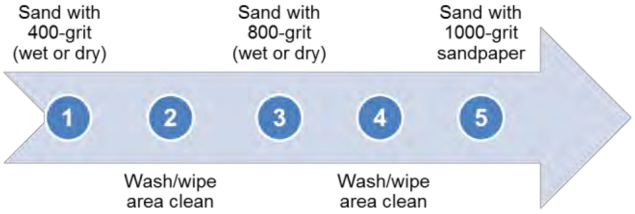


Figure 8-17. Sanding order.

When sanding by hand, sand in one direction per grit size, north/south with 220-grit, then west/east for 320-grit sandpaper. Refer to Figure 8-18. Remove dust between sanding

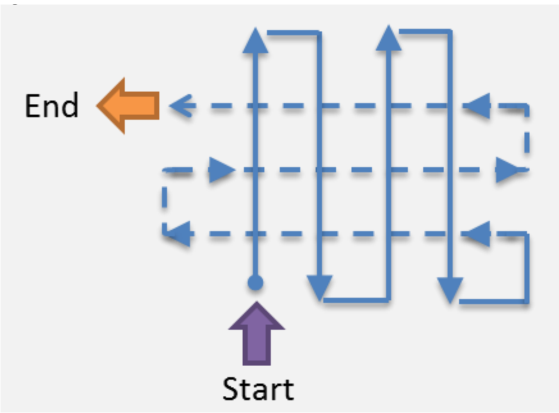
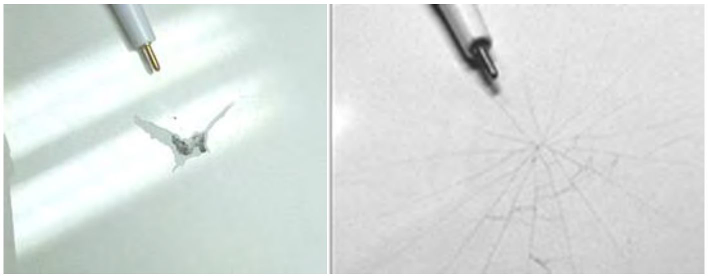


Figure 8-18. This diagram shows the north/south, west/east direction to hand sanding a repair patch.

2. Clean the patch area. Remove all sanding dust with a clean rag, and then use a suitable solvent (described in previous Mix and Measure paragraphs above).
3. Buff with a clean wool pad and rubbing compound, change the pad, wash with soap and water to remove rubbing compound residue, then wax and buff to a high gloss for the final finish. See paragraphs on Finishing Techniques for more detail.

8.5.7. Putty Patch—Holes or Cracks in Gel Coat

Holes or cracks in the gel coat need a putty patch if the defect is deeper than 1/32" but less than 1/16" (Figure 8-19).



Gouge

Crack

Figure 8-19. Defects in gel coat.

The preparation and procedure are the same as those given for minor surface repairs.

- For gouges-Grind out the damaged material and level the patch with 100-grit sandpaper. Make sure to bevel the edges and follow-up with a putty repair.
- For cracks-The total depth of the crack needs to be repaired, not just covered up.

There are two types to putty patching: ‘thick’ gel coat putty and reinforced putty.

- If only a ‘thick’ gel coat is required, use about two percent (2%) fumed silica.
- If reinforcing or strengthening putty is required, use one percent (1%) fumed silica and about 10 percent (10%) of a glass filler such as milled fibers, micro glass, or glass bubbles. Reinforcing putty should be used to resist patch cracking, if the laminate is weak or flexible.

Typically, a putty patch is followed by a spray patch, because air bubbles are entrapped in the patch or there is a slight color change due to the added filler. Follow spray patch application instructions.

8.5.8. Gel Coat and Laminate Repair—Holes, Punctures or Breaks in the Laminate

The following repair method is used for damage that penetrates completely through or deep into the entire laminate (>1/16"). This type of defect requires a laminate and gel coat repair.

A. Repair from the Inside

1. Prepare the affected area by cutting away the fractured portion of the laminate to the structurally sound part of the laminate. A keyhole or saber saw works well to cut away the ragged edges.
2. Roughen up the inside edges of the affected area, using a power grinder. Feather out the backside at least half the diameter of the hole to be patched.
3. Clean the surface and remove all paint or foreign substances as previously described in the paragraphs on Minor Surface Repairs - Spot Patching.
4. Use a template to give ‘shape’ to the part. Tape cellophane in place over a piece of cardboard (or aluminum) large enough to completely cover the affected areas with the cellophane toward the inside of the part. Aluminum is used when contour is present.
5. Cut glass fabric and mat to the shape and size of the hole. Cut another set of reinforcement

material one-half diameter larger than the hole. Materials and total thickness of each set should approximate that of the part being repaired.

6. Thoroughly mix an ample amount of resin (approximately one (1) pint per square foot) and catalyst (6.5 g, ml, or cc). Using the hole-sized set of reinforcement, daub catalyzed resin onto the glass mat to thoroughly wet it out. Wet out the fabric in a similar manner. Apply the mat against the surface inside the hole. Then apply the fabric.
7. Roll or squeegee out all air bubbles. Allow the area to cure well. Build this laminate up to the same thickness or greater than the thickness of the original laminate.
8. Apply catalyzed resin and the larger reinforcement over the hole-patch and the surrounding surface.
9. After the laminate has cured, remove the cellophane and backing from the outside of the hole. Roughen up this surface from outside, feathering the edge with a power grinder.
10. Follow the procedure in paragraphs on Minor Surface Repairs - Spot Patching for gel coat repair.

B. Repair from the outside

1. If it is not possible to access the backside (blind hole) of the part, a template will not be used. Cut a piece of cardboard slightly larger than the hole. Then cut the fiberglass mat and cloth along the same outline as the cardboard insert, only slightly larger. Thread a wire or wires through the center of the cardboard insert; follow with the fiberglass.
2. Roughen up the inside edges of the hole to at least half the diameter of the hole. If a power grinder cannot be used, thoroughly sand by hand with coarse sandpaper.
3. Wet out the fiberglass with catalyzed resin. Force the plug through the hole. (Do not worry about neatness; the first concern is a structurally sound repair.) Use the wire to pull back and secure the plug until the resin cures. When cured, check adhesion of the plug and proceed.
4. Mask the area with tape and paper to protect the surrounding surface. If a large void is present, repeat steps 6 and 7 from the Repair from the Inside procedure. Smaller voids could be patched with putty material.
5. Using 80-grit sandpaper, smooth and blend the surface to be coated into the surrounding surface.
6. Follow steps in Spray Patching paragraphs to repair the gel coat.

8.5.9. Finishing Techniques

A. Sanding

1. First, determine if sanding is necessary to smooth out the defect or patch.
2. If sanding is not needed, buff and wax the surface (see paragraphs on Buffing).

Finishers often stop sanding at 320-grit DA, which is too coarse for the final sanding step before buffing. This leaves sanding scratches on the repair, which require more buffing to remove these scratches.

1. Sanding should begin with 400-grit sandpaper.
2. Gradually increase to finer grit sandpaper such as 600, 800, and then 1000-grit. Each sanding step removes previous grit sanding scratches. For example, 800-grit sanding removes 600-grit sanding scratches. It is highly recommended to sand to the finest possible grit size so that the least amount of buffing is required.

   NOTE: If a coarser type paper is necessary to speed up sanding of the area, work step-by-step, up to 400-grit sandpaper. Follow each grit size sanding with the removal of any loose grit.
   NOTE: If a coarser type paper is necessary to speed up sanding of the area, work step-by-step, up to 400-grit sandpaper. Follow each grit size sanding with the removal of any loose grit.

Example

1. Sand with 220-grit sandpaper.
2. Wipe off dust.
3. Sand with 320-grit sandpaper.
4. Wipe off dust
5. Sand with 400-grit sandpaper.
6. Wipe off dust.

TIP

If a paper coarser than 400-grit is constantly required, review patching techniques to minimize orange peel and/or surface roughness. For fast, better, and more economical patches, do the least amount of work to get a good repair. Wet sand with 600-grit wet/dry paper. Wash off (using water) all loose dust and grit.

B. Buffing

Many finishers use high-speed electric buffers along with coarse buffing compound to remove scratches. High rpm (>3000 revolutions per minute) and too much buffing pressure can cause excessive heat build-up. Buffing should not heat the gel coat to a level greater than 'just warm'. Intense finishing of the gel coat creates comet tails, burns the gel coat, and causes the resin to postcure, producing fiber print-through.

Materials—Buff using a 100% wool pad with a medium grit rubbing compound. Polynt has found that 3M™ Compound and Finishing Material (Figure 8-20) quickly removes 600-grit scratches with the least amount of buffing and residual haze. Use this type of compound or equivalent.


3M™ wool (9") compounding pad

3M™ Compounding Material

Figure 8-20. Recommended buffing materials.

Ideal buffing speeds are from 1800-2400 rpm (with a DA sander). Work only in 2' x 2' square sections at a time.

Safety—Review safety procedures for using DA sanders and power buffers. Be aware that these tools can 'kick out' and spin off particles

Steps

1. Buff with a finishing glaze compound. Work in a 1' x 1' section at a time.
2. Using a separate, pre-wet synthetic pad, buff with a fine finishing glaze such as 3M™ Finesse-It II or equivalent, to remove swirl marks from compounding.
3. Thoroughly wipe the area to remove all traces of finishing glaze and residue.
4. Wash with soap and water before waxing.

Hints

- Always pre-condition a new/clean pad by pre-buffing with compound at low rpm in order to 'wet' the fibers of the pad.
- Do not use excessive buffing pressure. Let the weight of the buffer do the work.
- Use plenty of rubbing compound to lubricate and cool the gel coat surface. As the compound begins to dry out, lighten up on the buffer.
- 'Spur' the buffing pad when it starts to glaze over or change to a new pre-conditioned pad.
- Always keep the buffing pad tilted just slightly to the surface being buffed. Do not tilt the buffer so only the pad edge is being used.
- Wipe or wash off all loose compound and grit.
- Gel coats may leave some 'coloring' on the buffing pad. This is a function of the pigment used, and is not an indication of the degree of cure.

Wax—Always use a UV stabilized, exterior-protective paste wax.

8.5.10. Helpful Hints

A. Speed the Patching Process

To speed up the patching process and for patching in cold working conditions, use heat lamps, heat guns, or space heaters or pre-buff before sanding.

- It is recommended to pre-heat the patched area rather than heating the patch itself.
- Do not heat a repair over 120°F. This will cause distortion.
- The heated area is too hot if you can't hold your hand on the area.

Note: Overheating may cause blistering and poor color matching.

CAUTION: Patching materials are flammable; be careful.

B. Better Match

Spray patches generally match better than spot or putty patches.

C. Colors

Dissimilar colors behave differently in patching. When patching an older part, weathering may have occurred, so a tinting kit may be necessary. You can lightly sand and buff an area to see the true color.

D. Additives

Additional additives to the gel coat may cause a color change.

E. Patch Size

As a general rule, keep any patch as small as possible.

F. Incomplete Cure

If the patch is not cured thoroughly on the surface, wiping with a suitable, fast-evaporating solvent will clean the surface sufficiently to allow sanding without clogging the paper.

WARNING: Acetone and many other fast-evaporating solvents are highly flammable and can be toxic. Information on hazards and appropriate handling practices can be found in product SDS's and other literature.

G. Catalyst (Peroxide)

Check technical literature for the correct catalyst levels on all materials used.

H. Buffing Pressure

Do not use excessive buffing pressure. Excessive pressure creates heat. This heat may cause print-through and distortion. This heat and pressure can actually abrade the cured film of gel coat down to the laminate.

I. Measure Materials

One of the key reasons that patching problems occur is because the gel coat, catalyst and Patchaid® are not being measured accurately. Ideally, they are measured with a scale (by weight) or a graduated cylinder (by volume).

Polynt developed a quick, accurate and inexpensive method for measuring patching materials in the shop, without the continual need for a scale or graduated cylinder. This method involves making two castings of gel coat made from gel coat mixed with 0.5% catalyst. The 0.5% catalyst is used so that the castings don't get too hot and crack. The two casting plugs will be used as a quick way to measure 70:30 gel coat to Patchaid®, by simply marking the cup at the height of each plug.

Materials needed to prepare a 100 g and 30 g casting include:

- ≥ 130 g of gel coat
- Two (2) 5 oz. wax cups
- Appropriate catalyst

The procedure is:

1. Add 0.5% catalyst to gel coat and mix well.
2. Weigh 100 g of catalyzed gel coat into a wax cup (5 oz. cup for ≤100 g plug) and 30 g into a second cup.
3. Set the two cups on a level surface and allow them to cure.
4. Once the castings cool, remove the plugs from the cups (Figure 8-21).

Figure 8-21. 100 g and 30 g plugs.

The next time a patch mix needs to be made:

1. Use the height of the castings to mark two lines on the 5 oz. cup.
2. Fill the cup to the bottom line (30 g plug) with Patchaid® and fill the cup to the top line (100 g plug) with gel coat.
3. Thoroughly mix the gel coat and Patchaid®.
4. Catalyze at 2% for best cure. A 10-cc graduated cylinder should be used to measure catalyst. For a 100 g mix, use two (2) cc (2 ml) of catalyst.

J. Tinting

Sometimes tinting in the field is required, especially when patching weathered, faded parts made several years prior, or, for a one-time small job. Tinting is a skill that requires experience to do a prompt, adequate job. Polynt normally does not recommend tinting in the field, but for those who must, here are a few rules to follow:

- If the part is weathered, buff out the area to be patched to achieve the real color.
- Use only pigment concentrates designed for polyesters.

- Tint at least one-half gallon of gel coat at a time. The smaller the batch, the harder it is to tint.
- Make small additions (‘adds’), mixing well and scraping down the sides of the container between ‘adds’. Subsequent ‘adds’ should get smaller as the color is approached.
- Sometimes it is helpful to test each concentrate with 50 percent white gel coat beforehand, because it is easier to see shades.
- Get the basic color shade first (yellow, blue) then look for the minor differences, such as reddish, greenish, etc.
- If the color match is not close, put a wet spot of the batch on the solid part or next to the wet sample. As the true color approaches, it will be necessary to go to catalyzed spray-outs since some colors change from wet to cured.
- Once color match is reached, record what pigments and amounts were used to get the color in case it has to be matched again.

The approximate effects of adding a particular pigment concentrate are shown in Table 3.

Table 8-7. Effects of adding different pigment concentrates.

COLORANT (1)	PRIMARY COLOR	SECONDARY COLOR
White	Lighter	Chalky in dark colors
Black	Darker	Gray in pastels
Green	Green	Darker
Blue	Blue	Darker
Red	Red	Darker, pink in pastels
Gold Yellow	Yellow	Red

(1) Use only pigment concentrates designed for polyesters.

8.5.11. Troubleshooting Guide

Table 8-8. Troubleshooting Guide

PROBLEM	ITEM TO CHECK
COLOR DOES NOT MATCH	• Wrong batch used for patching • Fillers added • Too many accelerators added • Catalyst level off • Patch undercured • Trapped solvent • Dirty spray gun • Buffer developed too much heat
PATCH IS DULL	• Undercured • Catalyst level off • Low temperature • Sanding too quickly • Trapped solvent • PVA sprayed too wet
COMET TAILS	• Too coarse of sandpaper used on last sanding • Buffing too hard • Dry pad
LOW GLOSS	• Excessive buffing pressure • Coarse compound
SAND MARKS	• Too coarse of sandpaper used in last step; work up through 600-grit wet
RING AROUND PATCH (HALO)	• Edge not feathered • Not sanded properly • Porosity in original gel coat, may have to overspray • Undercured patch • Improper level of Patchaid®
CRACK REAPPEARS	• Crack was not fully ground out • Weak laminate
PATCH IS GLOSSY, PART DULL	• Original gel coat undercured • Buffer developed too much heat • Too much Patchaid®
POROSITY OR VOID IN PATCH	• Not sprayed or leveled properly • Filler not mixed in properly • Trapped solvent • Air not worked out
PATCH IS DEPRESSED/ SHALLOW	• Patch will shrink; allow for this by overfilling. • Do not sand and finish until patch is cured. 'Hot' buffing can cause patch to shrink. • Condition patch by pre-buffing before sanding.

8.5.12. Associated Data

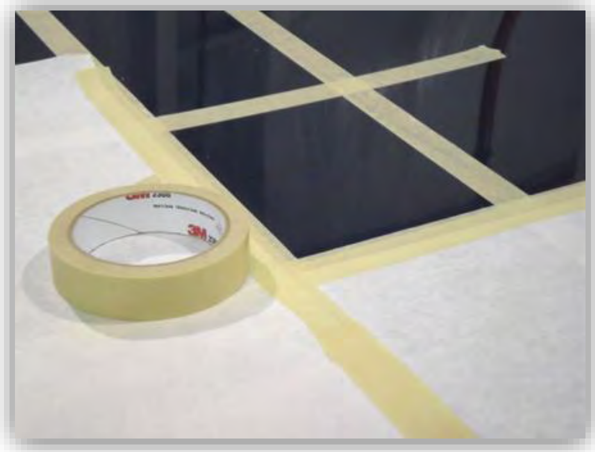
See chapter for Specialty Gel Coats: Metal Flake.

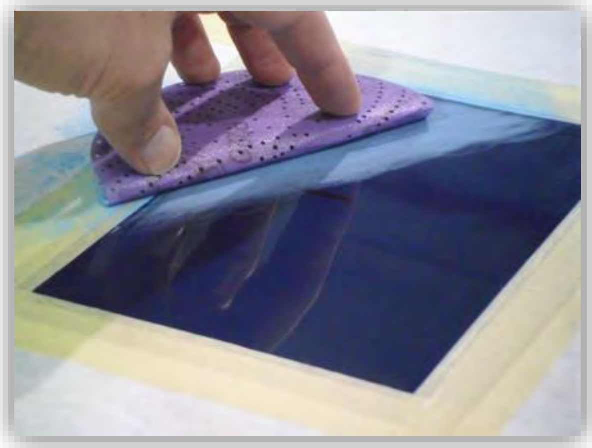
8.5.13. Patching Guide—Wall Chart

SPRAY PATCHING GUIDE	
Average gel coat weight per gallon is 10 pounds. There are 128 fluid ounces in a gallon.	At 10 pounds per gallon, each fluid ounce weighs approximately 35 grams. One cc/ml of catalyst is equal to 1.1 grams. (For shop use, one gram per cc/ml is acceptable.)
For best color match, always use the same batch of gel coat the part was made from.	
Use recommended level of Patchaid® to reduce the gel coat for spray patching	
These patching materials are formulated to:	
#1 - Help the patch spray smooth.	
#2 - Speed cure of the patch.	• For each color, establish a level of patching additive that gives best patching results. • Usually 30% Patchaid® works well. • Make a master mix of gel coat and Patchaid® for patching. The idea is if the mix works for one patch, it should work for all, if catalyzed with the proper amount of catalyst. • Important: The gel coat patching mix must be mixed thoroughly prior to each use. **USE 2% OF APPROVED 9.0% ACTIVE OXYGEN CATALYST**
#3 - Surface cure the patches for ease of sanding.	

1.0 fl. oz. of gel coat patching mix = 35 g; use 0.5 g/cc/ml to catalyze
2.0 fl. oz. of gel coat patching mix = 70 g; use 1.5 g/cc/ml to catalyze
3.0 fl. oz. of gel coat patching mix = 105 g; use 2.0 g/cc/ml to catalyze
4.0 fl. oz. of gel coat patching mix = 140 g; use 3.0 g/cc/ml to catalyze
NOTE: g/cc/ml are rounded to the nearest 0.5 g/cc/ml

PREPARE





MIX

Mix 10 minutes

MEASURE

SPRAY PATCH MIX

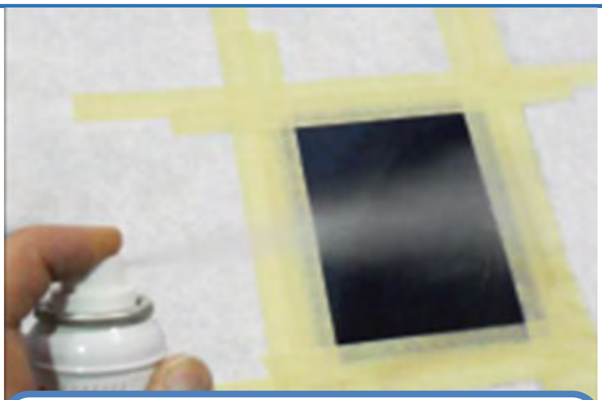
- **2 parts gel coat**
- **1 part PATCHAID®**
- **2% MEKP**

APPLY

Use a good quality touchup spray gun (e.g. 3M, Binks 115)

3M™ Accuspray Model HG09

Binks® Model 115



Patchaid® 970C961 Spraycure™ (wet-on-wet)

FINISH

Sanding discs

Buffing pad

Compound and Finishing Material

*All items shown under 'Finish' are 3M™ products.

9. Low Volume Closed Molding

Overview

- **Introduction**
- **Materials**
- **Preform Constructions**
- **Process Features and Variations**
- **Converting from Open Molding**

9.1. Introduction

Closed molding is a broad category of fabrication processes in which the composite part is produced in a mold cavity formed by the joining of two or more tool pieces.

Examples of closed molding processes include matched metal die molding of sheet molding compound (SMC) and/or bulk molding compound (BMC), resin transfer molding (RTM), vacuum assisted resin transfer molding (VARTM), and vacuum infusion. These processes are generally regarded as higher technology than open-mold processes because they require more planning, and often, more sophisticated and costly equipment. They do offer a number of significant advantages over open molding, including higher production rates, reduced labor, two-sided finish, greater design latitude, and reduced emission of Hazardous Air Pollutants (HAP). Consequently, the interest and usage of closed molding processes is beginning to increase from its current level of about 10 percent of today's UPR market.

Increased awareness of environmental impact on the part of composite fabricators, combined with governmental regulatory pressures, has led to the study and control of two aspects of composites fabrication. First, fabricators are concerned with the rate of HAP emissions. Second, there is concern with the absolute level of overall HAP emitted, which is determined by both the rate of emissions and the production volume. Closed molding processes can be used to reduce emissions as well as increase production relative to open molding.

There are many variations of the closed molding process, each having a unique or distinctive aspect. For the purposes of this technical discussion, these variations are categorized into two types: Resin Transfer Molding and Compression Molding.

Resin Transfer Molding (RTM)

Resin Transfer Molding (RTM) processes are those in which liquid resin is transferred into a closed cavity mold. The reinforcing fiber, any embedded cores, and inserts are placed into the cavity before the resin is introduced. Over time, a number of RTM variations have been developed. Common examples are Conventional Resin Transfer Molding (CRTM), Vacuum Assisted Resin Transfer Molding (VARTM), and Vacuum Infusion (VI). Figure 1 of the Low Volume Closed Molding: Materials section illustrates schematically some features of a typical RTM process.

Compression Molding

Compression molding processes use clamping force during mold closure to flow a pre-manufactured compound throughout the mold cavity. The clamping force is typically delivered to the system by some type of press. Sheet molding compound (SMC), bulk molding compound (BMC), and wet molding compound are examples of pre-manufactured compounds used in compression molding.

9.2. Materials

Overview

- **Introduction**
- **Resins**
- **Reinforcement**
- **Cores**
- **Filler**

9.2.1. Introduction

In general, the materials used in Resin Transfer Molding (RTM) processes are the same as those used in ordinary open molding, with the most significant differences in reinforcement technology. The process production rate determines many of the requirements for materials. Higher production rates require the use of premade reinforcement preforms and resins with short gel and cure times. Lower production rates use materials that more closely resemble typical open mold material systems.

9.2.2. Resins

All varieties of polyester and vinyl ester polymers are used in the RTM process. Polymer choice depends on end use. Most are formulated as low viscosity, non-thixotropic resins. Ideal viscosities range from 50-150 centipoise before adding any filler. Cure properties depend strongly on cycle times and can be adjusted either by the resin manufacturer or by the molder. Adjustments to gel time, cure time, and peak exotherm can be made by adding promoters, co-promoters, and inhibitors. These adjustments are not a trivial matter because they require very accurate measurements. In addition, some materials are toxic. Many molders prefer to buy pre-promoted, ready-to-use resins.

Resin gel times must be long enough for the mold to fill before gelation, and short enough to meet production rate goals. For high production rates of small parts, fill times are less than a minute, gel times are 2 to 3 minutes, and cycle times are less than 15 minutes. Exotherm control is very important for such rapid processes in order to maximize mold life. Molds can have provisions for cooling to remove exotherm heat. For large parts, fill times can approach 45 minutes, with gelation at 90 minutes, and at least overnight cure.

Selection of peroxide initiators depends on the production rate. Various MEKP initiators are common. In some cases, different peroxide initiators are preferred. When a quicker gel and cure time are desired, acetyl acetone peroxide (such as 2,4-pentanedione peroxide) is used. To extend the gel time, blends of MEKP and cumene hydroperoxide or blends of acetyl acetone peroxide and cumene hydroperoxide are used.

9.2.3. Reinforcement

Glass fiber is a typical type of reinforcement. It is available by pattern cutting roll goods or preform fabrication.

A preform is a construction of glass fiber that has been shaped to fit into the mold cavity. A preform can lower cycle times two ways: first, the preform fabrication time is not a part of cycle time; second, the preform construction is easily placed into the mold. Glass forms that are not shaped to fit the mold require more care when they are placed in the mold. Preform fabrication can utilize either roving and conventional glass forms or conformable constructions. For a more complete discussion of preform technology, see Section 9.3 in this chapter on Preform Constructions.

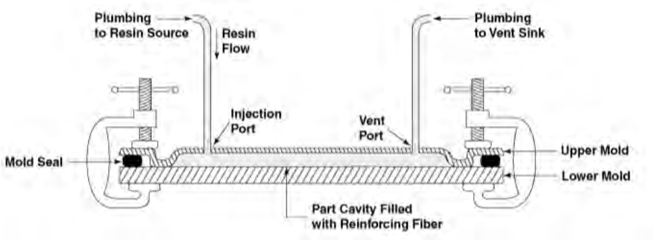


Figure 9-1. In a typical RTM process, resin is transferred to a mold cavity that contains dry fiber reinforcement.

In closed molding, continuous filament mat (CFM) is used instead of the chopped strand mat (CSM) commonly used in open molding. CFM will conform to the mold shape more reliably than CSM, which also has a tendency to tear and wash in the resin flow, leaving unreinforced areas. Special constructions have been developed specifically to improve conformability by using special knits. Other constructions provide a sandwich style laminate with a low density core fiber and glass skins on either side.

CFM is a non-woven mat of continuous fiber that generally contains some binder. CFM is very lofty (much thicker for the same weight until compressed) compared to CSM. Weights for this glass form use the units of ounces per square foot (osf). Typical weights are 1.5 osf and 2.0 osf.

Cored glass constructions are available under a variety of trademark names. They share a common architecture by having three distinct layers. The outermost skin layers are glass fiber, while the inner layer is a polymer fiber. The cored construction adds considerably to bending stiffness without adding the weight of additional glass. This is because the polymer fiber core material is much less dense than the glass fiber and because bending stiffness increases greatly with an increase in thickness. Stitched molding mat (SMM), a product of Owens Corning®, and Rovicore™, a product of Chomarat, are examples of core mats with skin weights varying from 1.5-2.0 ounces of glass and from 5-7 ounces of core.

CSM is generally not used by itself in pressure injection processes. This material is held together with a binder that is soluble in styrene. When used alone in a pressure injection process, the material has a tendency to wash and leave un-reinforced areas. During mold closure, the material also can tear easily. For these reasons, other mats are more frequently selected. CSM is relatively inexpensive and added locally to increase glass skin thickness, but generally in combination with CFM or stitched mat (SM). The weights for this glass form use the units of ounces per square foot (osf), with typical weights ranging from 0.75-3 osf.

Stitched mat (SM) is a special chopped strand mat that is produced without any chemical binders. The strands are held together mechanically with a polymer stitch yarn. This mat is available in weights ranging from 1-4 osf. This mat is considerably more conformable than ordinary CSM.

Surfacing veil (SV) is a non-woven mat of either glass or polymer fibers. These materials range between 3-40 mils thick. They provide a resin-rich layer adjacent to the part surface. This improves both cosmetic appearance and corrosion resistance. Reduced fiber blooming after sanding is another benefit.

9.2.4. Cores

There are a variety of reasons for molding cores into the laminate. Some provide section thickness (therefore bending stiffness) without adding a lot of weight. Others provide hard points for locating screw or bolt installations. Cores can range from plywood to a PolyVinyl Chloride (PVC) foam or urethane foam-filled honeycomb. There is a large variety of embedded materials in common use. Even strips of metal have been sandwiched between fiber layers.

Some cores are not compatible with the liquid injection process because they will simply fill up with resin and add too much weight. One example is open cell honeycomb.

9.2.5. Filler

Some resins are designed for use in filled systems in which fillers are used to replace some resin, resulting in both cost savings and improved cosmetic appearance. The peak exotherm temperature is also lowered which, as an added benefit, contributes to long mold life. Calcium carbonate, calcium sulfate and aluminum trihydrate are commonly used. Filler use increases both the resin viscosity and the finished part weight and commonly varies from 15-45% by weight. In general, the filler size is in the 6-10 micron range to keep the glass pack from filtering the filler. A nominal 8 micron particle size is commonly used. Finer filler, as low as 3 micron, is also used.

9.3. Preform Constructions

Overview

- **Introduction**
- **Preforming Process Description**
- **Characteristics of the Various Binders**

9.3.1. Introduction

The preforming process can vary from fairly simple to rather complex. Briefly, this process consists of the manufacture of a reinforcing mat, which has the shape of the part to be molded. This process accommodates molding those parts that have complex shapes, deep draws, and sharp radii, which are not easily moldable with commercial flat reinforcing mats. Because of the uniform distribution of the fibers, parts made using preforms generally have higher physical properties compared to parts made by other processes. Preforms are traditionally used in the compression wet molding process but are also very useful in other processes such as cold press molding, resin transfer molding (RTM), structural reaction injection molding (SRIM), and vacuum infusion (VI).

Preforms are usually made of chopped fiber glass roving strands or fiber glass mat reinforcement. However, the reinforcing fibers may be glass, carbon, graphite, aramid, or other polymers. Preforms are made in a separate step and delivered to the mold as needed, allowing for more efficient use of resources.

Polymeric binders are used during the manufacture of preforms. A binder is a bonding resin applied to the reinforcing fibers to hold them in position so that shapes are maintained as needed for even fiber distribution in a mold.

Binders are available in various forms, including aqueous emulsions, aqueous solutions, 100% reactive liquids, solvent solutions, and reactive powders. Thermosetting binders usually cure or set up through polymerization caused by the action of heat on peroxide initiators and/or melamine cross-linking agents. Some binders are designed to cure by UV or visible light energy. Preferred binders also have reactive sites that can form a chemical bond with both the fiberglass reinforcement and the matrix resin, thus producing composites with superior mechanical properties.

9.3.2. Preforming Process Description

Three main methods are used in making preforms. These are:

- Directed fiber
- Thermoformable mat
- Conformable reinforcement

Some of the characteristics of each of these three processes follow.

Directed Fiber Preforming

When this method is employed, chopped fiber roving (along with binder) is sprayed onto a screen made in the shape of the part to be molded. A vacuum is drawn from the back side of the screen. This holds the fiber/binder in place. The screen, still under vacuum, is then placed in a high-volume, forced-air oven where the water or other carrier solvent(s) are removed and the binder is cured. The cure/bake cycle is generally 350-400°F (177-209°C) for one to five minutes. With some binders, lower temperatures can be used; however, if they are aqueous based, lower temperatures require increased time for water removal. Directed fiber preform binders are usually in liquid form, but solid powdered binders have also been used.

A variation of this method is the use of a string binder. In this variation, some strands of the roving are precoated with a binder resin that is either a high melting point thermoplastic or a thermosetting resin that is solid at room temperature and cures at elevated temperature. Like the standard directed fiber method just described, the roving is chopped onto a screen, but without the need for a liquid binder spray. It is then baked as described before. In a variation of string binder, a thermoplastic strand is chopped along with standard fiber glass roving. When indexed into an oven, it partly melts and adheres to the glass strands it bridges.

Some comments on directed fiber preforming are:

- Best method to obtain uniform glass distribution and excellent part definition over complicated, three-dimensional shapes.
- Molded parts are stronger than those made by SMC/BMC at the same reinforcement content.
- Lowest cost method of preforming.
- Poorest in housekeeping requirements.

Thermoformable Mat Preforming

With this method, a fiber mat is made with or treated with a thermoplastic binder. The mat is heated, usually in an oven, and then placed in a cold mold made in the shape of the part. The mat is pressed to conform to the mold. After cooling, the mat retains the shape of the part. Comments on this method are:

- Fewer housekeeping problems compared to directed fiber method.
- Lower energy requirements than directed fiber method.
- Not recommended for making complex, deep draw parts.
- More expensive than directed fiber method because of the higher cost of using mat and because of cutting waste of mat.

Conformable Reinforcement Preforming

With this method, a mat made of chopped fibers is placed on the mold. It can be easily made to conform to the shape of the part to be molded. One can cut the mat to the general shape of the mold, place it in the mold, and then press on it to conform it to the shape of the mold.

Comments on this method are:

- Relatively clean, easy-to-use method of glass placement.
- Some mats are more filamentized than conventional reinforcing mats, restricting flow through them.
- May result in areas of low/no reinforcement in parts with deep draws.
- Much more expensive than other methods of preforming materials.
- Low or no capital investment to make preforms.
- Good material to add to other preforms to increase glass content in resin rich areas.

9.3.3. Characteristics of the Various Binders

Each type of binder has its advantages and disadvantages, and is briefly described in Table 9-1.

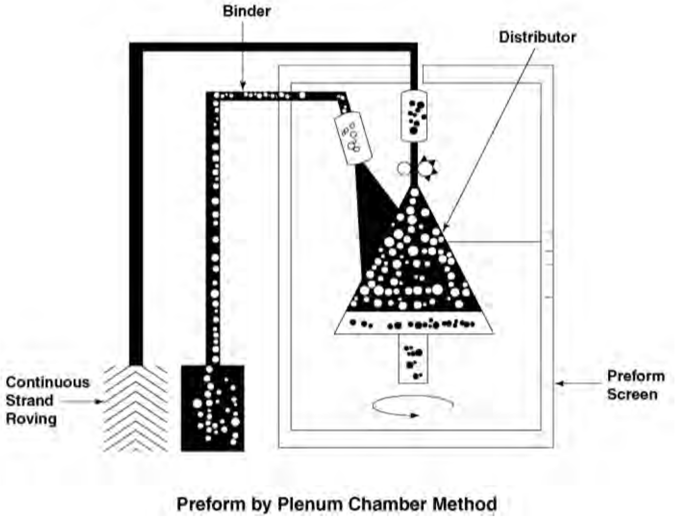


Figure 9-2. Preform by Plenum Chamber method.

Table 9-1. Binder characteristics.

Binder Characteristics		
Binder Type	**Advantages**	**Disadvantages**
Aqueous emulsion binders	• No VOCs • Excellent preform stability • Thermosetting/rapid cure • Good glass compaction with good flow-through properties • Chemically bonds to matrix resins and to glass • Excellent part moldability	• Energy needed to remove water
Aqueous solution binders	• Low or no VOCs • Thermosetting/rapid cure • Good glass compaction with good flow-through properties	• May contain formaldehyde • Energy needed to remove water • May be pH dependent
100% reactive powder	• Precatalyzed • No VOCs • Fast cycle time • No water/solvent removal • Lower energy required	• Housekeeping problems (dusty)
String binder	• No solvent removal • Fast cure • Lower energy required	• Requires very high suction or double screen for compaction • Emerging technology; expensive

9.4. Process Features and Variations

Overview

- **Process Features**
- **Variations**
- **Troubleshooting**

9.4.1. Process Features

To facilitate understanding and communication when discussing the various RTM process variations, a process description and naming convention is presented in this section. All resin transfer molding processes can be characterized by five basic process features:

- Resin pressure head
- Resin transfer scheme
- Upper mold type
- Mold clamping method
- Mold open-close method

For each of these process features, there are at least four variations that are commonly used. These variations are presented in Table 1, followed by a basic description of each feature variation, examples of commonly known variations, and finally, a detailed description of each feature.

Table 9-2. Common variations used in RTM process features

Resin Pressure Head	Resin Transfer Scheme	Upper Mold Type	Mold Clamping Method	Mold Open-Close Method
Pressure to Pressure	Discrete Port	Rigidized Laminate	Vacuum Clamps	Hand Lift
Pressure to Atmosphere	Edge Manifold	Shell Laminate	Mechanical Clamps	Mechanical Hoist
Pressure to Vacuum	Inter-laminar Manifold	Silicone Multi-use	Pneumatic Clamps	Pneumatic Actuators
Atmosphere to Vacuum	Face Manifold	Bag Film, Single Use	Hydraulic Clamps	Hydraulic Actuators
Vacuum to Vacuum	—	—	—	—

Resin Pressure Head

The first and most significant feature, this is the state of pressure across the resin from injection point to vent point. It is the driving force that causes the resin to flow through and saturate the fiber pack. The resin pressure head is described by first stating the condition at the injection location and then stating the condition at the vent location. The variations are:

- Pressure to Pressure
- Pressure to Atmosphere
- Pressure to Vacuum
- Atmosphere to Vacuum
- Vacuum to Vacuum

These scenarios form the basis for the differences between the common definitions for vacuum-assisted resin transfer molding (VARTM), resin transfer molding (RTM), and vacuum infusion processing (VIP), among others.

Resin Transfer Scheme

This describes the plumbing pathway used to transfer the resin into the fiber pack. The pathways are:

- **Discrete Port Injection**-The resin is introduced at specific points called ports or injectors.
- **Edge Manifold**-A channel along the part edge (or entire perimeter) provides the resin pathway into the fiber pack.
- **Interlaminar Manifold**-A layer of high-permeability material is placed midway through the laminate thickness.
- **Face Manifold**-The resin is introduced below or (usually) above the fiber pack using some form of resin distribution manifold. Often, this resin distribution manifold is nothing more than ordinary bubble wrap packing material.

Upper Mold Type

This describes the materials and construction used for the mating mold. The terms ‘upper’ and ‘lower’ are used to describe the mold halves, due to the fact that gravity acts vertically, and gravity is most often used to assist in separating mold halves.

Variations for the upper mold type are:

- **Rigidized Laminate**-The conventional RTM mold type.
- **Shell Laminate**-A thin glass reinforced laminate.
- **Multi-Use Silicone**-Otherwise known as a silicone vacuum bag.

- **Bag Film Single Use**-A vacuum bag constructed from rolls of vacuum bag film.

Mold Clamping Method

This describes the means for holding mold pieces together. Variations are:

- Vacuum clamps
- Mechanical clamps
- Pneumatic clamps
- Hydraulic clamps

These variations have a significant impact on cycle time and each have different cost requirements.

Mold Open-Close Method

This describes the method for separating mold pieces to allow inserting the dry glass and removing the finished part. Variations are:

- Hand lift
- Mechanical hoist
- Pneumatic actuators
- Hydraulic actuators.

These variations also affect the cycle time for molding and have varying costs.

9.4.2. Variations

Resin Pressure Head

The Resin Pressure Head is the state of pressure across the resin from the point of injection to the vent location. This pressure drop causes the resin to flow through the fiber pack. At some point in the mold cavity's boundary, the resin enters the mold through the injection port. As the mold fills, the resin displaces the air. This air escapes through a vent called the vent port. The resin pressure head is the difference in pressure between these two points.

At the injection port, when resin pressure is higher than normal atmospheric pressure, the injection is under pressure. When resin pressure is normal atmospheric pressure, the injection is under atmospheric pressure. At the vent port, when resin pressure is normal atmospheric, venting is to atmospheric pressure. When resin pressure is lower than normal atmospheric pressure, venting is to vacuum.

The resin pressure head is described by identifying the condition at the injection location and then describing the condition at the vent location. As outlined previously in Resin Transfer Scheme, there are five combinations that are used in RTM:

- Pressure to Pressure
- Pressure to Atmosphere
- Pressure to Vacuum
- Atmosphere to Vacuum
- Vacuum to Vacuum

Conventional RTM uses Pressure to Atmosphere. VARTM uses Pressure to Vacuum. Vacuum Infusion uses Atmosphere to Vacuum. These are significant differences that greatly impact the remainder of the process features and variables. Figures 1-3 illustrate the Pressure to Vacuum, Pressure to Atmosphere and Atmosphere to Vacuum resin pressure heads.

In the Pressure to Vacuum or Atmosphere to Vacuum or Vacuum to Vacuum processes, the vent port must be attached to a resin trap of some sort. Otherwise, the resin will enter the vacuum system and plug it up.

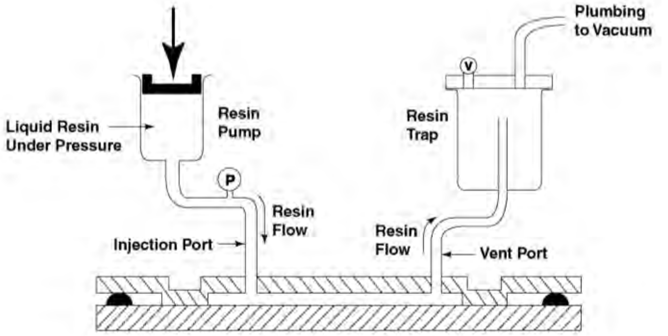


Figure 9-3. For the Pressure to Vacuum Head, a pump supplies the injection part with resin under pressure and a vacuum is applied to the vent part.

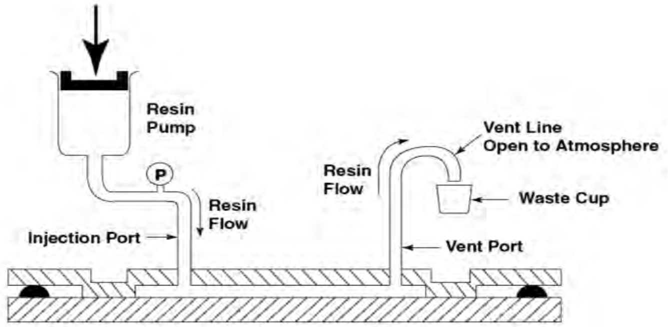


Figure 9-4. For the Pressure to Atmosphere Head, a pump supplies pressurized resin to the injection part and the vent part is open to the atmosphere.

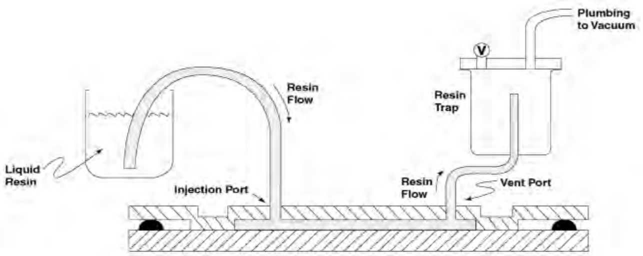


Figure 9-5. For the Atmosphere to Vacuum Head, a vacuum source applied to the vent part draws the resin from an unpressurized container through the injection port and into the part.

The Resin Transfer Scheme

It is very important to consider the molding process at the very beginning of part design. The part must be designed not only to be the part, but also to be successfully molded. This is necessary to ensure that the fiber pack creation and mold filling processes are economically viable.

In all variations of resin transfer molding, the objective is to transfer the resin into the fiber pack. Pressure forces must be generated in some fashion to drive the resin throughout the part. Once there is pressure on the resin, it will flow. The resin will prefer to follow the path of least resistance. The position of the resin as it advances into an unfilled area is called the resin flow front. This flow front moves throughout the mold until the mold is completely filled. The control and management of this resin flow front is at the center of the RTM process. The sections that follow discuss flow in general terms and the various types of resin transfer schemes.

A. **General Considerations to Controlling Flow**—The glass within the mold cavity is compressed somewhat by the mold. The more the glass is compressed, the more resistance there is to resin flowing through it. The less the glass is compressed, the less resistance there is to resin flowing through it. The ability of the resin to flow through a fiber pack is called its permeability. The easier it is for resin to flow, the more permeable the fiber pack is.

   There are two main resin flow situations: diverging flow and converging flow. Diverging flow starts at a point or area and the resin flow front goes outward until it meets some boundary condition. One example of diverging flow is when there is only one port, Discrete Port Injection (Figure 4).

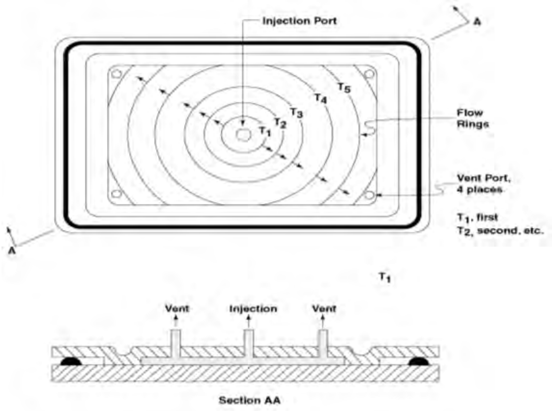


Figure 9-6. In diverging flow, resin enters the mold cavity at a point and flows outward. Here, Discrete Port Injection is used.

Converging flow starts at several points or around the perimeter. The multiple resin fronts meet (converge upon) each other. Examples of converging flow are:

- Edge Manifold method-The manifold spans either opposite sides or the entire perimeter (Figure 5).
- Discrete Port Injection-There are two or more injection ports.

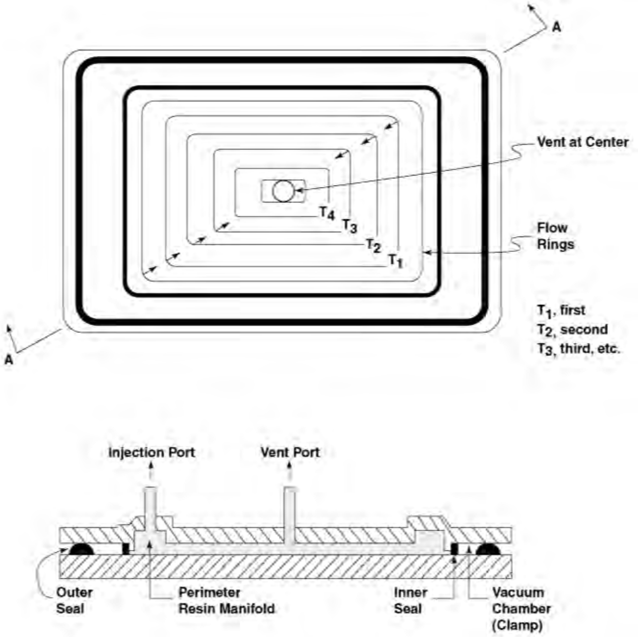


Figure 9-7. In converging flow, resin enters the mold cavity at a point and flows to a single point. Here, an Edge Manifold supplies resin to the entire perimeter.

If the fiber flow front gets out of control, it gets ahead of itself, and closes upon itself, sealing in a dry spot. To avoid dry spots, one must determine where the resin front is getting ahead of itself, and then slow it down in these areas or speed it up in other areas. These strategic areas are located by producing a series of parts with short shots of resin, so that the parts are filled to varying degrees. Like a time-lapse camera, this set of specimens will clearly show where the resin is travelling too quickly and too slowly.

Sometimes a dry spot can be percolated out of the part. This is accomplished by allowing resin to continue to flow out the vent port. Depending on where the dry spot is in relation to the vent, a considerable amount of resin may need to be released. If the dry spot occurs in a consistent place, adding a vent port at the center of the dry spot will let the air out and allow the dry spot to fill.

Special cases can be constructed when there are mixtures of the two types of flow. Generally, this should be avoided by carefully considering the fill process before the upper mold is designed and built. In terms of broad generalizations, diverging flow vents to the perimeter and converging flow vents in the center of the part.

For the converging flow, the flow fronts probably don't converge right at the vent location. So, the vent must be kept open until all the air works its way out of the part. For this reason, converging flow may waste more resin. The amount wasted depends strongly on the management of the resin flow front.

Special attention must be paid to the distance that the resin flow front must move.

- If one path is farther, it will take more time to get there.
- If there is an open channel pathway, the resin will prefer to follow that channel.
- If the fiber pack is less permeable, the resin flow front will move more quickly.
- If there is a vent to atmosphere or vacuum draw to an area, the flow front will tend to flow toward the draw more quickly.

These are the fundamental principles of resin flow front management. Trial and error usually produces an arrangement that fills properly.

B. **Discrete Port Injection**—The resin enters the part cavity at a specific point called a discrete port. The injection port is plumbed directly into the part cavity. Usually, only one port is preferred. This method always uses a diverging flow front; any converging flow fronts will seal in a dry spot. It is best to vent at the farthest reaches of the perimeter. The reinforcement is placed in the mold. The mold halves are closed. Resin is injected until it fills the fiber pack and flows out of the vents. As the resin reaches each vent, that vent tube is sealed off. Once the last vent is sealed, the injection tube is sealed off. An example of discrete port injection with a diverging flow field can be found in Figure 4.

C. **Edge Manifold Injection**—A resin injection channel along the part edge characterizes the Edge Manifold Injection process. The reinforcement is loaded and the mold halves closed. The resin is plumbed to the channel through the injection port. Since the channel is an open space, resin prefers to flow down the channel rather than flowing into the fiber pack. Once the channel fills, if not earlier, flow into the fiber pack begins. When the manifold follows only a small portion of the perimeter, the flow is diverging and venting is performed on the far sides of the part. When the manifold runs completely around the perimeter, the flow is converging and the vent is positioned at the flow center of the part. If the flow fronts do not converge simultaneously at the vent location, resin flow is continued until any air bubbles work their way out. This adds to resin waste. An example of edge manifold injection with a converging flow field can be found in Figure 5.

D. **Face Manifold Injection**—The Upper Mold contains numerous resin channels. This can be as simple as bubble wrap packing material under a single-use vacuum bag or as complex as a Laminate Rigid Upper Mold with resin channels molded in. The resin is plumbed to these channels through the injection port. The resin prefers to flow down the channels rather than flowing into the fiber pack because empty space is more permeable than a compressed fiber pack. Once the channels are full, the resin saturates the fiber pack. A peel ply may be necessary on the top of the laminate if the resin ridges that remain on the part due to the manifold pathways must be removed. Usually, multiple perimeter vents are used for the resin. A good perimeter vent is necessary to vent the air as the fiber pack is wet out.

E. **Flow with Rigidized Laminate Upper Mold**—For this variation, the mold cavity is discretely the same every time the molds are closed. If one were to add an extra layer of glass, it would be squeezed down to the same height as the glass pack with one less layer. Since the amount that the glass is compressed affects its permeability, this affects the resin flow front. For this reason, it is very important to have good dimensional accuracy in the mold cavity thickness. Large variations in the cavity can cause the fiber flow front to behave erratically.

   Glass compression and the resulting loss of permeability may also be used to control the flow front. An extra layer in strategic locations will slow the front. Similarly, one less layer will speed the front.

F. **Other Features**—A visual method for determining when the mold is full involves using witness holes. A polyethylene tube through a fitting into the mold is often used. When the resin fills the tube, that vent is closed. This is repeated until all vents are closed, injection halted, and the injection tube closed. Simple clamps can be used to pinch the hoses. Bending the hose and sticking the bent end into a large washer is an economical method for sealing the port. When the polyethylene hose does not go entirely through the injector or vent fitting, one must drill out the cured resin before the next part is made.

   Permanently mounted thermocouples can be used to monitor part exotherm. This information can be used by the operator to determine the demold point. Generally, the part is not removed before the peak exotherm temperature is reached. The demold point strongly depends on the production rate and the part requirements. Surface profile is compromised by rapid demold because the part is still curing and shrinking. When the resin is curing and shrinking without being in contact with the mold surface, the lack of support results in more fiber print and profile.

   Dielectric sensors can be used to monitor resin flow and cure. The simplest dielectric sensors will measure at only one point, such as a resin trap at a vent location. These sensors can provide the signals to close the vent valves automatically, alert the operator to gelation and indicate the approximate part demold time. This can greatly reduce the likelihood for operator error.

   When a series of dielectric sensors are used, a computer model displayed on a screen can show, with color changes, the mold fill process and cure event throughout the part. Since it can take a bit of time to fill a mold, and the resin cure starts at catalyzation, the computer controller can even increase the catalyst level slightly toward the end of the fill process so that the entire part cures more simultaneously. This can decrease the cycle time for large parts.

Tooling

For the purposes of this discussion, a closed mold set contains the following items:

- Lower Mold
- Upper Mold

The terms Upper and Lower are used to describe the mold halves. Generally this is because gravity acts vertically, and gravity is most often used to assist in separating mold halves. Although many prefer to consider molds male or female, many molds have elements that are in some areas male and other areas female. In addition, it is possible to have either one as the upper or lower. Therefore, upper and lower mold halves are the more general description. While there may be more than two physical tooling pieces, these pieces incorporate all of the following features:

- **Part Cavity**-The physical space between the upper and lower molds in which the part is produced.
- **Mating Flange**-The portion of the lower and upper molds which come into contact with each other when the mold is assembled.
- **Flange Seal**- A rubber extrusion placed in a special recess between the mating flanges; sometimes omitted. Some compression of the rubber seal is produced by the mating flanges when the mold pieces are assembled.
- **Injection Port**-The location in the resin plumbing where the resin enters the assembled upper and lower mold set.
- **Vent Port**-The location in the boundary for the part cavity where air escapes when the resin is being transferred to the glass pack.
- **Alignment Device**-The mechanism for aligning the upper and lower molds; sometimes not present; sometimes accomplished with the part shape itself.

Particular requirements for the molds depend largely upon the pressures that are generated during the molding process. For laminate molds, all of the ordinary requirements for open mold polyester tooling apply. There are, however, additional requirements for molds that are subject to either injection pressures or large closing forces. In general, the processes that generate large resin pressures require a robust framing system and a high grade polyester or vinyl ester resin and gel coat. For higher temperature processes, epoxy resins and vinyl ester gel coats are preferred. Upper molds also have special requirements that are not described in the chapter on Polyester Tooling. These special requirements will be described in the sections that follow.

When Shell and Rigidized Laminate type upper molds are used, special consideration must be given to orient the pattern to provide a mold parting flange that is both flat and horizontal (or very nearly so). This allows the mold to release from the part by separating due to a true vertical motion. If the parting flange is not in a single plane, or not very close to a single horizontal plane, great difficulties in sealing the mold will be encountered during mold closure. This is because the mold seal rubber is dragged along the non-horizontal mating flanges as the flanges come together in a vertical motion. This will most likely result in two things: a leaky mold that is a housekeeping challenge; and a mold that produces unfilled parts. Certain rubber sealed extrusions will be more tolerant of non-flat flange geometries.

Sometimes, the part boundary is extended so that the mating flange is more nearly flat and horizontal. The extended portion is trimmed during post-mold finishing operations.

A. **Lower Mold**—The Lower Mold construction falls into one of the following three categories:

   - Lower Mold Conventional
   - Lower Mold Conventional with a Wide Flange
   - Lower Mold Robust

   When the upper mold is the Bag Film, Single-Use mold, the lower mold is a conventional open mold with a conventional flange. For both the upper mold Shell Laminate and Elastomer Multi-Use processes, the lower mold is a conventional open mold with a wide flange to accommodate sealing the upper mold to the lower mold. Flange details will be covered in the sections that describe the associated upper molds. The third category, Lower Mold Robust, is discussed below.

B. **Lower Mold Robust**—There are a few cases in which the resin pressures are considerable. When this is the case, the lower mold must be robust to resist these pressures without excessive deflection and subsequent fracture. When the RTM process uses pressure to fill the mold and when the upper mold is a Rigidized Laminate, the lower mold must be robust. This is the conventional RTM mold design.

   Another case where significant resin pressures are generated is when resin is hand applied and hydraulic clamps close the mold, causing the resin to flow throughout the fiber pack. This is the conventional wet mold. (See chapter on Compression Molding.)

   The flange is typically four to five inches wide. It must be wide enough to accommodate both a primary and secondary seal, as well as resin traps at the locations of the vents, but narrow enough to resist excess deflections. The resin traps allow some amount of air to percolate out after the resin first reaches it and before the vent must be closed. It is very important to clearly establish the filling, venting, alignment, and clamping issues prior to the start of lamination. See associated sections for more information.

   The gel coat is either polyester or vinyl ester and the laminating resin is either a high grade polyester or a vinyl ester. If a polyester gel coat is used with a vinyl ester or epoxy laminating resin, a special adhesion coat should be applied. A surfacing veil, generally 10 mils thick, is placed in the tooling gel coat when it reaches the tack stage and brush laminated to a low glass content (10-20%), while carefully avoiding entrapped air. Entrapped air must be removed and the veil replaced in a second lamination stage. The skin coat is typically one layer of 1.5 osf CSM at 35+ weight percent glass. The laminate is as much as 12 osf CSM at 35+ weight percent glass and two laminated layers of 1.5 osf CSM in each lamination step.

   The framing is very robust. The particular frame design depends on the means of clamping. Individual hydraulic cylinder and mechanical clamps, either screws or toggle style, require the most robust frame. This is because clamping forces are localized only at the clamp location. Mold frames for pneumatic clamps or a hydraulic platen press can be somewhat lighter since the clamping force is more evenly distributed across the frame. However, these frames must have planar and parallel contact surfaces to be used successfully in a press. If they don't, the press forces will crush sections of the mold. For additional press mold requirements, see the paragraphs on Pneumatic Clamps.

The frame is built about ¼"-¾" offset from the mold using 2"x4", 2"x2", 1"x2", and ½"x2" square tubular steel with typically 0.063"-0.125" wall thickness. The mold panel size between framing members is generally no larger than 4"x6" to 6"x8". The frame is tacked together and then removed from the mold for final welding. In a properly constructed frame, all the steel elements are carefully fitted and welded on all sides. End caps are placed over all open ends.

The completed frame is fitted onto the mold, filling the gap between the frame and the mold with a bedding mixture of resin and either glass or ceramic microspheres. Before doing this, the mold is covered with release film. This allows the bedding mixture to bond to the steel frame but not to the mold laminate.

The steel frame should be thoroughly cleaned on the contact surfaces, and a brush coat of resin should be applied before installation. This will help the steel bond to the bedding mixture.

After cure, the assembly of frame and bedding mixture is removed. Grinding on the edges of the bedding mixture provides a neater, cleaner appearance. Finally, silicone sealant is applied to the bedding material contact surface, and the frame assembly is installed permanently on the mold.

C. **Tooling, Upper Mold Type**—The upper mold can take many forms, depending on the particular process. Most closed mold sets use a silicone rubber seal for process reasons related to mold filling and housekeeping purposes. Resin leaks, drips, and puddles during the mold fill process should be avoided through mold design features. This is important because once the resin has cured, a chisel and hammer is often used to clean off the resin debris. There is no greater threat to a mold's long and productive life than a hammer and chisel.

Any place that is likely to collect resin should be coated with a layer of silicone, about ¼" thick. This will allow the molder to pry out the cured resin rather than using a grinder or chisel.

Many upper molds have two seals, inner and outer. In some cases, this is a primary and a backup seal. With some separation between the seals, a vacuum chamber can be made around the part perimeter. This chamber can have two functions: providing the mold clamping force in Vacuum Clamping processes; and porting vacuum to the part perimeter in Pressure to Vacuum or Vacuum to Vacuum processes. These vacuum ports can be point vents, made by placing a vacuum venting material through the inner seal. Or, the entire perimeter can be vented by careful design and construction of the pinch-off area.

D. **Creating the Mold Cavity**—The upper mold is usually constructed using the lower mold as a platform. There are various cavities that will exist between the upper and lower molds. To produce these cavities, two major methods can be used.

For the upper mold, Rigidized Laminate incurs considerable cost during construction of the upper mold. The other reusable upper mold types are either less expensive to remake (Shell Laminate) or somewhat forgiving (Elastomeric Multi-Use) with respect to cavity variations. However, for the upper mold, using Rigidized Laminate, it is very important to know what part thicknesses and glass loadings are required. Once the upper mold is made, these cannot be changed without going to considerable expense. Simply adding glass will change the flow characteristics, making the mold-filling process difficult or impossible. It is preferable to demonstrate a sound part design before building the upper mold.

Using the lower mold, a complete part should be carefully hand-laminated. Thorough attention to glass loading and glass/resin ratio should be exercised. Cores or inserts, if present in the design, should be installed during the lamination process. The part should be tested sufficiently to prove out the design before proceeding with designing and building the upper mold pattern.

E. **Dimensional Waxing**—Dimensional waxing is probably the most economical and accurate means for producing the part cavities. Starting with the lower mold, the dimensional wax is applied to mimic the part thickness. Wax stock is currently available in a wide range of thicknesses and several temperature ranges. It is important to use the high temperature variety due to the exotherm heat generated during mold cure. The adhesive backing helps keep the wax in position. Dimensional waxing is very much an art requiring skill and finesse for accurate thickness control.

Dimensional waxing is most successfully accomplished in a temperature-controlled environment. Sometimes, dimensional wax is applied in two layers. The first layer is thinner and placed as tiles with channels between pieces. These channels form a vacuum manifold. This vacuum manifold serves to hold the second, thicker layer in place. This configuration can reduce the likelihood of pre-release during the gel and lamination stages of mold building. In general, it contributes to higher accuracy in the mold cavity dimension.

Clay can be used to produce fillets in tight radii and to fill the seams between adjacent courses of wax. The preferred clays are very stiff at room temperature. A hard clay produces a better gel coat surface on the cured mold. A heat lamp or other kind of hot box is usually required to condition the clay so it can be easily molded. Once it cools, the clay becomes very stiff and provides a good molding surface. Some clays can inhibit the gel coat cure during mold fabrication, so the clay should be checked to ensure this does not occur.

The surface quality of the upper mold half depends critically on the quality of the dimensional wax and clay installation. Careful attention to detail will result in less re-work to the upper mold.

Prior to constructing the upper mold half, paste wax is applied over the clay and dimensional wax. Then PVA is sprayed over the paste wax to serve as a parting film between the pattern and the mold. When the upper mold is Elastomeric Multi-Use, a soap solution is instead sprayed on the pattern to facilitate release of the silicone bag material. It is important to test new combinations of materials on a small scale before expecting them to work on a large scale.

F. **Master Part**—The mold cavity can also be patterned by building a master part. In general, cavity thicknesses have greater variation when using the master part versus the dimensional waxing method. In the lower mold, a complete part should be carefully hand laminated. Very careful attention to glass loading and glass to resin ratio should be exercised. Any cores or inserts should be installed during the lamination process. The entire top surface is then sanded smooth. Body putty is used to fill major imperfections. The top surface is covered with a high quality surfacing primer followed by tooling gel coat, which is sanded and buffed to a high gloss. This preparation adds to the cavity size, so careful planning and execution are necessary to end up with the proper cavity. Also, keep in mind that female edges and corners have greater thickness variations; this results in resin rich areas on the production part. See the chapter on Polyester Tooling for more information on building patterns and plugs.

G. **The Pinch-Off**—The pinch-off is a mold feature that can serve several functions. The pinch-off is that certain part of the mold cavity at the edge of the part where the two mold halves come together. The mold mating flange is just outside the pinch-off. There is still a gap between mold halves in the pinch-off. Generally, the same or smaller gap is carried onto the mating flanges. In the pinch-off, the separation distance is much less than in the cavity area. In general, 0.015" of pinch-off space is allowed for every 1.5 osf of CFM. In comparison, 0.045" of cavity space filled with one 1.5 osf of CFM provides a laminate with 30 weight percent glass (zero filler load). The pinch-off compresses the CFM to roughly one-third its original height. This makes the glass pack less permeable and the liquid resin cannot easily penetrate this area. This prevents the resin from wetting out the laminate in or past the pinch-off area.

Immediately after molding, while the part is still not fully cured, the flashing can be torn off the part by hand or cut off with a hook knife. The flashing and the part separate at the pinch-off area. This type of part edge is adequate for some applications. For many applications, the part edge will need to be a high-quality cut edge.

The pinch-off also provides a vent path for the fiber pack. Air will vent through the pinch-off while the glass is still dry. A vacuum plenum must be provided outside the pinch-off area, in either the lower or upper molds. Once the resin arrives and wets the glass, air will no longer vent through the pinch-off. At the vent locations, the pinch-off is interrupted by making a channel from the part to the vent. This improves the effectiveness of the vent.

H. **The Rigidized Laminate Upper Mold**—The Rigidized Laminate upper mold is used whenever there are substantial resin pressures and/or large mold closing forces. This mold type is typically used in RTM.

In general, this mold is a glass laminate fitted to a heavy steel frame. See the Lower Mold Robust prpagraphs for a typical mold description. Generally, the mold flange has two rubber perimeter seals. In the Pressure to Vacuum process, the space between the seals serves as a perimeter vacuum manifold.

The Rigidized Laminate upper mold set is the heaviest of all. For example, a part larger than two square feet will have a mold too heavy to hand lift during demold. This system has the potential for the fastest production rates in very sophisticated processes. The Rigidized Laminate upper mold set is the most durable of the various molds and can be expected to have the longest life.

Parts that require gel coat present a special challenge for the Rigidized Laminate mold process. The extra process time for spraying and curing the gel coat extends cycle time. In addition, there are often cosmetic requirements for gel coated parts that demand excellent surface profile without distortion or fiber print. Rapid cycle times and quick demold events allow the part to cure without being in contact with the mold surface; this compromises cosmetic quality. To address both of these issues, the lower mold can incorporate two features: a dish and a pan. The dish contains the actual mold surface but no support frame whatsoever. The pan is a lower support mold that holds the dish. This lower support mold is a glass laminate mold with a very robust steel frame. Vacuum between the pan and the dish ensures that they nest perfectly. As a result, the supporting pan mold reacts the injection pressures during the mold fill process. Several of these dishes can be fabricated for each pan.

These dishes can be gel coated off line from the molding station. The gel coated dishes would then be processed, in sequence, through the mold station. After the part is molded, it can remain in the dish for some period of time. This will improve surface cosmetics in addition to throughput.

I. **The Shell Laminate Upper Mold**—The Shell Laminate upper mold will probably enjoy the most widespread use for small production run parts. This is largely because existing open mold assets can be readily converted to accept this type of upper mold. In addition, this upper mold is both the least expensive to fabricate and uses no new chemistry.

This upper mold is a thin glass laminate with a special flange detail. The flange detail usually has two seals. A vacuum applied to the cavity between the two seals usually provides the clamping force (vacuum clamps). In addition, vacuum venting to the part cavity can provide clamping forces across the entire part.

The Shell Laminate upper mold is similar to the Rigidized Laminate upper mold in that both are made with glass laminate. But the Shell Laminate is much thinner and has little or no framing.

The Shell Laminate upper mold generally is one of two types based on the flange detail. Both provide for a clamping force but they differ in resin transfer functions. One applies a vacuum to the part perimeter for a diverging flow fill from the part center to the edges. The other provides an Edge Manifold that serves as the resin pathway into the fiber pack for a converging flow fill to a vent at the part's flow center. Figures 4 and 5 show diverging and converging flow fields.

A typical flange detail is presented in Figure 6. There are two popular ways to develop the flange detail. The preferred method is to pattern the flange detail around the perimeter of the mold using dimensional waxing and other conventional pattern building techniques. In this method, the flange is laminated when the upper mold is laminated, except the flange is usually thicker.

The other method is to miter and butt prefabricated stock lengths of a flange detail around the part perimeter. When the upper mold is laminated, narrow strips of wet glass are placed across the flange butt joints, and the laminate in the part cavity is lapped over the flange pieces, thus forming a one piece upper mold and flange.

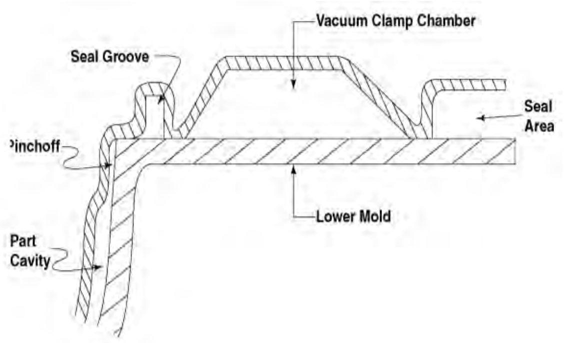


Figure 9-8. A flange detail for the upper mold shell laminate type incorporates two seals and a vacuum clamp chamber to hold the upper mold to the lower mold.

The Shell Laminate upper mold can be built by spraying clear gel coat over the prepared and properly released pattern, followed by laminating the mold. Clear gel coat provides an upper mold that is translucent so that one can watch the fill process when the upper mold is used. The laminate thickness is generally 4-12 osf CSM over the part cavity and 4-18 osf CSM over the flange. The thickness is strongly dependent upon the part geometry. Lamination stages are limited to 1.5 osf for skin coat and three osf per lamination operation to avoid excess heat generation.

The flange detail commonly has some provision for alignment. Sometimes the lower mold will have an upturn flange at its outermost perimeter that is matched correspondingly by the upper mold flange. Sometimes, it is a downturn flange. The dimensions needed for successful locating will depend on the overall part area and depth. If no provision is made for locating, then the overall part shape will try to locate the two mold halves. However, slight misalignments will cause fractures in edge and corner locations of the upper mold that result in reduced mold life.

The Shell Laminate upper mold is a durable mold that will endure many molding cycles when properly built and properly cared for. Mold failure is generally characterized by fracture of the laminate in edges and corners. This is aggravated by a poor fit in the corner and/or inadequate alignment features in the molds.

J. **The Elastomer Multi-Use Upper Mold**—Elastomer Multi-Use systems generally use silicone vacuum bags. Be advised that silicone is a chemical class just like polyester. There are many different formulations from single component to two components, and either addition cure or condensation cure varieties. It is important to demonstrate compatibility between the silicone and the molding resin. The cure of polyester resin can be inhibited when in contact with certain materials.

There are two types of multi-use bags, typically designated as conformal or non-conformal. Non-conformal bags are fabricated from flat sheets of calendered silicone. These are limited to parts with a flat profile and mild curvature. The typical technique for joining adjacent pieces usually involves butt splices of calendered material covered with a lap of uncured rubber. Heat curing is accomplished under a single-use vacuum bag.

Conformal bags are molded to the part's upper mold line. They can be molded from calendered sheet stock that is partially cured or from bulk silicone material. For the calendered stock, pieces are applied to cover the pattern, a Bag Film Single-Use vacuum bag is applied, and it is cured in an oven. For the bulk silicone, it is applied to the pattern surface by brushing or other means. Often, a polypropylene mesh or some other flexible reinforcement is embedded in the silicone to provide strength and durability. Some varieties of silicone will cure at room temperature.

The flange detail can range from a tacky rubber seal tape to an aluminum or fiberglass flange detail with ethylene-propylene-diene monomer (EPDM), silicone, or neoprene rubber seals. The flange detail may provide a vacuum chamber around the part perimeter. For small parts, this type of bag is easily handled. For large parts, handling becomes difficult and it becomes easy to tear or damage the bag. Improper storage can result in damage and premature bag failure.

A 'V' or 'C' groove in the lower mold flange can also serve as a seal for the Elastomer Multi-Use upper mold. When the upper mold is fabricated, this groove in the lower mold is filled with elastomer. The elastomer extends beyond the groove as well. Simply placing the upper mold in place around the lower mold flange provides the seal once vacuum is applied. In some cases, a vacuum plenum (groove) in the lower mold flange (which is not replicated in the upper mold), located just inboard of this seal groove, must be used to ensure the upper mold seal integrity.

K. **The Bag Film Single-Use Upper Mold**—The Bag Film Single-Use systems use the classic vacuum bag constructed from roll stock material. This method enjoys widespread use both in the aerospace industry and with very large fiberglass parts. Each time the part is built, a new vacuum bag is constructed. This method is typically used for parts that have small production runs and low production rates.

There are two fundamental approaches to vacuum bagging: surface bagging and envelope bagging. In surface bagging, the vacuum bag is sealed to the tool face. The tool should not contain any penetrations that would cause leaks.

The tool laminate can also leak vacuum if it has porosity. This porosity can be repaired by using a vacuum bag to draw a vacuum on one side of the mold face while painting an elastomeric seal material on the back side. Vacuum forces will draw the seal material into the porosity and seal the mold face. Several applications may be necessary.

In envelope bagging, the vacuum bag completely encapsulates the tool. This is only practical on smaller, somewhat flat parts.

There are a few items which are commonly used to construct vacuum bags, although not all of them are always used. These items are:

- Peel ply
- Release film
- Breather material
- Bleeder material
- Bagging film

All of these items are considered expendable goods. In other words, one buys them for each part and throws them away once the part is cured. This is practical for low production run products, but is too expensive for higher volume applications.

1. **Peel Ply**-Peel ply is a nylon, polyester or fiberglass fabric that is laminated into the part surface. The fibers in the peel ply are treated (or left untreated) so that no bond occurs with the laminating resin. After the part is laminated, the peel ply is removed by peeling it off, hence the name. This leaves a clean, slightly textured surface that can be bonded to or painted on without further surface preparation, provided it is not left open to the air for an extended time.
2. **Release Film**-Release film is a film that doesn't bond to resin. It is used to ensure that a part does not bond to another item, such as a vacuum breather or vacuum bag. It can be perforated to allow resin or vacuum to pass through or non-perforated, which prevents resin or gasses from passing through. Release film is always in contact with the laminate. It forms the border between the part and the vacuum bag system.
3. **Breather Material**-Breather material is a key element of the vacuum bag system. Without breather, the forces on the vacuum bag are not consistent from one spot to another. In fact, some areas of the vacuum bag may have no force whatsoever.

   This is because the vacuum bag, in contact with either a mold surface or a wet laminate, will tend to seal off and not pass the vacuum. A breather works to vent vacuum under the bag everywhere the breather material is. Breather material is usually a spun mat made from a polymer fiber. A non-woven paper product such as handy wipes is an example of a low cost breather.

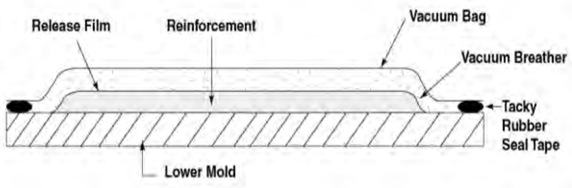


Figure 9-9. A vacuum bag system may incorporate the vacuum bag, vacuum breather, and a release film. No resin transfer plumbing is shown in this view.

4. **Bleeder Material**-Bleeder material is used to extract (soak up) excess resin that exits a part. It generally is used in conjunction with perforated release film. The release film prevents the bleeder stock from becoming part of the laminate. The bleeder material can be any type of fibrous material. Polymer fiber such as spun polyester fiber is common. Glass stock can also be used at a greater expense.

5. **Bagging Film**-Bagging film is the last layer. It is the layer that the atmospheric pressure acts upon.

   In general, this is a nylon film that is carefully selected for its good elongation properties. It forms the boundary between the vacuum and the atmosphere. This pressure difference results in a compaction force.

   Many types of nylon film are plasticized by moisture. The ambient humidity has a strong effect on the bag material's softness and elongation. If a roll of bag film dries out, it becomes very crinkly and hard to work. The bag stock can be restored to usable form by putting it in a tent with an ordinary vaporizer. Once the film absorbs some moisture, its desired properties will return.

6. **Seal Tape**-The bag is sealed to the flange using a sealing tape that is a rubber based material with high tack. A common size is ⅛"x½" and comes in 25-foot rolls.

Since the bag is made from flat roll stock, numerous pleats are used to fit the bag into and onto edges and corners.

All the items mentioned above are considered disposable items and are consumed during each molding cycle.

L. **Mold Seals**—Most molds for Resin Transfer Molding have rubber extrusions for seals. Various synthetic elastomers are used, such as polysiloxane (silicone), polychloroprene (neoprene), and ethylene-propylene-diene monomer (EPDM) rubber. Many times, a double seal arrangement is used. Numerous cross-sections are available.

   The seal and its geometry have a strong effect on the design of all upper mold flanges that are re-usable. Silicone seals are almost always used at the part boundary. Resin doesn't stick to the silicone, making mold maintenance easier. The backup seal is generally EPDM rubber, which is much less expensive than silicone. Some processes use neoprene rubber seals.

Clamping Method

The Clamping Method has a cost in terms of capital requirements with a corresponding benefit in cycle time. Part size strongly influences the choices of clamping method, but the biggest driver is the way the resin pressure head is developed. The general clamping types are vacuum clamps, mechanical clamps, pneumatic clamps and hydraulic clamps.

A. **Vacuum Clamps**—Vacuum clamps are a very useful and practical way to clamp molds together. In general, vacuum clamps consist of two rigid shells that come into contact with a rubber seal between them. These shells form the boundary of a cavity. When vacuum is applied to the cavity, atmospheric pressure forces the shells together. The size of the cavity and the level of vacuum will determine the magnitude of the clamping force.

   Figure 8 shows a perimeter vacuum clamp. Refer to Figure 6 for an example of a typical flange detail for Shell Laminate upper molds.

   Sometimes, a vacuum clamp arrangement consists of a single seal that surrounds the part cavity. Vacuum is applied in a wholesale fashion to the part cavity to provide the clamping function.

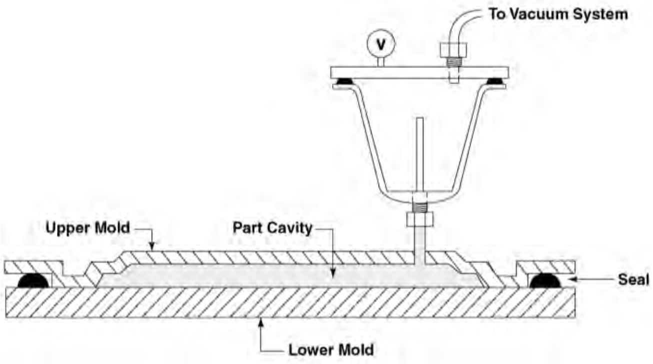


Figure 9-10. In the RTM configuration, vacuum applied to the mold cavity results in a clamping force across the entire part. Here the resin is applied before the upper mold is installed.

B. **Mechanical Clamps**—Mechanical clamps are generally very robust and located at approximately 18 inch intervals around the perimeter. Clamp locations are generally reinforced with ⅜" or ½" thick steel plate. Generally, the clamps provide for the alignment of the upper and lower molds. Screw clamps are typically two machined pieces that provide alignment. Generally, a 1" diameter bolt through the top piece and a replaceable nut in the bottom piece provide the clamping force.

   Toggle clamps include a pair of hooks with a lever arrangement like a break-over clamp to provide the clamping force. One of the hook elements has a provision for length adjustment.

Welding of the final clamp elements usually doesn't occur until the upper mold frame is constructed. At that time, the clamp/alignment elements are held in the tightly closed position while they are welded in place to ensure their alignment.

C. **Pneumatic Clamps**—Pneumatic clamps generally consist of two horizontal and essentially parallel platens and an air bag. In a pneumatic press, the platens don't need to be perfectly parallel, but they do need to be very flat. The platens are held a fixed distance apart by a number of large threaded rods with heavy duty nuts positioned above the upper platen and some holding nuts below the upper platen. This allows for some variation in the height of the closed mold set. It is not a trivial matter to adjust this height, so limited production runs should be made with molds that are nearly the same height. The closed mold set is shuttled into position between the platens. There is only a small empty space between the mold set and the top platen. An air bag built into the lower platen inflates and lifts the mold set upward against the upper platen. Since the air bag inflates quite a bit, and since it inflates until it closes the gap, it compensates for the fact that the platens may not be exactly parallel, as long as they are truly flat. This is not the case for a hydraulic press; the quality of a hydraulic platen press is directly determined by how parallel, in addition to how flat, its platens are.

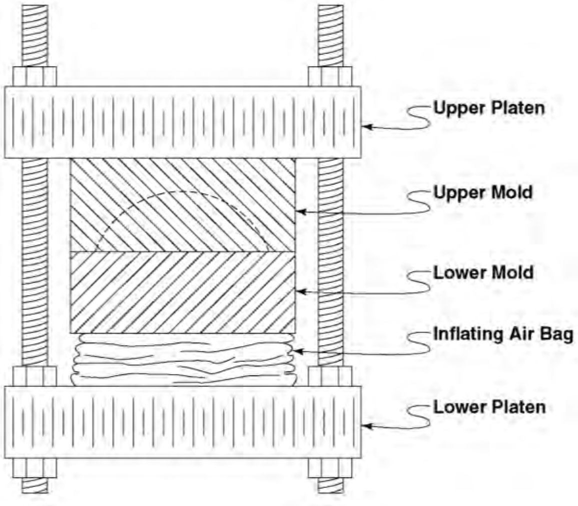


Figure 9-11. The pneumatic press uses compressed air to inflate an airbag. This forces the assembled mold set upward against the upper platen, clamping the upper and lower molds together.

D. **Hydraulic Clamps**-There are two types of hydraulic clamping systems. The first is a platen press. The second type uses a number of hydraulic cylinders placed around the mold perimeter.

The platen press design uses offset geometry to move the clamp's claw out of the way during the opening motion. The closing motion moves the clamp into position for applying the clamping force. In this way, the upper mold can be lifted clear of the lower mold.

The second design uses pneumatic cylinders to swing the hydraulic clamp elements out of the way so the mold can be opened, and back in place so the clamping force can be applied.

Unless a mold set is run non-stop, the cost of hydraulic systems limits the flexibility of this system. This can be addressed by the use of a clamping frame device. This clamping frame can be used with similarly sized closed molds. A particular closed mold set is installed in the clamping frame and a brief production run is then executed.

Mold Set Open-Close Method

The Open-Close Method has a cost in terms of capital requirements with a corresponding benefit in cycle time. The size and weight of the mold is the biggest driver for selecting the Open-Close method. The cycle time is the next biggest driver.

For small molds and moderate production rates, the Hand Lift method is frequently used. In general, if it takes more than two people to lift and handle a mold, another method becomes preferred.

There are several variations of Mechanical Hoist. A winch is the least expensive and most cumbersome to use. A manual chain hoist is generally used only for limited production rate, mold building, or research and development processes. Most often, the electric chain hoist is used. Often, two or three hoists are used simultaneously on one mold. This method has the greatest flexibility at the lowest cost, but only provides moderate production rates.

When the desired production rate is faster and the mold is large and heavy, a custom manipulator is used to open and close the mold. The controls for a manipulator can vary in sophistication. For a simple control system, there is a greater likelihood for operator error. A very complex control system can use a Programmable Logic Controller (PLC) to apply logic in process operation. In general, a manipulator is a large steel structure with actuators to move the mold halves. Some actuators may separate the mold halves while others may shuttle a mold half to the loading or gel coating station. The cylinders can be pneumatic or hydraulic actuators. In general, pneumatic actuators cost less and hydraulic actuators can apply greater forces.

Equipment

The equipment for RTM can range from a few C-clamps, paper tubs, wooden stir sticks, and a catalyst bottle to upwards of hundreds of thousands of dollars in facilities and equipment. We will discuss some of the general items below.

A. **Pressure Systems**—There are two methods of providing resin under pressure. A pressure pot is the least capital intensive method. A standard injection machine is more capital intensive. For the pressure pot, the pickup tube is one end of the polyethylene tubing that directs the resin to the mold. Catalyzed resin is placed in a disposable tub inside the pressure pot so that valuable solvent is not expended on cleaning functions. Compressed air provides the pressure head that forces the resin through the system.

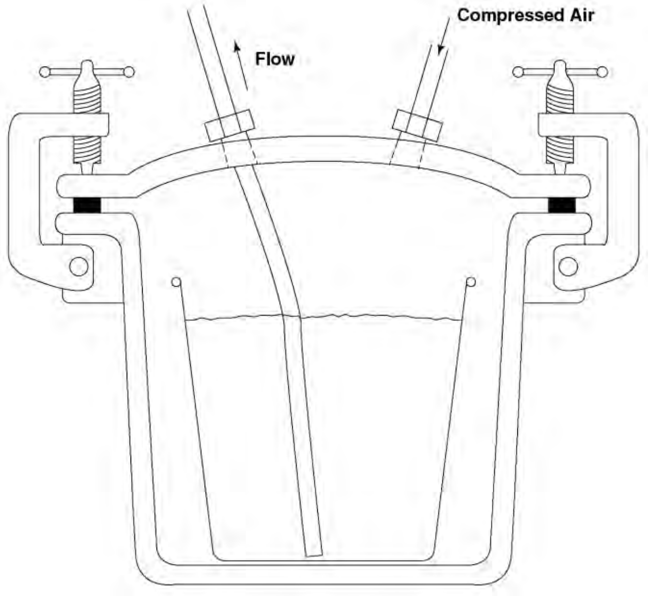


Figure 9-12. A standard pressure pot can be modified to deliver resin under pressure or vacuum.

The injection machine is generally a dual positive displacement pump arrangement driven by an air motor. Different pump configurations and lever arrangements provide settings for varying catalyst ratio. Conceptually, it is the same system that is used for modern choppers and gel coat units although variations in pumps and provisions for ratios may vary.

B. **Vacuum Systems**—There are two basic means of providing a vacuum source: a venturi or a mechanical vacuum pump. A venturi uses compressed air to produce a vacuum. This is the lowest capital investment option, but the vacuum flow rates are small and the compressed air requirements are large. It is not the most economical source of vacuum for large demands, but it is an excellent source of vacuum for R&D functions, for mold making, and for limited production. A venturi vacuum system can be pieced together for less than $50 in parts costs. An assembled system will cost from $300 to $500.

A moderate-size, industrial-style vacuum pump system can be purchased for less than $5,000. This system has a vacuum cutoff switch to provide a preset range of vacuum and a tank similar to an air compressor system. The compressor and tank size should be chosen based on current and near-term projected vacuum needs. The plumbing throughout a plant does contribute to the tank size. Ordinary 4 inch diameter, Schedule 40 PVC pipe is commonly used to plumb vacuum throughout a facility. This can add considerably to the volume of the vacuum storage tank and improves drawdown capacity.

Vacuum regulators are approximately 10 times the cost of conventional compressed air regulators. In some instances, separate low and high vacuum systems are economical. The very low vacuum system can use a shop vac. This is useful for evacuating large amounts of air to a slight vacuum. This is especially valuable in the Bag Film Single-Use processes. Once the low vacuum evacuation is complete, one can switch to the higher vacuum system for the resin injection process.

C. **Resin & Vacuum Plumbing**—Once the resin is catalyzed, it is plumbed to the mold. The resin enters the mold through an injection port, the mold fills, and the resin may exit the mold through a vent port. If the resin is allowed to cure in the plumbing, some provision for removing it will be needed. In simple systems, the injection and vent ports can be drilled out between parts.

Another method uses disposable polyethylene tubing that lines the metal injection or vent port. It is discarded between parts.

A third method uses a valve body that directs catalyzed resin into the mold. When flow is complete, the valve body seals the mold. Solvent is used to flush the lines and valve body. The solvent and resin waste are then plumbed into a covered waste container. Such a valve body can also be fitted to the vent ports.

When vacuum is applied to the vent port, a resin trap is placed in the plumbing between the mold and the vacuum system. This trap is a reservoir that catches resin and prevents it from entering the vacuum system. A resin trap is shown in Figure 11.

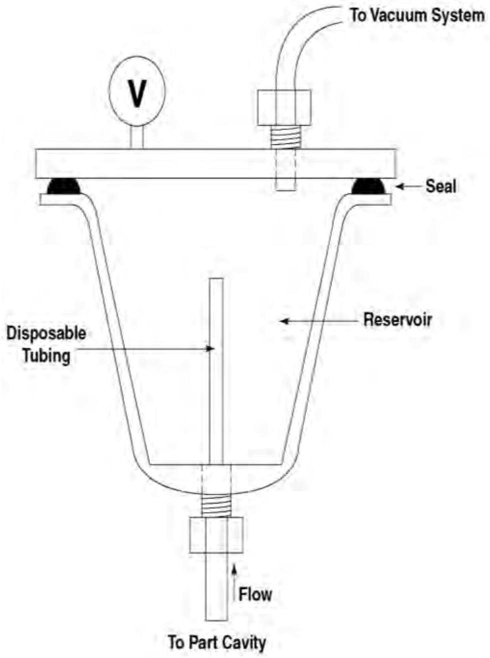


Figure 9-13. Resin trap separates the vacuum system from the part cavity in Pressure to Vacuum and Atmosphere to Vacuum resin transfer schemes.

An air ejector is a device that is molded into the closed mold. It is used to blow (not push) the part out of the mold. It consists of a cylindrical housing with a cylindrical piston device at its center. It works by using two compressed air lines. While the part is being molded, one of the compressed air lines applies air pressure to hold the piston to keep the ejector port closed. To demold, the other compressed air line is used to move the piston away from the part surface. This causes a gap between the piston and the part surface. Compressed air flows into this gap and releases the part as shown in Figure 12.

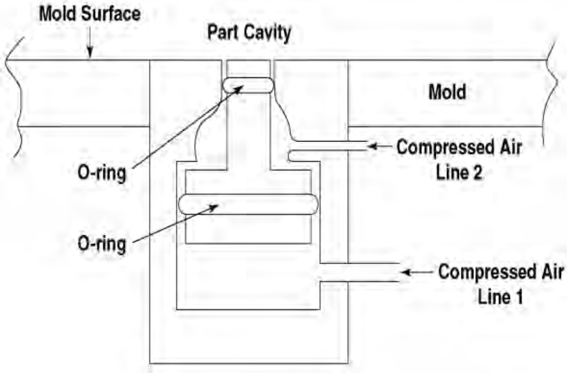


Figure 9-14 - When compressed air is applied to Line 1, the ejector piston is held in contact with the part surface. When compressed air is applied to Line 2, the ejector piston moves away from the part surface, allowing compressed air to release the part from the mold.

D. **Hydraulic Pressure Systems**—Hydraulic systems can be used to clamp molds in high rate production processes. A small system, with a pump, cooler, accumulator, valves, hoses, and eight hydraulic cylinders would cost about $10,000. They tend to be durable systems. Pumps can be rebuilt, as can most cylinders. This type of equipment can be used on a clamping frame that will accommodate a variety of similarly sized molds. Such a configuration is like a mini hydraulic platen press. Hydraulic platen presses are very expensive and quickly run into the hundreds of thousands of dollars. Hydraulic clamping systems are only used on the highest production rate processes.

9.4.3. Troubleshooting

Table 9-3. Troubleshooting

PROBLEM	POTENTIAL CAUSES	POTENTIAL SOLUTION
Laminate shell mold cracks in edges and corners	• Mold too thick • Mold not aligning well during closing • Mold cavity too thick in edges and corners	• Reduce thickness and use aligned fiber reinforcement. • Alignment devices must engage before part features force alignment. • During patterning, dimensional wax should not bridge corners and/or the master part must not be too thick.
Mold does not fill	• Injection location(s) not in best spot • Vent location(s) not in best spot • Part cavity too thin for the glass loading	• Try new locations. • Try new locations. • Redesign part cavity and/or glass loading.
Dry spots in part	• Resin flow front splits in two at start of dry spot and rejoins at end of dry spot	• Put vent at dry spot to allow air to escape. • Modify injection location.
Mold leaks resin	• Mold seal not compressed • Mold pieces don’t fit well	• Add spacer to mold seal groove under mold seal rubber to shim it outward. • Redesign geometries.
Warpage or distortion of molded part	• Cure and shrinkage after demolding • Incomplete cure • Unsymmetric laminate	• Cool parts in jigs to maintain shape. • Delay demold point to allow more cure. • Increase molding temperature. • Increase catalyst level. • Switch to hotter catalyst. • Change resin promoter package. • Correct unsymmetry.

9.5. Converting from Open Molding

Overview

- **Introduction**
- **Design and Prototyping**
- **Designing the Reinforcement Package**
- **Closed Mold Design Details**
- **Patterning the Upper Mold**
- **Closed Mold Fabrication**
- **Upstream Processes**
- **Executing the Closed Mold Process**
- **A Discussion of Vacuum**

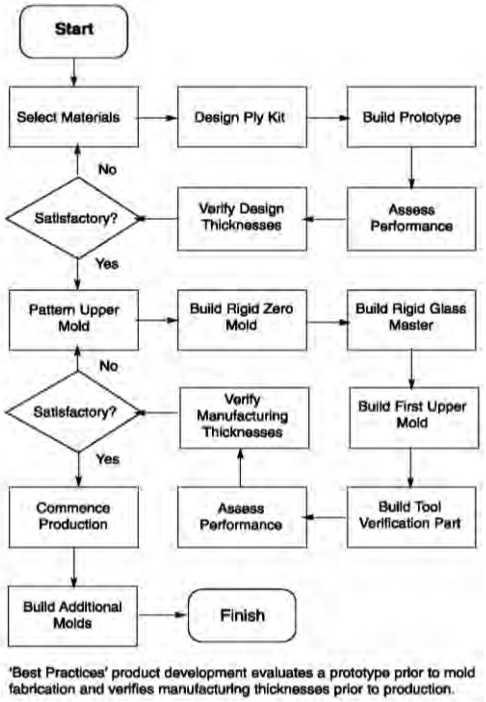
9.5.1. Introduction

The term ‘Best Practices’ describes the actions and considerations that produce a sort of optimum set of results. Many times, these actions are arguable, depending upon which ‘optimum’ is desired. Some things depend upon the specific part design and production plan. For the purposes of this section of the manual, the ‘Best Practices’ are those actions and considerations that contribute to successful production of gel-coated cosmetic parts with high as-molded quality for production runs of hundreds to thousands of parts.

Closed molding presents some unique challenges to the established open molder. It is most important to focus on the product development process from part design through production scale-up. Figure 9-15 presents this process in the context of ‘Best Practices’ for minimum cost.

A. **High-pressure RTM-**Large quantities of small, non-gel coated parts are best produced using conventional, high-pressure RTM. Rapid cycle times are necessary to offset the high tooling costs. Rapid cycles are achieved with a combination of high-pressure injection, heated molds to drive the cure, and hydraulic actuation to rapidly open and close the mold set. The upstream process of gel coat application/cure can easily double the cycle time, challenging the economics and applicability of high-pressure RTM. It is the most expensive process for large parts.

B. **Shell Laminate RTM (Light RTM)** is the process of choice for most parts without any negative draft. The process uses low-pressure injection to vacuum venting with vacuum clamping. The upper molds should be considered semi-disposable for optimum economics. There is very little benefit from flow media because the upper mold is rigid enough to prevent the glass pack from becoming completely compressed, and a positive displacement resin pump provides a suitable pressure drop.



‘Best Practices’ product development evaluates a prototype prior to mold fabrication and verifies manufacturing thicknesses prior to production.

Figure 9-15. ‘Best Practice’ product development example process for mold production.

C. **Silicone Bag RTM**, with low-pressure injection to vacuum venting, is the process of choice for die-locked geometries or parts with exceptionally deep draws. Some shops appreciate the ability to fold the upper molds and store them in a pigeon-hole shelf unit. Flow media provide little benefit because the resin transfer operation inflates the cavity, and resin flows quickly across the glass pack top surface in the manner of a temporary face manifold. The high cost of silicone relative to fiberglass will always make this process slightly more costly than Shell Laminate RTM.

D. **Vacuum Infusion** is the process of choice for limited production runs or for parts that require high glass content. Some means of bulking the laminate are necessary to achieve thicknesses common to open mold designs. Extremely large parts are also good candidates for vacuum infusion, although these are usually limited-number production parts anyway.

Flow media is required in vacuum infusion. Under vacuum and without a resin pump, the flexible bagging film compresses the glass pack considerably, reducing permeability and flow velocity below practical limits. Surface flow media is often removed and discarded after molding. Interlaminar flow media is becoming more popular, although it does provide lower interlaminar shear strength than a glass-reinforced ply.

Since the bagging film is not reusable, the cost recurs with each part manufactured.

9.5.2. Design and Prototyping

A prototype is a necessary step in a product's development. The prototype serves to validate the design's fit, form, and function. Many times, the process is abbreviated by not addressing function. Fit and form are evaluated for the prototype, but function is not evaluated until further down the product development cycle when it is sometimes discovered via a product failure. In open molding, the solution manifests itself in changes to the laminate schedule. A part is designed, a pattern is prepared, a mold is constructed, and a part is produced. The part is evaluated for fit and form, and the design is certified as acceptable. If function is later found to be lacking, additional reinforcement materials can be added to an open-molded part without much concern for the mold design.

When the upper mold comprises vacuum bag film or silicone rubber, adding additional plies of material to increase part strength and stiffness is equally non-consequential. But when the upper mold is rigid, adding additional plies of material becomes problematic. The part cavity remains the same. Thus, the plies must be compressed to a greater extent, with a corresponding decrease in their permeability. At some point, the plies become so compressed that they don't wet out properly and don't exhibit their normal strength. White fiber bundles visible at the part surface are evidence of inadequate wet out. Further ply compression can even prevent resin from flowing through the region, resulting in dry spots.

Many variables work toward or against proper and consistent mold filling. The biggest factor is the consistency of the glass fiber pack. Best results are achieved by controlling the type and amount of reinforcement, as well as the location and extent of ply overlaps. This is achieved by designing the ply kit before the mold cavity is designed. This requires material selection prior to ply kit design, and includes not only the type of glass reinforcement, but the specific form (usually width) for that glass type. The benefits of this approach are two-fold: minimizing material waste; and ensuring consistent mold-fill performance.

9.5.3. Designing the Reinforcement Package

There are various methods of preparing the reinforcing pack, including:

Preforming

This method produces the reinforcing pack in an upstream operation known as preforming. The preform is placed dry in the empty mold, the mold set closed, and the resin injected. The most rapid cycle times are achieved using the preform approach. The reinforcement pack can also be assembled in the empty RTM mold. The lower mold is engaged during this process, which adds directly to cycle time.

Continuous Filament Mat (CFM)

The most common reinforcement, Continuous Filament Mat (CFM), is also the least expensive. Its architecture results in resin-rich and fiber-rich areas with more fiber print than other materials. It is not very conformable and requires cutting and darting for complex geometries. CFM is the most commonly used reinforcement for conventional RTM processes.

Stitched Chopped Strand Mat (Stitched CSM)

Offers much greater conformability than CFM. The polymer fiber cross-stitches in Stitched CSM prevent the fiber wash that would be seen during the fill process with ordinary CSM.

Other Options

Other stitched materials are used as structural materials. These are available in a wide variety of configurations, often with three or more distinct layers. A common example is 1808 material. This is a three-layer material. The first layer is aligned glass fiber in the warp direction, while the second layer is aligned glass fiber in the weft direction, and the third layer is chopped mat.

Special Constructions

One interesting product comprises two layers of glass reinforcement separated by a layer of polymer fiber core. The polymer fiber core adds thickness, and thus bending stiffness, without the full weight of a glass ply. Available from several sources, these materials tend to be very conformable and provide good cosmetics. They do suffer from reduced interlaminar shear strength due to the low strength of a polyethylene or polypropylene fiber ply.

A spun-bound polymer fiber ply works effectively as a print blocker when placed against the gel coat layer. With this approach, there is a trade-off between the cosmetic quality and the tendency of the gel coat layer to crack.

In vacuum infusion, the flexible bag film upper mold tends to compress the glass reinforcement so much that the permeability becomes very low, and therefore, the resin flows very slowly. Certain materials have been designed that resist compression and provide a ready flow path for the resin. These can be placed within the laminate thickness or above the laminate for subsequent removal.

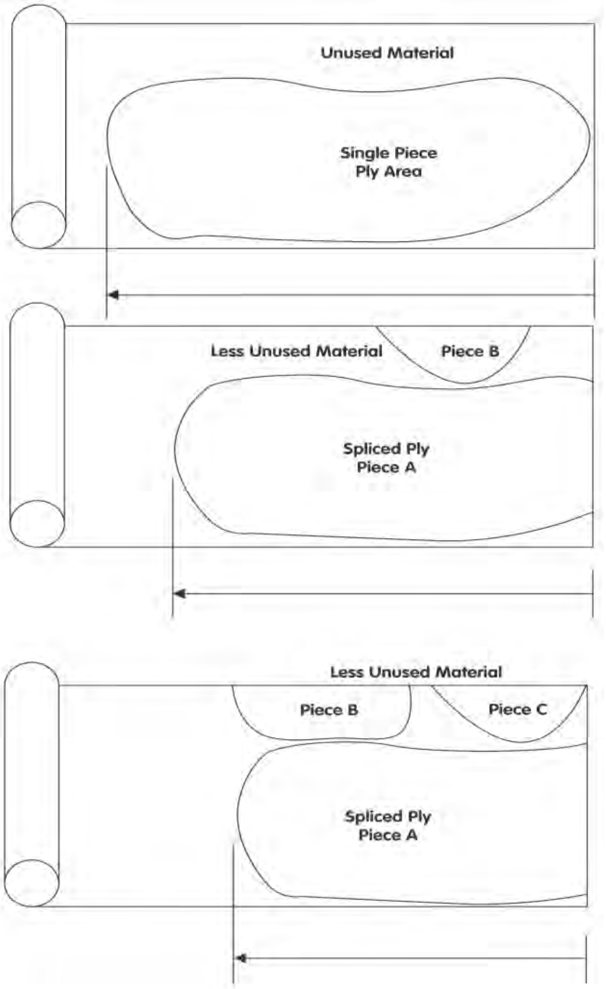


Figure 9-16. Intentional ply splices can be used to minimize roll goods usage.

The ply kit must be designed and proven before designing the mold cavity. Material types and forms are selected by fiber architecture, areal weight and width, respectively. The ply kit is designed by determining the minimum number of lineal feet required of that width material to build the part thickness. This usually requires ply splices to be located somewhere on the part. Figure 9-16 illustrates how intentional ply splices can be used to minimize roll goods usage. Any overlap areas are designed into the part cavity in the form of additional thickness. This approach ensures consistent filling during the resin transfer operation by eliminating highly compressed areas in the reinforcement pack that serve as flow restrictions.

Nesting plies in a ply kit is another method of minimizing material usage. Nesting refers to the operation of orienting different ply details so that the greatest fraction of material is utilized. Plies from different parts should never be comingled in a single nest for the same reason that different parts should not be ganged together in a single mold; it leads to higher material usage.

Replacing any one scrap part requires production of all the parts nested or ganged together. Nesting is common for aerospace designs in which individual ply details are precisely designed. Nesting is not the low cost approach to minimizing material usage unless the design is a minimum weight design. For a minimum weight design, ply splices must be precisely controlled in order to ensure design integrity. Ply splices are weak spots that must be accounted for in strength analysis. Seldom are glass fiber polyester resin composites designed to minimum weight. More likely, they are designed to minimum cost. Usually, ply splices can be located with concern for assembly fit tolerance and without regard for part strength provided that basic splice rules are followed. Above all, splices should never be superimposed through the thickness.

There are two types of splices: butt splices and overlap splices.

A. **Butt Splice**-The butt splice comprises two ply details oriented so that the edge of one ply is adjacent to the other. A butt splice should be avoided when the ply constitutes a significant fraction of the part thickness. Since the reinforcement is discontinuous across the splice, the joint is significantly weaker than the area away from the splice.

Butt splices are preferred when assembly fit tolerance requirements preclude additional part thickness.

B. **Overlap Splice**-The overlap splice comprises two ply details oriented so that some portion of the end of one ply lies on top of the other. Overlap splices provide greater strength than butt splices. Overlap splices almost always require additional part thickness to accommodate the extra reinforcement material. Overlaps should never be less than 10 times the ply thickness. For good load transfer, the overlap ratio should be 20 times the ply thickness or better.

Once the ply kit is designed, the materials should be used to hand laminate or vacuum infuse a part for prototype testing. This testing should evaluate part functionality and verify that the part thicknesses and reinforcements are adequate for the design. Careful attention to glass content and part thickness is imperative to a successful structural evaluation. Once the laminate schedule is proven, the prototype part should be cut into pieces to verify design thicknesses. Then, and only then, should the part cavity be designed and patterned.

9.5.4. Closed Mold Design Details

Certain design details can greatly impact the performance of a mold set on the factory floor. While they are not critical for success, they can contribute to the robustness of the process.

Closed Mold Features That Add Robustness

The mold set should be designed so that the upper mold cannot be accidentally installed at the wrong clocking relative to the lower mold. If the lower mold is oriented at 12 o'clock, it should not be possible to close the mold at any orientation other than 12 o'clock.

The mold halves should separate with a true vertical motion. Many times, open mold parts are designed with some negative draft that requires the part to be pulled somewhat horizontally prior to being moved vertically out of the mold. This should be avoided in closed molding unless a device is fashioned to align and move the mold pieces into the mated configuration. This will also require special seal extrusions for proper functioning.

For both the Shell Laminate and Silicone Bag RTM processes, the mold assembly procedure should require only moderate hand pressure and the vacuum clamps, without resorting to mechanical clamps.

Closed Mold Framing and Thickness

For the three process variations, laminate thickness, structural reinforcement, and construction materials vary considerably. A conventional RTM process minimizes fill times with high injection pressures. Its mold frame must not only support the weight of the mold laminate, but also the injection pressures. The frame itself must be structurally tied to the mold laminate. Both the lower and upper mold must be held to shape and clamped together. The highest pressures are at the injection point, which is usually at the part center. This area needs to be adequately reinforced to prevent mold cavity deformation.

In contrast, an open mold frame only serves to support the weight of the mold laminate. The open mold frame acts as a cradle to support the mold laminate, with flexible glass laminate ties that don't couple the mold and frame structurally. This cradle design is much more tolerant of thermal shock than a structural RTM framing system because thermal expansion differences between the steel reinforcement and glass laminate are absorbed by deflections of the light ties.

The Shell Laminate upper mold must be thin to resist cracking. This thinness allows the mold to bend and flex without generating a great deal of interlaminar shear stress. The laminate schedule should include one 20 mil layer of tooling gel coat, a 10 mil conformable glass veil directly against the gel coat, a chopped glass skin coat, and one layer of a structural material such as 1708 or 1808. These are non-crimp fabrics with chopped mat stitched into a three-layer assembly. Additional thickness should be used over the vacuum clamps, edge manifold, and alignment devices. Vinyl ester should be the minimum grade resin material.

Closed Mold Alignment Devices

Problems with aligning the mold halves can show up in various ways. The simplest feature is a thickness variation in the part's vertical walls. One side is thinner while the opposing side is correspondingly thicker.

In other cases, certain geometric features work to align the molds after the outermost vacuum seal is established. When this happens, the mold is not free to float into position. The interference that occurs at these geometric features can cause stresses that fracture a Shell Laminate upper mold. The resulting vacuum leaks will introduce air into the mold cavity, displacing resin and resulting in voids and/or dry spots in the part.

Extending the lower mold flange beyond the outer seal can provide a simple alignment feature. Any alignment device must engage itself prior to those features on the part. Figure 9-17 shows an alignment device that does not engage before part interference occurs. A better design is shown in Figure 9-18; the height of the diagonal surface is slightly greater than the height of the part features that otherwise would align the molds.

Three or four of these details are required to provide mold alignment. These details also serve as wedge points when the upper mold needs additional force to affect release, without causing damage to the rubber seal extrusions.

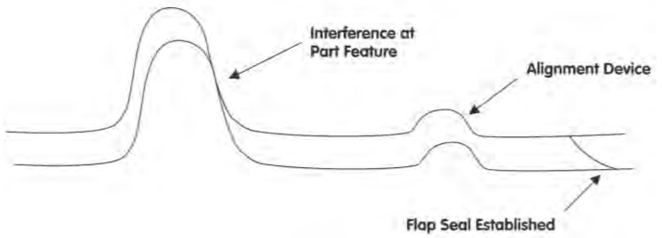


Figure 9-17. In the upper and lower mold line sketch above, the alignment device is ineffective. For clarity, not all mold features are depicted.

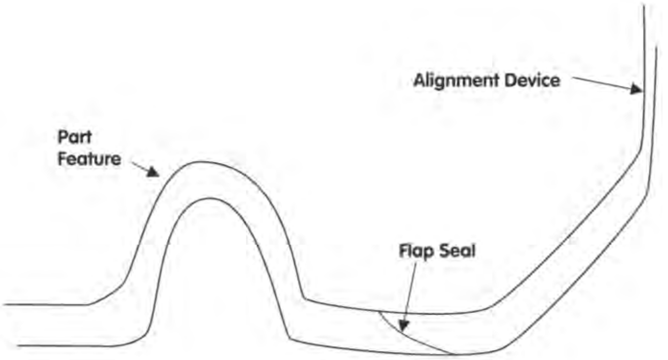


Figure 9-18. In the upper and lower mold line sketch above, the alignment device engages prior to flap seal contact or part feature interference. For clarity, not all mold features are depicted.

Closed Mold Demold Devices

A common problem when converting from open mold lamination to closed molding occurs when a lower mold is designed according to the criteria 'simply an open mold with a wide flange.' For the open mold, the part edge is often located on a vertical but drafted surface. The open-molded part is commonly laminated with the glass reinforcement lapping over the flange inside edge, extending sometimes beyond the outside edge. This 'flange laminate' is subsequently trimmed from the part. However, this material provides a convenient demolding tab. Wedge tools are inserted between the mold flange and this offage, producing a lifting force that serves to begin the demolding event.

When the newly designed closed mold system features reinforcement that ends at the flange inside edge, there is no longer a 'flange laminate' that can be used as a demolding tab. When mold release requires mechanical assistance, wedges placed between the mold flange and the resin that filled the edge manifold easily break off the unreinforced resin without generating adequate lifting force to effect part removal. Then, when wedges are placed between the mold sidewall and part, the forces are mostly in the horizontal direction, not in the vertical lifting direction. Although demold can be achieved in this manner, the more common result is gel coat scarring near the boundary of the edge manifold. This becomes progressively worse throughout the mold service life.

A fiber-reinforced demolding tab can be incorporated into the molded part by extending the part surface upwards and outwards as shown in Figure 9-19. A simple bevel at 45° from vertical accomplishes this with little added cost to tooling and part manufacture. The upper transition, from the diagonal to the horizontal, also provides an accurate guide for cutting the dry glass. This provides for consistency in the perimeter edge manifold width, with resultant increases in fill consistency.

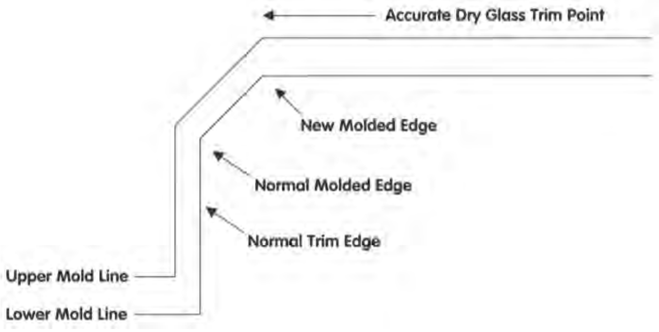


Figure 9-19. Extended the part so that there is a one inch long bevel at 45°. This replaces the open mold flange laminate with a reinforced tab that assists in demolding when wedges are used.

Closed Mold Sealing Issues

A rubber extrusion seals against a physical surface by being compressed against the surface. One way to achieve this is to use a solid rubber profile that is compressed by moving the mold pieces together. This contact is best accomplished by moving the surfaces together in purely a perpendicular fashion. The initial contact occurs before the mold pieces are completely together. As the mold pieces are brought into contact, the seal is compressed.

When two mold pieces come together, there are two components to the motion. One is perpendicular to the surface while the other is parallel to the surface. Problems arise when bringing the surface and the extrusion into contact by motion that includes a parallel component. From the time when contact is first established until the seal is compressed, the parallel motion serves to drag the seal extrusion. Best results are obtained when the contact surfaces move together in purely a perpendicular fashion.

Another method uses a hollow rubber profile that fits in a seal groove and is expanded by pressure once the mold pieces are assembled. Tucked inside the seal groove, the parallel motion cannot drag the seal extrusion.

Resin Transfer Ports, Manifolds and Vents for Shell Laminate RTM

Proper, symmetric mold filling is almost always best achieved with two injectors and one vent. These injectors will be called the ‘primary’ injectors. The resin is supplied to the entire part perimeter via the edge manifold. The resin flow will converge on the vented flow center. The flow center depends on the planform (the outline of an object when viewed from above) and the thickness. For a single cavity thickness, the flow center is in the planform center. If half the part is twice as thick, the flow center is skewed towards the thick area, because it takes more resin to fill up the greater thickness. The vent should always be located at the flow center.

The injectors are positioned by finding the ‘longest straight line distance across the part.’ For certain odd part shapes, this ‘straight’ line may be ‘bent’ at one or more locations. Measure a path across the part with a cloth tape measure (available in the sewing aisle at grocery or discount stores) until you identify the longest straight line path. The vent is almost always along this path. If the thickness is not constant, or if there is more part to one side of this line, the line will move in a parallel sense toward the ‘thicker’ or ‘bigger’ area. ‘Thicker’ is relative to ‘longer’ when it comes to the path because it takes more resin to fill up the thicker cavity. The two primary injectors are positioned at the part perimeter at these points.

For large parts, or extremely odd shapes, two secondary injectors may be used. These injectors are located midway between the primary pair of injectors. With a consistently thick part, the secondary injectors would be placed exactly between the two primary injectors. For parts with varying thickness, the secondary injector would be skewed towards the thicker portion of the part.

If parts are much longer than they are wide, secondary injectors are not used until later in the fill process. The delay time depends on the length-to-width ratio. The longer it is versus width, the longer the secondary injectors are delayed.

Certain part designs require a second resin manifold located a portion of the way from the edge manifold to the flow center. The edge manifold is used to fill the part until the resin reaches the inner manifold. Then, resin flow is directed through the inner manifold until the part is completely full. This is necessary for large parts, parts with high glass content, or parts with heavy filler loadings and thus, higher viscosity matrix material.

Examples of Injector and Vent Locations

1. **Example 1**- Part #1 is a perfect square of uniform thickness. The longest straight-line path across the part is on the diagonal. Two injectors are located on opposite corners. The vent is located midway between the injectors, at the center of the square. Most often, the injectors are mistakenly placed at the middle of a side.

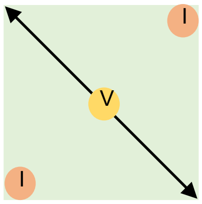


Figure 9-20. Perfect square.

2. **Example 2**- Part #2 is a long rectangle of uniform thickness. The longest straight-line path across the part is on the diagonal. Two injectors are located on opposite corners. The vent is located midway between the injectors, at the center of the rectangle.

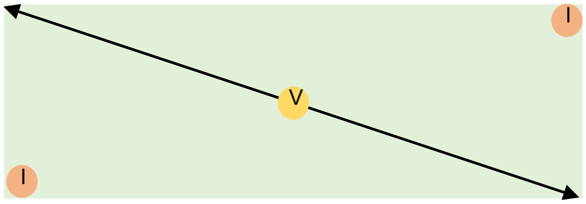


Figure 9-21. Long rectangle of uniform thickness.

3. **Example 3**- Part #3 is a perfect circle of uniform thickness. The longest straight-line path is any one of the diameters. The injectors are located at both ends of the diameter and the vent is in the center

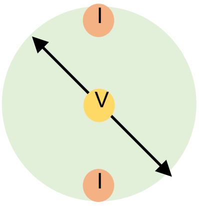


Figure 9-22. Perfect circle of uniform thickness.

9.5.5. Patterning the Upper Mold

There are three methods of patterning the upper mold geometry. Each can produce the necessary upper mold, although with varying results.

Machining from Tooling Block

The highest degree of accuracy is achieved with a computer-controlled cutting machine. Solid modeling techniques are used to produce a computer aided design (CAD) /computer aided manufacturing (CAM) data file that is used to control a numerically controlled (NC) cutting machine. A plug blank is first constructed from tooling block or other pattern materials.

Calibrated Sheet Pattern Materials

The lower mold can also provide the basis for the upper mold geometry. Pattern materials are placed into the lower mold to simulate the part thickness. Calibrated thickness sheet wax provides a high degree of accuracy. Other pattern materials can be used, particularly in thick areas. Mold features such as the edge manifold and vacuum clamps are also patterned upon the lower mold. This master plug then provides the surface definition for the upper mold.

The Master Part

A master part can be constructed using either hand lamination or vacuum infusion. The lower mold is used for this method. Careful attention to glass content is required to ensure accurate mold cavity thickness. Inside edges tend to be thicker than intended for hand laminated parts. Some amount of grinding may be necessary to achieve back side radius requirements. The entire part surface must be coated with a filler type primer material and finished smooth for molding the upper mold. This method does not provide the same accuracy as the other methods presented.

9.5.6. Closed Mold Fabrication

Most patterns are not durable and are suitable for only one pull. The demold process usually imparts sufficient forces to destroy the pattern. As a result, two options present themselves for consideration. Either one accurate upper mold can be built from the pattern, or a robust master with accurate upper mold geometry can be built that can yield any number of high accuracy upper molds.

In almost all cases, a Zero mold should be made from the pattern. This Zero mold is so named because it is used as a step in the production of tooling. It has the geometry of the upper mold, but is not the same construction. The Zero mold should be constructed in a manner similar to a conventional open mold. Steel framing is preferred but wood is acceptable when encapsulated in glass laminate. A fiberglass master mold is made from the Zero mold. The production molds are made from the fiberglass master mold. In this method, accurate upper mold geometry has been maintained through the successive moldings.

A common mistake is to forgo the master mold building step and build the upper mold directly from the pattern. The Shell Laminate upper mold can be easily warped or cracked during use as an RTM mold. When this happens, geometric accuracy is lost. Any master produced from a warped/cracked shell laminate upper mold will not have the correct geometry, consistent mold fill performance, or accurate part thicknesses and weights. The only recourse is to repattern the upper mold using the lower mold as a basis. This requires that the lower mold be taken out of production for one to two weeks for the mastering process. With a high quality fiberglass master, a new shell laminate upper mold can be produced in two days while the current mold set is still in production.

9.5.7. Upstream Processes

Processes that occur upstream of the liquid injection procedure reduce lower mold productivity when the mold is engaged in that activity. These processes can include taping/masking, applying and curing gel coat, and loading the reinforcement materials. Multiple lower mold pieces can be used to address the need for Work In Process (WIP) at each operation.

For conventional RTM, the lower mold tooling cost becomes prohibitive when gel coat is an upstream operation. The benefits of rapid cycling disappear, and the need for high pressure injection wanes.

9.5.8. Executing the Closed Mold Process

During the course of building parts, certain actions can have undesirable effects. These effects can go unnoticed or their causes can be unknown. Regardless, bad habits during process execution usually add production cost.

Resin Transfer

The proper amount of resin must be transferred to the closed mold cavity. This is best accomplished with a resin pump that automatically shuts off after pumping the desired quantity of resin. For both the Shell Laminate RTM and Silicone Bag RTM processes, the mold cavities are full before they appear to be full. Resin pressure lifts the upper mold slightly as the mold fills. When the proper amount of resin is transferred, the vent vacuum causes the upper mold to return to its design height as the resin reaches the vent location. When properly executed, very little resin exits the mold cavity at the vent location.

Transferring the proper amount of resin is particularly important for the Shell Laminate RTM process. The resin flows from the perimeter edge manifold and converges on the vacuum vent at the flow center. As the fill process begins, there is no hydrostatic pressure on the resin flow front in the unobstructed flow channel. As the resin begins to move into the glass pack, the pressure increases according to the distance traveled through the glass pack and the rate of resin delivery. The pressure is highest at the edge of the part and lowest at the flow front. The pressure forces the upper mold to move upwards, producing a thicker mold cavity that requires more resin to fill. If resin pumping continues until the resin enters the vent trap, the pressures rise very quickly due to the small vent diameter relative to the large injector diameter. Usually, the higher exotherm temperatures experienced in the greater mass will cause the upper mold to take a permanent set. When this occurs, part thickness is permanently impacted for this mold set.

Vacuum Leakage

Whenever vacuum is applied to the mold vent, the mold set must be vacuum tight. Minor vacuum leaks are the root cause of most problems encountered when developing a closed mold system that features vacuum venting. These problems produce parts with dry spots and air voids. Vacuum integrity is one of the more difficult concepts for open mold technicians to appreciate, particularly when the vacuum leakage is through the mold laminate. On the other hand, technicians working with high pressure (i.e., autoclave) lamination processes quickly learn to respect leakage through the mold laminate.

A. **Measuring Vacuum Leakage for the Closed Mold Set**—A vacuum gauge is required to determine minor vacuum leakage rates.

   1. Vacuum is applied to the mold set.
   2. The level of vacuum is noted.
   3. The vacuum source is interrupted and the time interval is measured.
   4. After a prescribed time, the level of vacuum is again noted.
   5. The difference between the initial vacuum and the vacuum after five minutes corresponds to the overall vacuum leakage rate.

   For a very tight mold, vacuum will hold steady during the entire five-minute test. A leak-down of 0.5"-1" of mercury is consistent with a well-sealed mold. Even this level can make part manufacture difficult for high vacuum processes. For leak-down rates from 1"-2" of mercury, most parts can be successfully fabricated. For a leak-down exceeding 5" of mercury in 5 minutes, successful part manufacture is difficult, if not impossible, even if vacuum is vented before resin gelation.

   It is vitally important to have a leak-free mold. To ensure the vacuum integrity, a leak-down test must be performed on every new mold set. Since there are two separate cavities in the Light RTM mold, the leak-down test should be performed twice: once on the clamp chamber and once on the part cavity.

   1. Ensure that both molds have a serviceable coating of release agent.
   2. Load the glass and cores into the lower mold.

3. Prepare the upper mold by installing a new injection tube.
4. Position the upper mold upon the lower mold.
5. Install the resin trap at the vent location.
6. Clamp off the injection tube.
7. Apply a full vacuum to the clamp chamber via the clamp fitting.
8. Apply half vacuum to the part cavity via the resin trap.
9. If the mold set does not close and seal, apply manual force to the upper mold until the flap seal contacts the lower mold flange.

Once the flap seal is established, the upper mold will draw towards the lower mold until the inner seal comes into contact with the lower mold flange.

10. Vent the vacuum connection to the part cavity by disconnecting the line to the resin trap while maintaining the vacuum connection to the clamp chamber. The inner seal should allow the clamp to maintain a closing force between the mold halves.
11. Interrupt the vacuum supply to the clamp cavity without venting the clamp to atmosphere.
12. Monitor the level of vacuum present in the clamp cavity as time passes. The clamp should maintain enough vacuum to remain clamped for 30 minutes or longer.

    If the clamp does not maintain vacuum very long, there is a leak. It may be necessary to find and repair this leak.
13. Once vacuum integrity has been established for the clamp chamber, apply vacuum to the part cavity.

    At this point, both the clamp and the part cavity are under vacuum.
14. After a few minutes, interrupt the vacuum supply to both the clamp and part cavity.
15. Monitor the level of vacuum present in the part cavity as time passes. The part cavity should maintain vacuum for 30 minutes or longer.

    If the part cavity does not maintain vacuum very long, there is a leak. It is probably necessary to find and repair this leak.

    Some leaks are not harmful. If the clamp leaks, that leak is not across the inner seal, and the vacuum system can keep ahead of the leak, successful molding is possible. If the part cavity leaks and that leak is right at the resin trap vent location, successful molding is possible.

    If, however, the part cavity leaks and the leak's location is away from the vent location, the vent vacuum will draw air into the part and the displaced resin will accumulate in the resin trap. A large leak will allow most of the resin to exit the part via the vent fitting. If the resin trap overflows, resin will enter the vacuum system and require immediate removall.

B. **Vacuum Leakage through Laminate Porosity in the Closed Mold Skin**—All laminates contain some amount of porosity or micro-porosity. When this porosity is great enough, atmospheric air will leak into the mold cavity by traveling through the porous laminate.

   Of all the possible leakage paths, this one is the most difficult for process engineers to comprehend. A simple experiment can be performed to show this phenomenon.

   1. The experimenter should build two vacuum bags.
   2. One vacuum bag should be on the mold side of a porous laminate.
   3. The other vacuum bag should be on a glass plate.
   4. Each vacuum bag should be equipped with both a vacuum gauge on the resin feed line, and on the vent line, a vacuum source that can be interrupted without venting the bag to atmosphere.
   5. Perform a vacuum leak-down test on both vacuum bags. The vacuum bag on the glass plate serves to demonstrate that the student can successfully build a good vacuum bag which maintains vacuum for a long time.

   If the mold skin porosity is resulting in vacuum leakage, successful part manufacture may not be practical.

C. **Resin Outgassing**—During resin manufacture, air is introduced into the resin during blending operations. This air dissolves into the resin in the same way that carbon dioxide dissolves into water to form the fizz in carbonated beverages. Reducing the pressure above the solution and increasing its temperature provides a driving force which forces the dissolved gases out of solution in the form of bubbles.

During the resin transfer operation, applied vacuum first acts to degas the resin, pulling dissolved air out of the resin solution. It is normal for bubbles to form at the resin flow front. Many times this is mistakenly attributed to 'styrene boil.' Instead, these bubbles are largely due to degassing.

Vacuum does not draw air bubbles 'through' the resin. On a sealed system, vacuum will cause the air bubbles to become larger in accordance with Boyle's Law. Applying vacuum to the vent merely increases the pressure head that forces the resin to flow through the mold cavity. Air bubbles move through the mold cavity by virtue of being carried by this resin flow. Any air in the system must exit during the resin transfer operation. Problems arise when air enters the system late in the fill process. There must be enough resin flow to carry the bubbles to the vent. This requires that more resin enters the mold cavity.

Downstream Impacts

Operations that occur downstream from the closed mold process can be affected by changes in the part that directly result from the change to closed molding.

A. **Open Mold Tabbing**—Open mold tabbing is the process of affixing a secondary structural element to a previously laminated part using open mold laminating techniques. This is a secondary lamination process. Secondary lamination requires that the underlying surface is not fully cured and not extremely smooth. Timing is the key parameter. The underlying part is allowed to gel and cure to some extent. To achieve a good secondary bond, the secondary laminate must be applied before the part cures too much.

If too much time elapses, then the part surface must be mechanically abraded prior to applying the secondary laminate. This procedure removes contaminates as well as provides a mechanical 'keyway' for the secondary laminate adhesion. An alternative to mechanical abrasion is the use of a peel ply. The peel ply produces a textured fracture surface when it is removed from the cured part.

There are two components to secondary laminate adhesion. One is a chemical bond with resin unsaturation in the underlying part. The second is a mechanical bond due to the surface roughness on the underlying part.

To understand the importance of mechanical bonding, consider the following scenario.

1. Select a well-cured substrate comprising a molded surface with exterior gel coat.
2. On one half of the substrate, do not perform any sanding; this will be called the smooth substrate.
3. On the other half of the substrate, lightly sand the gel-coated surface with aggressive sandpaper, such as 60-grit, until the gloss is removed and the surface is covered with sanding scratches; this will be called the sanded substrate.
4. Solvent-wipe the surface to remove all traces of dirt and contaminants from both halves of the substrate.
5. Apply a nominal thickness (¼"-½" thickness) of catalyzed polyester bonding putty to each half of the substrate.
6. Allow the bonding putty to cure.
7. Evaluate the bond quality by using a putty knife to pry the bonding putty from each half of the substrate.

The putty on the smooth gel coat substrate will release with much less effort than the putty on the sanded gel coat substrate. The difference is due entirely to the mechanical keyway provided by the sanding scratches. In this case, both pieces were equally well cured and not subject to oxygen inhibition as is the case with a back side open mold laminate.

B. **Adhesive Bonding**—The substrate surface features will determine the appropriate type of adhesive to use for successful bonding. Some adhesive types contain an etching agent that enhances the adhesion on smooth, gel coated surfaces. Alternatively, some adhesive systems use a primer wipe to soften the substrate prior to bonding. Methacrylate adhesives are becoming increasingly popular as a replacement for open mold tabbing.

Conclusions

- Variations of the RTM process are suitable to replace open mold lamination.
- Attention to detail is a key ingredient to the success of transitioning.
- Building an accurate mold cavity that is free from vacuum leaks is the pertinent challenge for Shell Laminate RTM and Silicone Bag RTM processes.
- For rigid upper mold types, the fabrication of the upper mold must follow successful prototyping to include the ply kit and lamination schedule (not just in regard to fit and form, but also function).
- Designing the ply kit prior to the upper mold provides for the most economical part material usage.
- The upstream process of gel coating has a distinct impact on the economics of conventional RTM due to the time involved with applying and curing the gel coat.
- The downstream processes of secondary lamination and adhesive bonding must also be examined for suitability with a given closed mold process due to the different nature of smooth, molded surfaces.

Appendices

The following sections provide additional information that many consider useful.

A. **Flow Theory**—Flow through porous media can be described mathematically. A French civil engineer in the mid 1850’s formulated a relationship known as Darcy’s Law. This relationship is:

$Q = -KA\ dh/L$=Rate of Fluid Flow

- Q is the rate of fluid flow
- K is the hydraulic conductivity
- A is the cross sectional area of the porous medium
- dh is the change in pressure over the length L
- L is the path length

This equation shows that which is intuitively obvious. The flow is quicker when the hydraulic conductivity is greater, when the flow area is greater, when the pressure drop is greater and when the fill path is shorter. Rapid fluid flow requires greater hydraulic conductivity, larger flow area, larger pressure drops and shorter fill lengths. The flow is slower when the hydraulic conductivity is lower, the flow area is smaller, the pressure drop is lower and the path length is longer.

The hydraulic conductivity is also known as the permeability. This permeability is greater when the fiber is less compacted. Conversely, when the fiber is highly compacted, the permeability is low, and flow is reduced. The orientation and arrangement of fibers in the reinforcing pack will also affect the permeability. These features are referred to as the fiber pack architecture.

To expand on Darcy’s Law further and define the hydraulic conductivity K:

K = (Intrinsic permeability) x (fluid density) x (Acceleration due to gravity)/(fluid viscosity)

The intrinsic permeability of the porous media is the property determined by the reinforcement form and its degree of compression. A lower fluid viscosity causes an increase in the hydraulic conductivity with a corresponding increase in the rate of fluid flow.

The two resin properties of interest, density and viscosity, are both functions of temperature and degree of cure. As a mold fills, the viscosity increases until gelation occurs.

B. **Shell Laminate Mold Design Checklist**

Lower Mold

☐ Does my lower mold have features that allow me to wedge out a stuck part without causing damage to the mold surface?

☐ Is the boundary of the edge manifold easily identified to enable accurate material trimming?

☐ Is my flange design appropriate for my seal rubber extrusions?

☐ Will the upper mold fit in only one clock position?

☐ Does my mold set come together and separate with a pure vertical motion?

Upper Mold

☐ Have I designed and proven my part?

☐ Have I designed my ply kit so that I know where my overlaps will be?

☐ Have I chosen cavity thicknesses that corresponds to the materials and glass content specified by the proven design?

- ☐ Have I identified the flow center and injector locations?
- ☐ Does my mold set have alignment devices that align the mold set before the part features force the molds to align?
- ☐ Does my mold set have features that allow me to wedge the upper mold off the part/lower mold without destroying my rubber seal extrusions?

C. Shell Laminate RTM

Step-by-Step Process Description

1. Mask the lower mold flange at the flap seal for gel-coating.
2. Apply gel coat.
3. Load the cavity with specified glass and core.
4. Trim reinforcement at the edge manifold.
5. Place upper mold approximately in position.
6. Install and clamp the injector tube(s).
7. Install the vent line or resin trap.
8. Apply vacuum to the part cavity at the vent first.
9. Apply hand pressure to bring the outer flap seal into contact with the lower mold.
10. Apply vacuum to the clamp cavity once outer seal integrity is established.
11. Vent the part cavity to check the inner seal.
12. Reapply the vacuum supply to the part cavity.
13. Perform Leak-down Test.
14. Transfer the proper amount of resin into the part cavity. Clamp off the injector tube.
15. Maintain vacuum on both the part and clamp cavities until the resin gels.
16. Once the resin gels, remove the resin trap and clean immediately.
17. Maintain vacuum on the clamp chamber until the part cures sufficiently to meet the part and process design requirements.
18. Remove the upper mold.
19. Perform mold maintenance immediately.
20. Allow the part to continue curing sufficiently to meet the part and process design requirements.
21. Remove the part.

D. What makes a good Shell Laminate RTM mold design?

A properly designed and built Light RTM mold has certain features:

- The mold set is vacuum tight.
- The upper mold cannot accidentally be installed at the wrong clocking relative to the lower mold. If the lower mold is oriented at 12 o'clock, it is not possible to close the mold at any orientation other than 12 o'clock.
- Alignment devices align the mold set before the part's geometry does.
- The mold can be assembled and sealed using only moderate hand pressure and the vacuum clamps, without resorting to mechanical clamps.
- The fill is consistent from part to part.
- The glass is not so compressed as to prevent fiber wet out.
- A known amount of resin is transferred to the part cavity and very little (tablespoons) makes its way into the vacuum trap.
- The molds separate with a true vertical motion.
- It is easy to wedge the upper mold off the lower without damaging the rubber seal extrusions.
- It is easy to wedge the part off the lower mold without damaging the lower mold gel coat surface.

9.5.9. A Discussion of Vacuum

Vacuum bags work by using the Earth's atmosphere to provide a force. The weight of the Earth's atmosphere amounts to approximately 14.7 pounds per square inch. Whenever a vacuum is applied to a closed cavity, the Earth's atmosphere can apply up to 14.7 pounds per square inch against the outside walls of the closed cavity. This 14.7 pounds per square inch is for a full vacuum at standard temperature and pressure (STP). STP is defined by scientists to be 77°F (25°C) at sea level and will produce approximately 14.696 psi of normal atmospheric pressure.

Vacuum is not an entity or a thing. It is just a pressure that is lower than normal atmospheric pressure. Pressure is a scale much the same as temperature; both indicate how much of something is present. Pressure indicates how many gas molecules are contained in a certain volume at a certain temperature. If there are zero gas molecules in a volume, there is zero pressure. There is no such thing as negative pressure. Pressure can only be positive or zero. The amount of vacuum can vary, but there is a maximum value of 14.7 psi vacuum. This is an average number; the exact maximum depends on one's altitude and weather conditions (current barometric pressure).

Consider an 'empty' open container at 77°F (25°C), at sea level on a standard Earth day. Close it and seal it. It would contain some number of gas molecules at one atmosphere of pressure, which is the same as 14.7 pounds per square inch absolute (psia) pressure. Since Earth's atmosphere is one of pressure, 14.7 psia pressure is considered to be the same as zero psi gauge (psig) pressure. Zero psig pressure means the gas is not compressed any more than it already is in the surrounding air. To convert, take absolute pressure and subtract 14.7 psi to get gauge pressure; conversely take gauge pressure and add 14.7 psi to get absolute pressure. Most times, the word 'gauge' is left off, much the same as the words 'per square inch' are left off when it is said that 'The tire takes 35 pounds of air pressure'; neither is technically correct but both are used widely as an abbreviation.

Taking that same container of air, consider removing some portion of the air molecules. This would cause the pressure in the container to drop lower than the 14.7 psia. For instance, the new pressure in the container might be 9.7 psia. The amount of vacuum is the difference between the normal atmospheric pressure and the actual absolute pressure. In this case the amount of vacuum is 14.7 minus 9.7 = 5 psi vacuum. In this example, the Earth's atmosphere is now exerting 5 psi of force on the outside of the container's walls. If one were to pump out all the air, one would have a full vacuum. A full vacuum is zero psi absolute, which is the same as 14.7 psi vacuum, which is the same as minus 14.7 psi gauge pressure. Notice that the gauge pressure is a negative number in this example. It is not a negative pressure. It is a negative number because we took the actual pressure, which was zero psi absolute and subtracted one atmosphere's worth of psi.

The amount of vacuum is generally not expressed in terms of pounds per square inch. Usually, vacuum is referred to as inches of mercury. Even though vacuum is widely used, most people don't care how much vacuum they have as long as they have enough. Originally, most of the people who cared how much vacuum they had were scientists. In the laboratory, scientists can make a very accurate vacuum gauge with ordinary lab items. These simple gauges read vacuum in inches of mercury. Since commercially manufactured gauges were originally sold mainly to the scientists, they used the same inches of mercury scale of vacuum.

On the other hand, the earliest compressed air gauges were used by engineers who made tools and other things that work with air pressure. These gauges have the units of pound per square inch because square inches are easy to measure, and calculating the force is simply multiplying the pounds per square inch (psi) times the square inches that the pressure is acting upon.

To understand inches of mercury, consider a U-shaped tube that is filled with mercury, with both ends pointing upward and open to the atmosphere. The mercury in the left side of the U is at the same height as the mercury in the right side of the U. Now, keep the left side of the U open to the atmosphere. Connect the right side of the U to a full vacuum. There is a certain amount of 'pull' to a vacuum. The atmospheric air pressure pushes downward on the mercury in the left side of the U. At the same time, there is a full vacuum pull on the right side. Since there is only a certain amount of vacuum pull, the mercury goes downward in the left tube, upward in the right tube until it balances out. Now the mercury in the right and left tubes are at different heights. If one measured the distance between the two, it would be 30.00 inches of mercury from a full vacuum. A partial vacuum is any amount of vacuum that is less than full vacuum.

10. Compression Molding

Overview

- **Introduction**
- **Materials and Typical Compound Formulations**
- **Compounding Processes and Equipment**
- **Molding Processes and Equipment**
- **Troubleshooting Guide**

10.1. Introduction

Compression molding involves molding a pre-manufactured compound in a closed mold under pressure and often using heat.

Typical compression molding applications include:

- Appliance housings
- Automotive body panels and structural parts
- Basketball backboards
- Cafeteria trays
- Door skins
- Furniture
- Electrical circuit boards and boxes
- Personal water craft
- Satellite dishes
- Shower/tubs and sinks
- Utility boxes

A pre-manufactured compound is a combination of some or all of the following: thermoset resin, catalyst, mold release, pigment, filler, various additives, and fiber reinforcement.

Compounds can be produced in several forms, including sheet molding compound (SMC), bulk molding compound (BMC), and wet molding compound.

Two additional compound forms are Low Pressure Molding Compound (LPMC) and Low Pressure, Low Temperature Molding Compound (LPLTMC). These compounds can be either in sheet or bulk form but are specially formulated to allow molding at lower pressures and/or lower temperatures than conventional SMC and BMC. Lower molding pressures mean lower press tonnage requirements, which reduces the capital expense for a new press or increases efficiency of an existing press. Lower molding pressures can also mean lower tooling costs since materials other than tool steel can be used. Lower molding temperatures can result in lower tooling costs and lower energy costs.

Table 10-1 compares the various types of compounds.

Table 10-1. Various types of compounds used in compression molding

Property	Sheet Molding Compound (SMC)	Bulk Molding Compound (BMC)	Wet Molding Compound
Part cross-section	Complex	Complex	Uniform
Parts per eight-hour shift	100-500	100-1000 (could be higher if multiple cavity molds used, i.e., dishes or electrical outlet boxes)	50-100
Compounding equipment	SMC machine and required mixing and dispensing equipment	BMC mixer	Mixer
Time required for maturation after compounding	2-5 days	0-2 days	None
Glass type	Normally chopped, but may include unidirectional or rolled/mat products	Chopped	Preform or rolled/mat products
Mold charging	Charge weight and geometry are predetermined. Charge cutting and loading is done manually or by computer-controlled slitting and loading.	Various (manual, injection or transfer)	Place preform in mold by hand and pour resin over
Molding temperature	Conventional: 270-320°F (132-160°C) Low temperature: 180-220°F (82-104°C)	Conventional: 270-320°F (132-160°C) Low temperature: 180-220°F (82-104°C)	Room temperature to 300°F (149°C)
Molding pressure	Conventional: 500-3000 psi Low pressure: 50-200 psi	Conventional: 500-3000 psi Low pressure: 50-200 psi	<50 psi
Mechanical properties	Good to high (with roll good or unidirectional fibers)	Low	High

10.2. Materials and Typical Compound Formulations

Overview

- **Resins**
- **Shrinkage Control Additives**
- **Catalysts**
- **Inhibitors**
- **Pigments**
- **Mold Release**
- **Fillers**
- **Thickeners**
- **Fiber Reinforcement**
- **Specialty Additives**
- **Typical Compound Formulations**

10.2.1. Resins

Unsaturated polyester resins (UPR) are the basis for most compression molding compounds. The type of UPR used varies, depending on the performance requirements for the finished part and cost. Resins used for compression molding can be broken into four broad categories:

A. Structural Resins—isophthalics, terephthalics, and urethane hybrids

Structural resins are used in applications requiring excellent mechanical properties and/or temperature and chemical resistance.

B. Low Profile Resins

Low profile resins are used in applications requiring excellent part appearance, dimensional stability, or class A surface profile, such as automotive body panels. Low profile resins are characterized by high reactivity rather than polymer type.

C. General Purpose Resins—orthophthalic or dicyclopentadiene

General purpose resins are used in applications that are cost sensitive and have more lenient part performance requirements than structural or low profile applications.

D. Specialty Resins

Specialty resins are designed for very specific application requirements, such as weather resistance or flame retardancy.

10.2.2. Shrinkage Control Additives

Unsaturated polyester resins shrink 3-7% by volume during cure. This shrinkage can create a variety of defects in molded parts, such as surface distortion, waviness, fiber print, and warpage. Shrinkage of unsaturated polyester resins can be controlled by the use of shrinkage control additives. However, the use of shrinkage control additives can reduce mechanical properties. Shrinkage control additives can be divided into two categories: low shrink additives and low profile additives.

- **Low shrink additives** minimize shrinkage but do not eliminate it. Low shrink additives are used in applications with lenient surface appearance and dimensional stability requirements. Low shrink additives are especially useful in applications requiring pigmentation. Common low shrink additives are polystyrene, polymethyl methacrylate, and rubber elastomers.

- **Low profile additives**, when used at appropriate levels, eliminate shrinkage and can even result in slight expansion. Low profile additives are used in applications requiring excellent surface appearance and dimensional stability, such as automotive body panels. Molding compound formulations using low profile additives have limited pigmentability and are generally white or light pastel colors. Common low profile additives are saturated polyesters and polyvinyl acetate.

Blends of low shrink and low profile additives are frequently used to impart the benefits of both types of additives to the molded part.

10.2.3. Catalysts

Catalysts or peroxide initiators initiate the chemical reaction of the UPR and monomer. For elevated temperature processing, the heat from the mold causes the catalyst to decompose, initiating the reaction. For ambient or low temperature processing, a promoter or a combination of promoters is needed to accelerate decomposition of the catalyst. Typical promoters are cobalt and amines. Catalyst selection depends on the molding temperature. Some common catalysts and their molding temperature ranges are given in Table 10-2. Two or more catalysts are often used to ensure complete cure.

Table 10-2. Common catalysts and molding temperature ranges.

Catalyst Type	Processing Temperature Range °F (°C)
Benzoyl peroxide (BPO) and amine promoter	90-120°F (32-49°C)
Benzoyl peroxide (BPO)	180-250°F (82-121°C)
Tert-butyl peroxy-2-ethyl hexanoate (PDO)	220-280°F (104-138°C)
Tertiary butyl perbenzoate (TBPB)	250-320°F (121-160°C)

10.2.4. Inhibitors

Inhibitors are used to control compound shelf life and cure rate. Two commonly used inhibitors are butylated hydroxy toluene (BHT) and para-benzoquinone (PBQ). BHT has little effect on elevated temperature cures but does significantly lengthen room temperature shelf life. PBQ lengthens both room temperature shelf life and cure time.

10.2.5. Pigments

Many, but not all, molding compounds are pigmented and a broad range of molded-in colors can be achieved. However, some limitations on color do exist. Fillers used in compression molding compounds can add color to the compound and limit the possible colors of the molded part. Also, the type of shrinkage-control additive used can limit color possibilities. Generally, darker and richer colors are more difficult to achieve. Darker colors can shift hue during maturation/aging.

Pigments are added during compound manufacture in either powder or pre-dispersed paste form. Powder pigments can be difficult to disperse in the compound due to agglomeration. Pre-dispersed pigment pastes are easier to disperse and can be used at lower concentrations than dry powders. Common white pigments are titanium dioxide and zinc sulfide. Carbon black is often used for black pigmentation. Pigment paste dispersions generally consist of the pigment dispersed in an unsaturated polyester grinding vehicle. Pigments can affect the shelf stability and reactivity of molding compounds.

10.2.6. Mold Release

Compression molding compounds generally contain internal mold release. Some of the most commonly used internal mold releases are zinc stearate and calcium stearate. Liquid mold release additives are also available. Use of these additives results in much lower SMC paste viscosity than that obtained with stearates.

10.2.7. Fillers

Compression molding compounds, with the exception of those used to mold parts for structural applications, are highly filled. Fillers lower material costs while enhancing molded part appearance, reducing shrinkage, promoting the flow of glass reinforcement during molding, and contributing to a harder, stiffer part. However, fillers increase the viscosity of molding compound paste, limiting the amount of glass that can be used. Glass content is directly related to the mechanical properties of the molded part with higher glass content yielding superior mechanical properties. Fillers also provide opacity and increased part density.

The most common fillers are calcium carbonate, clay, and alumina trihydrate. Clay fillers are used in applications requiring resistance to acid. Clay fillers are often used in combination with calcium carbonate fillers to control the compound paste viscosity, promote flow, and improve crack resistance in molded parts. Alumina trihydrate is generally used in applications requiring flame retardancy and/or good electrical properties.

10.2.8. Thickeners

Thickeners are used in sheet molding compound (SMC) to transform the material into a manageable, reproducible molding material. Thickeners chemically react with the resin portion of the compound, resulting in an increased viscosity. Thickeners are the last component added to the compound paste and begin to react immediately after addition.

Typical thickeners are alkaline earth oxides or hydroxides such as MgO, $Mg(OH)_2$, CaO, and $Ca(OH)_2$. MgO provides the quickest thickening of those listed and is the most commonly used thickener.

Thickeners are sometimes used in combination to achieve a particular thickening profile. Thickeners can be added as a powder or pre-dispersed paste. As with pigments, pre-dispersed pastes are easier to disperse in the compound and generally result in more consistent thickening.

A typical thickening profile is described in terms of paste (all ingredients except reinforcement) viscosity. During compounding, the paste viscosity must be low enough to allow for pumping and reinforcement wet out. Compounding is generally accomplished in less than 30 minutes from the time of thickener addition. Initially (immediately after thickener addition), paste viscosities are 10,000-60,000 cps (similar to thick pancake batter). The paste viscosity typically increases to 300,000-1 million cps (similar to pudding) in the first 60 minutes. After compounding, the material is moved to a maturation room, typically maintained at 90°F (32º), until it reaches its release viscosity. At the release viscosity, the compound has the required characteristics to allow it to be molded. These characteristics include:

- The compound must be manageable to allow for charge preparation.
- The viscosity must be high enough to carry the fiber reinforcement as the material flows in the mold.
- The viscosity must be low enough to permit sufficient flow for mold filling at reasonable molding pressures.

The release viscosity is typically between 10-30 MM cps (similar to bread dough) and is achieved in one to four days. The viscosity of the material continues to increase even after it has reached its release viscosity. The rate of this increase determines the molding window of the material. SMC may be moldable up to 100 million cps, depending on part complexity and molding pressure. Factors affecting thickening of a SMC formulation include thickener type and level, the acid value of the UPR, molecular weight of the UPR, and water content of the compound.

10.2.9. Fiber Reinforcement

Many types of fiber reinforcements, including glass, carbon/graphite, and aramid, can be used in compression molding. The most common fiber reinforcement in compression molding is glass. Various forms of glass fiber are used, depending on the type of compression molding compound being produced and molded. Chopped fibers ranging in length from ⅛"-1/2" are used in bulk molding compounds. Continuous rovings are used in SMC production. The roving is chopped to ½"-2" lengths during the SMC compounding process. The most common length of glass fiber for SMC is 1".

Glass fiber preforms, made to the general size and shape of the part, are used for wet and cold molding. For these processes, the glass and compound paste are combined during molding rather than during compound manufacturing as for BMC and SMC. Please refer to the section Low Volume Closed Molding: Preform Constructions for more information on glass fiber preforms.

Surfacing veil is often used in wet or cold molding to provide a resin-rich layer. Surfacing veil is a non-woven mat of either glass or polymer adjacent to the part surface. This improves molded part appearance and corrosion resistance. Reduced fiber blooming after sanding is another benefit.

Another factor in glass fiber reinforcement selection is the type and amount of sizing. Sizing is applied during glass fiber manufacture and holds the individual glass filaments together to form glass fiber strands. Glass fiber used in compression molding generally has 1-3% sizing by weight. Sizings can influence fiber characteristics such as chopability, abrasion resistance and resin wet out.

Sizings are categorized by their solubility. Sizings that have low solubility are categorized as hard. Fibers with hard sizings have good strand integrity, are easy to chop, and have good strengths. However, fibers with hard sizings can be difficult to wet out during compounding and can result in fiber print and non-uniform pigmentation in molded parts. Sizings that are highly soluble are categorized as soft. Fibers with soft sizings can be difficult to handle and chop; however, they are easy to wet out during compounding and contribute to good surface profile and uniform pigmentation in molded parts. Fibers with medium sizings have characteristics in between fibers with hard and soft sizings.

10.2.10. Specialty Additives

Other additives used in compression molding compounds include:

- Surfactants to reduce the viscosity of filled systems allowing more filler to be used.
- Additives to improve flame retardancy, such as antimony trioxides, tris phosphates, chlorinated paraffins and zinc borates.
- Additives to improve weathering, such as ultraviolet (UV) absorbers.
- Additives to improve compatibility between resins and shrinkage control additives.

10.2.11. Typical Compound Formulations

Typical formulations for SMC, BMC, wet molding and cold molding compound are shown in Tables 10-3 to 10-5.

Table 10-3. Typical SMC formulations.

SMC Formulation Component	Typical Materials	Quantity
Resin	Unsaturated polyester	55-100 parts
Shrinkage Control Additive	Low shrink additive: • Polystyrene • Polymethyl methacrylate • Rubber elastomer Low profile additive: • Polyvinyl acetate • Saturated polyester	0-45 parts
Catalyst	t-Butyl perbenzoate	1-2 parts
Inhibitor	para-Benzoquinone (PBQ)	0.005-0.05 parts
Pigment	Various	As required
Mold Release	Zinc stearate	3-6 parts
Filler	• Alumina trihydrate • Calcium carbonate	150-250 parts

Thickener	• Group II Alkaline earth oxides
	• Hydroxides
	  • $Mg(OH)_2$
	  • $Ca(OH)_2$
		0.5-1.5 parts

Glass fiber	Continuous roving chopped during compound production, ½"-2" lengths, commonly l" lengths. Continuous glass fiber can be used for structural applications.	15-65%

Table 10-4. Typical BMC formulations.

BMC Formulation Component	Typical Materials	Quantity
Resin	Unsaturated polyester	55-100 parts
Shrinkage Control Additive	Low shrink additive: • Polystyrene • Polymethyl methacrylate • Rubber elastomer • Finely powdered polyethylene Low profile additive: • Polyvinyl acetate • Saturated polyester	0-45 parts
Catalyst	• t-Butyl peroctoate (injection or transfer) • t-Butyl perbenzoate (manual)	1-2 parts 1-2 parts
Inhibitor	Para-Benzoquinone (PBQ)	0.005-0.05 parts
Pigment	Various	As required
Mold Release	Calcium stearate	7-12 parts
Filler	• Alumina trihydrate • Calcium carbonate	200-400 parts
Glass fiber	Chopped roving ⅛"-1" lengths	10-30%

Table 10-5. Typical Wet Molding formulations.

Wet Molding Formulation Component	Typical Materials	Quantity
Resin	Unsaturated polyester	55-100 parts
Shrinkage Control Additive	Low shrink additive: • Polystyrene • Polymethyl methacrylate • Rubber elastomer Low profile additive: • Polyvinyl acetate • Saturated polyester	0-45 parts
Catalyst	Various	Various
Inhibitor	Various	Various
Pigment	Various	As required
Mold Release	Fatty acid or stearate	Various
Filler	• Alumina trihydrate • Calcium carbonate	< 100 parts

10.3. Compounding Processes and Equipment

Overview

- **Sheet Molding Compound (SMC)**
- **Bulk Molding Compound (BMC)**
- **Wet Molding Compound**

10.3.1. Sheet Molding Compound (SMC)

The sheet molding compound process involves three basic steps.

1. A compound paste is mixed that includes all the formulation ingredients except for the reinforcement.
2. The compound paste and reinforcement are combined and formed into a sheet.
3. The compound is allowed to thicken or mature.

Mixing of Compound Paste

Mixing of the compound paste can be done by batch, continuously or as a combination of batch and continuous mixing called batch/continuous mixing. For all paste mixing processes, the paste must be mixed well to ensure all components are completely dispersed. Highly filled compound pastes will heat during the mixing process and the temperature must be monitored. To control the thickening reaction, the temperature of the paste, when delivered to the compounding equipment, should be 85-90°F (29-32°C) for batch processes. Higher temperatures can be used for continuous processes.

A. **Batch Mixing**—Batch mixing involves mixing the compound paste in a mixing vessel such as a pail, drum, or mixing kettle using a high shear Cowles mixer. All formulation components are added to the mixing vessel manually. Batch mixing is an economical method adequate for preparing small amounts of compound paste for short production runs. Batch mixing has some disadvantages for long production runs, including low material efficiencies, batch-to-batch variations, and labor requirements for delivering the batch mix to the compounding equipment.

B. **Continuous Mixing**—Continuous mixing is best for long runs. This method involves pumping liquid ingredients and metering dry ingredients to a continuous mixer. Continuous mixing results in a very consistent compound due to accurate pumping and metering of the ingredients. Continuous mixing also results in very little waste. However, the length of setup time makes short runs of multiple formulations impractical.

C. **Continuous/Batch Mixing**—Continuous/batch mixing is a combination of the batch and continuous mixing processes that uses ‘A’ and ‘B’ component batch tanks. The ‘A’ side generally includes all compound paste ingredients except thickener. The ‘B’ side consists of thickener or thickener pre-dispersed in a non-thickenable resin mix. The ‘A’ and ‘B’ sides are pumped at a predetermined ratio through a static or dynamic mixer to the compounding equipment.

Compounding

The compound paste and reinforcement are combined and the compound formed into a sheet using an SMC machine. SMC machines are sized by the width of compound that they produce. SMC machine widths vary from two to five feet. The most common width is four feet. Figure 10-1 shows a SMC machine.

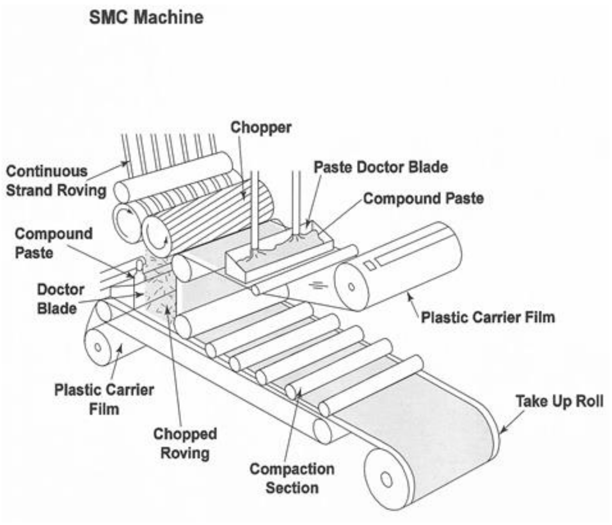


Figure 10-1. SMC machine.

The compound paste is delivered to two reservoirs called doctor boxes; it is deposited on a carrier film that is being pulled through the machine. A metering blade called a doctor box blade, set to a predetermined height above the film, controls the amount and thickness of the compound paste deposited on the film. Continuous strand roving is pulled through a glass chopper and the chopped glass fiber is dropped on the compound paste on the lower film. The upper and lower films meet so that a sandwich is created between the carrier films consisting of two resin layers with chopped glass in the center. The carrier films are pulled through a compaction section in which pressure is applied to accomplish glass wet out. After compaction, the material is either wound on a take-up roll or festooned (folded similar to computer paper) into a box and moved to a thickening or maturation room.

The glass content of the SMC is determined by the height of the doctor box metering blades, the speed of the glass chopper, and the speed at which the carrier films are being pulled through the compounding machine. The glass content of the SMC is generally verified during production by comparing the areal weight of the compound being produced with the areal weight of the glass being dropped on the compound.

A gamma-backscatter gauge can be added on a traversing mechanism that monitors sheet weight and adjusts the chopper speed or doctor blade height.

The carrier film is typically a nylon/polyethylene co-extrusion. The nylon prevents monomer loss through the film and the polyethylene can be used to heat-seal the compound edges to prevent monomer loss. Film edges can also be folded or taped to prevent monomer loss.

The pressure in the compaction section is an important process parameter. The compaction pressure needs to be high enough to wet out the glass, yet low enough to prevent compound from being squeezed out of the film edges.

Thickening

The thickening or maturation room is typically controlled at 90°F (32°C) to provide consistent thickening of the SMC compound. To verify thickening and determine compound readiness for molding, a retain of the compound paste is taken after thickener addition, but prior to glass addition. This retain is stored with the SMC and monitored for viscosity. A Brookfield HB viscometer with T-bar spindles is typically used for these viscosity measurements.

10.3.2. Bulk Molding Compound (BMC)

During the manufacture of bulk molding compound, all formulation components are combined in the mixer. One of the most common mixer types is a sigma blade mixer. Liquid components of the formulation are pumped or manually added to the mixer and agitated until dispersed. Dry components, except for glass fiber, are added next and mixed until thoroughly wet. The glass fiber is the last formulation component added and is mixed in until thoroughly wet. Continued mixing of the compound after glass wet out can result in unnecessary degradation of the reinforcement, which can cause reduced mechanical properties of the molded part. BMC is ready to mold when it is discharged from the mixer, unless maturation time is required for chemical thickening.

10.3.3. Wet Molding Compound

Wet molding compound is the oldest and simplest compression molding compound form. Reinforcement is incorporated during the molding process rather than during compounding. Manufacture of wet molding compound involves mixing formulation components using a simple Cowles mixer.

10.4. Molding Processes and Equipment

Overview

- **Introduction**
- **Charging**
- **Part Formation**
- **Finishing**

10.4.1. Introduction

As stated earlier, compression molding involves pressing and curing a pre-manufactured compound in a closed mold cavity under pressure and often heat.

The compression molding process involves four steps.

1. The compound is inserted or charged into the mold.
2. The mold closes and the part is formed.
3. The part is allowed to cure.
4. The formed and cured part is removed from the mold and finished.

One to two operators per press are generally sufficient even for rapid cycle times. Additional operators may be required for very large parts. Operators can work on charge preparation for the next part or part finishing of the last part during molding.

10.4.2. Charging

Charging (or placing) of the material to the mold varies based on compound form.

SMC

The charge must be prepared by removing the carrier film from the sheet and cutting the sheet to the desired shape. Cutting can be done manually or by computer-controlled slitting. Two major factors influence the configuration of the charge:

A. **The charge must contain enough material to fill the volume of the closed mold.** Since, in most cases, it is impractical to measure volume, the amount of charge added to the mold is controlled by weight. The standard charge weight for a specific compound and mold are often determined experimentally. Depending on part size and the areal weight of the SMC, several layers of SMC may be needed to achieve the required weight.

B. **The surface area of the charge must be sufficient so that the material has time to flow and fill the mold prior to gelation.** As the surface area of the charge increases, the chance of trapping porosity in the molded parts also increases. Flow of the material in the mold helps to remove air from compound.

   Complex parts may require that several separate charges be placed throughout the mold to ensure complete fill. One drawback to multiple charges is that knit lines are created when the material flows and the charges meet. Knit lines are often low in strength and are susceptible to cracking.

   The shape and surface area of the charge are again generally determined experimentally for a specific compound and mold combination. The surface area of the charge is generally referred to as a percentage of the mold surface area or mold coverage.

After the charge is prepared, it may be loaded into the mold manually or with automatic loading equipment.

BMC

Three basic methods are used for charging BMC to the mold.

A. **Hand charge placement** is similar to charging of SMC in that the charges are controlled by weight. After weighing, the charge is placed in pre-determined areas of the mold.

B. **Transfer** involves the use of a plunger to force material into the mold. Pressure applied to the mold serves to hold the mold together during the compound charging rather than to compress the material into the mold.

C. **Injection** involves use of a screw extruder to push material into the mold. Pressure applied to the mold serves to hold the mold together during the compound charging rather than to compress the material into the mold.

Transfer and injection compound charging processes have shorter cycle times and require less labor than hand charging, but also require more capital expense.

Wet Molding

A fiber preform is placed in the mold and the compound paste is poured into the mold over the preform. The pressure applied to the mold during closing forces the paste to flow into the preform, wetting the glass fiber.

10.4.3. Part Formation

Compression molding is done using a matched-die tool. Figure 10-2 shows a simple compression molding tool.

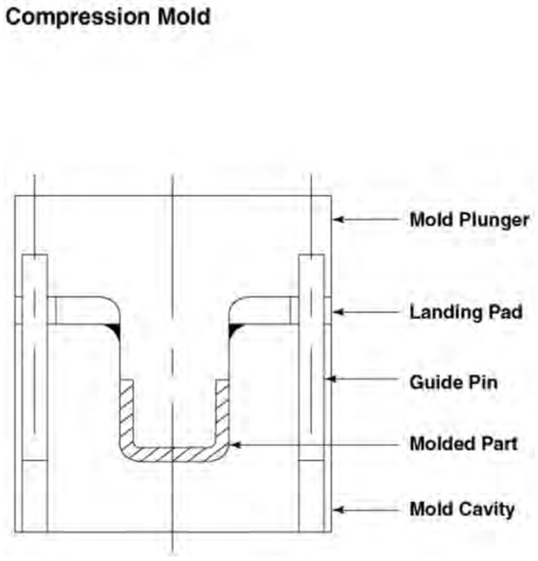


Figure 10-2. Compression molding tool schematic.

Tool

The tool consists of a cavity and a plug or plunger. Guide pins maintain the proper relation between the tool members. The tool cavity forms the outer surface of the part. The tool plunger forms the inner surface of the part being molded and serves to compress the compound when the tool is closed. The molding compound is thus confined to the open space between the plunger and cavity while it cures. Numerous features can be incorporated into the molds to facilitate production.

Elevated Temperature Molding

Elevated temperature molding requires provisions for heating in the mold design. Some presses are equipped with heating platens that transfer heat to the molds. In some mold designs, the cavity and plunger are drilled to permit a medium to circulate for heating. Common heating mediums are oil or steam. A boiler or hot oil heater is required to heat the steam or oil and circulate it between the mold and heating unit. Knockout or ejector pins are often used to push the molded part away from the mold.

Conventional Compression Molds

Conventional compression molds are made from P20 tool steel and are usually chrome-plated. Alternate tool materials such as aluminum, nickel shell and composite can be used for low-pressure compression molding. Tools made from these alternate materials are less expensive than tools made from tool steel; however, the production run life of tools made from these alternate materials is generally shorter than for tool steel.

Compression Molding

Compression molding is done in hydraulic, air, or mechanically operated presses; hydraulic is the most common. The two general types of hydraulic presses are downstroke and upstroke presses.

A. **Downstroke**-The downstroke press makes use of an overhead cylinder to move the top platen downward and apply pressure to the mold. This type of press is advantageous for molding large parts since the lower platen remains at a constant level and allows the operator to walk around the mold and on the platen as is sometimes required for charging or demolding large parts.

B. **Upstroke**-An upstroke press has the cylinder positioned below, and the ram moves the lower platen upward. This type of press provides greater safety for the operator. A malfunction in the hydraulic circuit causes the lower platen to drift downward, opening the press. A hydraulic malfunction in a downstroke press could cause an operator to be trapped.

Molds Bolted

Molds are generally bolted to press platens with clamp bolts at the front and back. Sheets of phenolic or glass-bonded mica are often used to insulate the mold from the press platen. Use of insulation reduces the heat transferred from the mold to the press and gives better thermal uniformity within the mold.

Mold Daylight

Mold daylight is the measurement between the upper and lower platens of the press in the open position. This dimension minus the stroke (the maximum platen movement) is the minimum die height to ensure that pressure will be applied to the part. The opening between mold halves must be sufficient to allow charging and part removal.

Press Controls

Press controls generally include pressure controls, closing and opening speed controls and a clamp timer. When the clamp time expires, the press automatically opens. Safety features, such as laser systems that prevent the press from closing if an operator is too close to the press, can also be incorporated.

Molding Conditions

Molding conditions vary between the different compound forms. Typical molding conditions are shown in Table 10-6.

Table 10-6. Typical Molding Conditions

Compound Forms	Pressure	Temperature	Time
SMC Conventional Low Pressure/Low Temperature	500-3000 psi 50-500 psi	270-320°F (132-160°C) 180-220°F (82-104°C)	30 seconds to 5 minutes
BMC Conventional Low Pressure/Low Temperature	500-3000 psi 50-500 psi	270-320°F (132-160°C) 180-220°F (82-104°C)	30 seconds to 5 minutes
Wet Molding Compound	<50 psi	Room temperature to 350°F (177°C)	2 to 10 minutes

Molding Pressure

Molding pressure is influenced by compound flow characteristics, press tonnage and part complexity. On a particular tonnage press, the larger the part, the lower the pressure that can be exerted. More complex parts require high molding pressures to ensure complete fill. Molding temperature and time are influenced by compound flow and cure characteristics and by part size and thickness.

10.4.4. Finishing

Finishing of the part involves flash removal, drilling of any holes required for assembly, and packaging. Flash removal can be accomplished with sandpaper, a file or a box knife.

10.5. Troubleshooting Guide

Overview

- **SMC Compounding**
- **BMC Compounding**
- **Molding**

10.5.1. SMC Compounding

Table 10-7. SMC Compounding.

Problem	Potential Causes	Suggested Remedies
Glass content too low	• Doctor box blade too high • Film speed too fast • Glass chopper speed too slow • Not enough glass rovings	• Reduce doctor box blade gap. • Reduce film speed. • Increase glass chopper speed. • Ensure proper amounts are feeding the chopper.
Glass content too high	• Doctor box blade too low • Film speed too slow • Glass chopper speed too fast	• Increase doctor box blade gap. • Increase film speed. • Decrease glass chopper speed.
Dry fibers in SMC	• Low compaction pressure • Paste viscosity too high	• Increase compaction pressure. • Reduce paste viscosity or slow thickening rate.
Compound squeezing out edges of film	• Compaction pressures too high • Paste viscosity too low	• Reduce compaction pressure. • Increase paste viscosity or increase thickening rate.
Compound contains air after compaction	• Compaction pressures too low • Paste viscosity too low • Glass content too high	• Increase compaction pressure. • Increase paste viscosity or increase thickening rate. • Reduce glass content.
Shelf life stability	• Premature gelation	• Minimize pigment amounts with carbon black, iron (brown), and cobalt (blue). • Use shelf life inhibitor. • Do not expose the material to excessive heat (store in a cool room at 60-70°F).

10.5.2. BMC Compounding

Table 10-8. BMC Compounding.

Problem	Potential Causes	Suggested Remedies
Dry filler or glass (can result in mold abrasion, blisters, etc.)	• Compound viscosity too high • Mixing times too short	• Modify compound formulation to lower the viscosity. • Increase mixing times.
Compound too wet (can make compound difficult to charge and can result in blisters, porosity, etc.)	• Compound viscosity too low • Mixing times too long	• Modify compound formulation to increase the viscosity. • Decrease mixing times.

10.5.3. Molding

Table 10-9. Molding.

Problem	Potential Causes	Suggested Remedies
Non-fills (mold not filled completely during pressing)	• Charge weight too low • Compound gels before mold is filled • SMC charge area too small • Tool shift deflection • Material discharged from mold • Trapped air • Molding on stops and cocked die/platen	• Increase charge weight. • Decrease molding temperature; decrease mold closing time; increase molding pressure; decrease compound reactivity. • Increase SMC charge area. • Move charge toward non-fill area. • Decrease pressure; reduce clearance of mold-shear edges. • Remove trapped air from charge prior to compression; decrease area of SMC charge to increase flow. • Increase charge weight after confirming gap is 0.003"-0.010" around all sides of the mold
Blisters	• Trapped air • Trapped or unreacted monomer • Dry glass in compound • Weakness at knit line	• Remove trapped air from charge prior to compression; decrease area of SMC charge to increase flow. Slowing press closing speeds will reduce initial flow and the tendency to trap air in the laminate. Tool misalignment during closing can cause uneven flow. • Reduce mold temperature; decrease compound reactivity; reduce styrene content of compound. • Increase SMC roller compaction; increase mixing time for BMC. • Modify charge to prevent formation of knit line.

Table 10-10. Molding (cont.)

Problem	Potential Causes	Suggested Remedies
Blisters (cont.)	- Incomplete curing	- Increase cure time; increase mold temperature; increase compound reactivity.
	- Contaminants such as moisture, press oils, lubricants, and external mold release	- Check mold, SMC, and raw materials for contaminants.
Cracks	- Excessive shrinkage	- Modify compound formulation to provide better shrinkage control.
	- Weakness at knit line	- Modify charge to prevent formation of knit line.
	- Sticking to mold surface	- Modify mold release in compound; apply external mold release to mold.
	- Sticking to flash area	- Clean and wax flash area.
	- Insufficient shrinkage	- Modify compound to increase shrinkage.
	- Sever undercuts or ejector pins holding part down, causing fracture	- Remove problem undercut.
	- Unbalanced ejector pins/plate	- Verify ejector pin motion.
	- Ejector speed is too fast	- Reduce ejection speed.
Surface porosity	- Area of charge is too large; air cannot escape because of short flow path	- Decrease charge area.
	- Pre-gel	- Decrease mold temperature; increase closing speed; decrease compound activity.
	- Unwet glass or air in compound	- Increase SMC compaction pressure; increase BMC mixing times.
	- Low viscosity compound	- Increase SMC maturation viscosity; increase filler or glass content.
	- Contaminants such as moisture, press oils, lubricants, and external mold release	- Check mold, SMC, and raw materials for contaminants.
	- Air entrapment due to dirty shear edges and vacuum ports	- Clean shears or vent ejector pins.
	- Mold halves too close in temperature, entrapping air	- Maintain temperature differential to keep shears edge open to allow air to escape.
Warpage or distortion of molded part	- Shrinkage after demolding	- Cool parts in jigs having desired shape; modify compound to improve shrinkage control.
	- Incomplete	- Increase cure time; increase mold temperature; increase compound reactivity.
	- One mold surface much hotter than the other	- Reduce differential between mold surfaces.

Table 10-10. Molding (cont.)

Problem	Potential Causes	Suggested Remedies
Warpage or distortion of molded part (cont.)	• Unbalanced construction • Fiber orientation	• Change laminate design. • Shorten flow path by modifying charge; increase compound viscosity to improve fiber carry.
Wavy surface on flanges or ribs	• Interruption of uniform flow	• Increase pressure; change mold design; modify charge.
Wavy surface on main part surface	• Insufficient shrinkage control	• Reformulate compound to improve shrinkage control.
Sink marks at rib or flange locations	• Non-uniform shrinkage during molding • Charge laid directly over ribs or bosses causes shrinkage • Low temperature differential causes simultaneous curing on core and cavity, increasing shrinkage • High molding pressure throughout hold time	• Reformulate compound to improve shrinkage control; increase mold temperature on one half of mold; shorten chopped fiber lengths; change mold design; modify charge. • Optimize charge pattern. • Increase temperature differential by 20°F (11°C) with appearance surface at a higher temperature. • Thirty seconds after compression, reduce pressure by at least 25%.
Scumming (dull or streaked areas on the part that transfer to the tool surface)	• Failure of the internal mold release at molding temperature • Incompatibility of resin additives	• Molding temperature below that of release agent; increase tool temperature. Increasing flow distance has a cleaning effect on the tool. • Incompatibility or amount of shrinkage control additive; reformulate material. Pre-gel of material cause separation of shrink control additives; increase the gel time of material.
Laking (areas of low gloss on cooled part)	• Pre-gel • Insufficient molding pressure • Mold contamination • Too much shrinkage • Mold temperature is low, or there are hot and cold spots on tool	• Decrease mold temperature; increase closing speed; decrease compound reactivity. • Increase molding pressure. • Clean and condition mold. • Modify formulation to reduce shrinkage. • Adjust tool temperature and heating issues; increase temperature on tool surface.
Dull part surface	• Pressure too low • Incomplete cure • Dull mold surface	• Increase pressure. • Increase mold temperature; increase cure time; increase compound reactivity. • Rework mold surface to a higher polish.

Table 10-10. Molding (cont.)

Problem	Potential Causes	Suggested Remedies
Flow lines (local waviness on part surface)	• Long flow path creating fiber orientation • Low viscosity creating fiber orientation	• Modify charge pattern. • Increase viscosity of compound to improve fiber carry.
Dieseling or Burning (dark brown surface stain, generally in non-filled area)	• Trapped air and styrene vapors raise temperature to ignition point	• Modify charge so material pushes air out of mold as it flows; reduce closing speed. Check for hot or cold spots on the mold surface.
Cobwebbing (white threadlike strands that appear on the SMC during carrier film removal)	• Polyester/Thermoplastic resin incompatibility	• Insufficient 1st hour thickening; increase level to obtain 500,000 cps in the paste. Excessive amount of thermoplastic additive; reduce level. Investigate one of the many additives that increase thermoplastic compatibility.

11. Casting

Overview

- **Introduction**
- **Cast Polymer**
- **Solid Surface**
- **Flexible Casting Resins**
- **Thermal Shock Testing**

11.1. Introduction

Casting is the simplest manufacturing process for unsaturated polyester resin. Casting processes are varied, but all involve pouring catalyzed resin, either filled or unfilled, into a mold and allowing it to harden or cure. Once cured, the part retains the shape of the mold. It is then removed or demolded and 'finished,' meaning the surface can be sanded, polished, and/or painted.

Casting applications include but are not limited to decorative figurines, polymer concrete, flex trim moldings, furniture, embedment castings (e.g., paperweights), and countertops and bathware. Although the general casting process is the same for all applications, raw materials used vary depending on the performance requirements for each type of finished product.

Three main categories of the casting industry will be covered in this chapter. These are cast polymer, solid surface, and flexible casting resins.

11.2. Cast Polymer

Overview

- **Introduction**
- **Materials**
- **Molds**
- **Manufacturing Process**
- **Troubleshooting Guide**
- **Supplies for Marble Production**

11.2.1. Introduction

This section will focus on the countertop and bathware industry, most commonly referred to as Cast Polymers. Cast polymer products are used in commercial, residential, industrial, and medical areas. The cast polymer product line has extended beyond the original kitchen and bath markets. Examples of cast polymer products are vanity tops, sinks, bathtubs, shower pans, wall panels, countertops, windowsills, flooring, bar sinks, interior and exterior facades, banisters, and furniture, with the list continuing to grow. There are three distinct product lines within cast polymers:

- **Cultured Marble**—gel coated surface; filled with calcium carbonate; usually pigmented and/or veined; opaque in appearance.
- **Cultured Onyx**—gel coated surface; filled with aluminum trihydrate; usually veined with a non-pigmented background; translucent in appearance, showing depth like natural onyx.
- **Cultured Granite**—gel coated surface; filled with specially designed granite filler to produce a multi-colored speckled appearance.

An unlimited variety of colors, cosmetic designs, and shapes that can be manufactured or fabricated provide cast polymer products with distinct advantages over their natural counterparts. In addition, natural products are porous (which can become a source of bacterial growth) and can easily be stained, while cast polymer products are not porous and are stain resistant.

11.2.2. Materials

Gel Coat

For cast polymer products of cultured marble, onyx, and granite, the use of gel coat is required. Gel coat is not used with solid surface products. It is a polyester coating that is applied to the mold surface and becomes an integral part of the finished product. The function of gel coat is to protect the part from its environment, providing chemical, water, and weathering resistance (UV stability). The gel coat is also accountable for the part's cosmetic surface and durability. It is the gel coated surface that is visible and therefore a critical aspect of the part.

Both pigmented and clear gel coats can be used to produce cast polymer products although clear gel coats are generally more popular.

Pigmented gel coats are mainly used to produce cultured marble. Parts produced with pigmented gel coats are solid colored. The pigmented gel coat forms an opaque coating and hides the color of the matrix poured behind it. Pigmented gel coats used in cultured marble are formulated similarly to those used in open molding.

Clear gel coats add depth and dimension to the part and allow artistic colors and designs in the matrix to be viewable. In cultured marble, clear gel coat provides the ability to view vein patterns in the matrix. Clear gel coat is required with onyx to accentuate the translucency and depth of the veining to more closely resemble natural onyx. Clear gel coat is also required to show off the multi-colored effect of granite filler.

Cultured granite can be manufactured using one of two methods:

- **Granite-effect filler** is mixed into the resin and poured behind a clear gel coat.
- **Specially designed spray granite chips** are mixed with a specially designed clear gel coat and then sprayed onto the mold. Standard marble matrix is poured behind it.

Clear gel coats used in the cast polymer industry are specifically formulated for cast polymer applications. Key differences from clear gel coats formulated for other industries are lower color and slower cure rates. Clear gel coats to be used with spray granite chips also have different viscosity and spray characteristics.

To meet performance requirements of bathware products, both pigmented and clear gel coats must be based on ISO/NPG polyester resins. Please refer to the chapters on Open Molding for additional information on gel coats.

Resin

Casting resin is mixed with fillers to make the matrix. The matrix gives the cast part its structural integrity. Resin suppliers formulate casting resins from several components, including the polymer, reactive monomer, promoters, inhibitors, and specialty additives. The specific components and amounts used are dictated by the end-use application, manufacturing process, required cure behavior, end-use physical properties' requirements, and manufacturing plant conditions. Plant conditions can dictate that resin gel time and/or viscosity be varied to account for seasonal temperature changes.

Unsaturated polyester polymers are the basis of casting resins. Cultured marble, onyx, and granite resins are based on orthophthalic polyesters. Cultured marble resins can also be based on hybrid polyesters. Because of color constraints, hybrid polyesters are generally not acceptable for cultured onyx or granite. For additional information on resin chemistry see section FRP Composites: General Chemistry of FRP Composites.

There are several advantages to using hybrid marble resins versus orthophthalic marble resins:

1. Hybrid resins are inherently lower in viscosity and higher in solids content.

   This is an advantage when reporting emissions (HAP and VOC content) for permit requirements.
2. Hybrid resins have superior filler wetting capabilities which allow higher filler loading.

   This helps to reduce material cost by reducing resin percentage in the matrix.
3. Hybrid resins tend to develop green strength and cure faster.
4. Hybrid resins have lower peak exotherm and shrinkage rate.

   The low shrinkage rate reduces the build-up of internal stress during the cure of the part, which improves the part's thermal shock resistance. Also, because of the low exotherm and shrinkage, hybrid resins are ideal for making large parts such as tubs and shower pans.
5. Hybrid resins are very compatible with lightweight fillers.

The monomer fulfills two roles in the polyester resin. First, it reacts and cross-links with the unsaturation sites in the polymer to form the cross-linked thermoset material. Second, it reduces the viscosity of the polymer to workable levels. The most common monomer used in casting resins is styrene.

Promoters, also called accelerators, split the peroxide catalysts used to cure casting resins into free radicals. These free radicals attack the unsaturation sites in the polymer, preparing them for reaction with the monomer. Promoters used in casting resins determine the cure behavior and also have a significant impact on the color of the finished part. In general, the higher the promotion level, the darker the cured resin color. As a result, the types and amounts of promoters used in casting resins vary depending on the production speed and color requirements for each application.

- For **cultured marble**, the matrix is usually pigmented or poured behind pigmented gel coat, making the cured resin color less important than for some other applications. As a result, marble resins are typically highly promoted for faster cure.
- For **cultured onyx and granite**, clarity and low-cured casting color are critical factors. Cultured onyx cannot be pigmented as heavily as cultured marble because it will reduce its translucency. As a result, onyx and granite resins have very low promoter levels and correspondingly slower cure rates.
- **Swing or dual-purpose resins** are a compromise between marble and onyx/granite resins. Swing resins contain a higher level of promoters than onyx/granite resins but less than marble resins. The result is a lower cured casting color than cultured marble but faster cure rates than onyx/granite. For most manufacturers, the small sacrifice in cured color is worth the increased speed of production with onyx and granite products. In many cases, the color difference is not noticed. The slower cure of swing resins in cultured marble applications can be addressed with catalyst. Manufacturers that do not want to buy separate resins for marble and onyx/granite applications also use swing resins.

Inhibitors provide shelf life stability to casting resins as well as help control the working or gel time. Free radicals generated in the polyester resin during storage or after the addition of peroxide catalyst react preferentially with the inhibitors. Only after all the inhibitors are consumed does the cross-linking or curing process begin.

In addition to the above materials, a number of other additives can be used in casting resin formulations to affect properties. These include processing aids such as air release agents and wetting agents. Additives can also be used to affect the product's performance, such as UV absorbers and light stabilizers for weathering performance.

Fillers

The filler is the largest part of the cast polymer composition. The type of filler to be used depends on the cast polymer product.

A. Cultured Marble

1. **Calcium Carbonate ($CaCO_3$)**—Typical marble filler is calcium carbonate (ground limestone). Calcium carbonate is mined and ground into small particles. Its size is measured in units called mesh. Filler particles are sorted through screens with different size openings. Mesh size is designated by the number of holes per linear inch, with lower numbers indicating a coarse or large particle size and higher numbers indicating a fine or small particle size. Calcium carbonate fillers are supplied as 'all coarse' or 'all fine' particles or as preblended bags of coarse and fine particles.

   A mixture of particle sizes of filler is used to provide maximum loading, with coarse 40-200 mesh and fine at 325 mesh. Fine particles fill in between coarse particles so that resin-rich areas are reduced and higher filler loadings can be achieved. For temperatures below 85°F, a mix ratio of 2 parts coarse to 1 part fine provides excellent loading properties while avoiding warpage and cracking problems. For temperatures above 85°F, a mix ratio of 3 parts coarse to 2 parts fine will maintain the same matrix viscosity.

2. **Dolomite**—Just like Calcium carbonate, dolomite is a mined mineral, a mixture of calcium carbonate and magnesium carbonate. It is supplied just like calcium carbonate. Dolomite is more abrasive than calcium carbonate and therefore may require more equipment maintenance.

3. **Lightweight Fillers**—The use of lightweight fillers in cast polymer products has been steadily increasing. Lightweight fillers are hollow spheres made of glass (silica) or plastic. They occupy space or volume but do not add weight, which effectively reduces the weight of a given part without changing its dimensions.

   Lightweight fillers are used with calcium carbonate. They can be bought separately or preblended with calcium carbonate to a known weight displacement.

   Typically, these fillers demand a higher resin percentage for wet out and to maintain a flowable viscosity. Also, because of its insulating effect, lightweight fillers cause the exotherm of the curing part to increase.

B. Cultured Onyx

1. **Aluminum Trihydrate (ATH)**—The filler of choice for cultured onyx, ATH is a by-product resulting from the processing of bauxite minerals in the manufacturing of aluminum. Onyx grade ATH is much brighter white than calcium carbonate, thus eliminating the necessity of using background pigment. It is a semi-translucent granular filler which provides a visual effect like natural onyx and has the added feature of acting as a flame retardant. At temperatures of 410°F (210°C), ATH releases its water particles, slowing combustion and reducing smoke generation.

2. **Lightweight Fillers**—The use of lightweight fillers is not recommended in cultured onyx since this would reduce translucency.

C. **Cultured Granite**—Granite effect fillers are gaining in popularity. Filler suppliers have specially formulated colors and particle size distributions to achieve a multi-colored speckled granite appearance and to give the product a cosmetic textured look. The colored granules may be coarse ground minerals or synthetically made from pigmented resins. The resin demand will vary greatly depending on the granule size(s) and distribution. There is a difference in granite-effect filler mixed into the matrix versus spray granite filler mixed into the gel coat and sprayed; therefore, method of application needs to be noted when purchasing these fillers.

While inexpensive initially, if not chosen and checked properly, fillers can become extremely costly. For example, if too much coarse filler is used and subsequently settles, a resin-rich area will result on the back side which could cause warpage. If too much fine filler is used, the viscosity will be very high, resulting in air entrapment. If the fillers contain too much moisture or become damp, they will affect the gel and cure.

Lot-to-lot variations and contamination of fillers can also affect the cured casting color. There can be significant particle size variations from lot-to-lot as shown in Table 11-1.

Table 11-1. Particle Size Variation in Lots.

Sieve Size	Lot A%	Lot B%	Lot C %
40	1.5	1.75	1.5
60	7	6.5	6.5
80	6.5	6.7	7.5
100	7	10	10.5
120	7	7.25	4
150	6	12	6
200	19.5	19.75	30.5
Through 200	45.5	36.75	33.5

Each lot should be checked as soon as it is delivered to determine if these factors will affect gel, cure, color, and matrix viscosity. To make this determination, make a part with the new filler and compare it to parts made with the lot already in use. Do not wait until it is time to switch to a new lot. Fillers should be checked in conjunction with the resin for their effect on matrix color, gel time, viscosity, and cure properties.

Catalyst/Initiator

Catalyst is the component needed to ‘harden’ the polyester resin mix into a solid mass. Technically, catalyst causes the reaction but does not participate in the reaction. In the composites industry, the correct term is initiator, which starts the reaction and is consumed by the reaction. There are three common types of room temperature initiators used in cast polymers:

A. **Methyl Ethyl Ketone Peroxide (MEKP)**—The most widely used initiator, MEKP is a clear liquid that easily mixes into the resin. It is the most cost-effective choice and is available in different strengths to give a variety of curing characteristics. The recommended range is 0.5-3% catalyst level based on resin amount.

B. **2,4-Pentadione Peroxide (2,4-PDO)**—Also known as acetylacetone peroxide (AAP), this initiator offers fast cure time and high peak exotherm. Although it does lengthen gel time, Barcol hardness builds quickly. Typically, 2,4-PDO is used during the colder temperatures. It is available separately or pre-blended with MEKP; however, pre-blends are the most popular. When blended, the MEKP controls the rate of the gel time and the 2,4-PDO provides the faster cure rate and higher peak exotherm. The recommended range is 1-2% catalyst level based on resin amount. Above 2%, 2,4-PDO peroxide may inhibit cure. The only disadvantage with this initiator is that with some resins, cured casting color may have a yellowish tint.

C. **Cumene Hydroperoxide (CHP)**—CHP lowers peak exotherm and lengthens gel and cure times. Lower peak exotherm reduces cracking, crazing, and shrinkage but also slows down Barcol development. CHP is most popularly used during hotter temperatures and/or on thick parts like shower pans and tubs. It is available separately or pre-blended with MEKP; however, pre-blends are the most popular.

Some control over gel and cure rates can be achieved by changing initiator levels and blending the above mentioned initiators. The initiator level should be maintained between 0.5-3% with 1.25% being the norm. Initiator levels below 0.5% may cause curing problems. Levels of 0.5% should only be used during hot ambient temperatures where the heat will serve as a secondary catalyst or in large mass products (e.g., tubs) where higher exotherms will be generated because of the part’s thickness. Initiator levels above 3% are at the point of diminishing return, with very little improvement seen in relation to the use of the higher amount. If the initiator level is excessive, the initiator will cancel itself out to the extent that the reaction will stall. As the initiator level moves outside the range of 0.5-3%, change should be made to a cooler or hotter initiator strength. Once this choice has been exhausted, a different gel time version of the resin should be ordered from the resin supplier.

11.2.3. Molds

The mold determines the shape, texture, and gloss of the finished part. It is a mirror image of the part, so any defect in the mold will be reflected in all the castings made from that mold. Simple molds have one size and shape. Custom parts require special dimensions so dividers and moveable bowls provide the flexibility to cast these one-time needs. Holding them in place can be done with double-face tape, suction cups, clamps, hot glue, or other ingenious methods. Providing cosmetic transitions, such as a small radius where the floating bowl or divider bars meet the deck, can be accomplished using wax fillets or clay.

NOTE: Different clays vary in formulation, and with some, there may be technical problems that can show up as fisheyes, pre-release, or that simply cause cure problems with the gel coat. One way to reduce these problems is to dust the applied clay with baking soda or fumed silica. Then make sure to blow off the excess powder before applying the gel coat.

Mold Materials

A number of materials can be used to make a mold. The most common are shown in Table 11-2.

Table 11-2. Common materials used to make molds.

Mold Type	Advantage	Comments
Fiberglass	• Easy to make • Long lasting • Can be textured • Radii can be built in • Easy to repair • Easy to handle • Easily customized	• Type most often used
Stainless Steel or Chromed Steel	• Durable • Hard surface • Smooth finish	• Expensive • Deep scratches and dents not easily removed
Formica or Melamine	• Easy to make • Can be textured • Inexpensive	• Not long lasting • Not durable • Surface finish is fair
Glass	• Perfectly flat • Low maintenance	• For flat panels only • Care must be taken not to crack or scratch the surface

Mold Configuration

Vanity top molds are modular or custom. Modular molds are fixed-size, one-piece, seamless construction with bowls, back splash, and any special features built in. Custom molds may have built-in back splashes but bowls and dividers are separate parts and positioned as desired.

Vanity top molds include the following accessories:

A. **Drain Plug**—Usually made of polyethylene, the drain plug measures 1.75 inches in diameter. It can be permanent or removable. It serves to form the drain hole and attachment point for an overflow assembly (if used). The plug is attached to the bowl during set up before gel coat application.

B. **Overflow Assembly**—Although not required by the national plumbing codes, overflows may be needed for some specific applications. A permanent plastic drain collar and tube may be encapsulated and remain in the bowl or a reusable flexible tube may be retrieved from the cured part. The tube attaches to the bowl and drain plug and should be installed after gel coat is applied. The end connected to the drain plug should remain unattached until after gel coating for easier gel coat application to the bowl. This will allow the critical area of water impingement to be easily gel coated to the proper thickness. The overflow tube should be spaced at least ½" from the bowl surface to help prevent cracking.

C. **Faucet Plugs**—These form 1" diameter holes for faucet installation. Plugs may be solid knockouts (re-usable) or cardboard rings that remain in the part. Plugs may be placed on wet gel coat to be held in position when the gel coat cures. Clay can also be used to hold them in position.

D. **Female Hat**—The hat functions to hold the matrix in place to form the bowl's wall thickness. It is contoured to the male bowl mold and allows for overflow assembly (if used). It is usually constructed with fiberglass, polyethylene, or polystyrene. Fiberglass and polyethylene hats are reusable (removed from part). Polystyrene hats are permanent (remain on the part).

   Hats may be full or partial. Full hats are usually used with modular molds. Full hats completely cover the mold and can be clamped in place for the one-pour production method. Partial hats are sometimes used with modular molds and always on custom molds since these molds will differ in bowl location. Partial hats cover the bowl only and are used in the two-pour production method.

Polyethylene Dividers

These are often used to custom-size flat areas, such as wall panels, back splash, and vanity decks, into various shapes or sizes.

11.2.4. Manufacturing Process

Overview

The 12 steps listed below provide a very general outline of the manufacturing procedure for cast polymer:

1. Prep and set up molds.
2. Apply mold release agent to the molds.
3. Spray gel coat onto the mold.
4. Remove gel coat overspray from mold flange while gel coat is still wet. This is easily done by applying masking tape on the flange before gel coating and then removing the tape after gel coating.
5. When the gel coat is 'castable,' apply matrix (resin, filler, catalyst, pigment) to the gel coated mold.
6. During the process of transferring the matrix into the mold, a variety of veining techniques can be applied to achieve the final cosmetic appearance of the part.
7. Vibration is added to level the matrix in the mold and removes air bubbles from the gel coated surface.
8. Remove excess matrix from the mold flanges after the matrix gels but before it shrinks.
9. When possible, remove the back hat, open the back splash, and eliminate any other constraints on the part.
10. Demold the part as soon as possible to avoid internal stress fractures.
11. After demolding, place the part on a supporting surface to retain its shape during cure. If it is a solid surface product, it is recommended that the part be postcured.
12. Once cured, the part is finished (trimmed, sanded, and polished) and repaired (if necessary).

Mold Preparations and Maintenance

The mold determines the texture, smoothness, and gloss of the finished part. It is imperative that the mold be kept in optimum condition. New molds must be broken in following the directions of their manufacturer. (If building a mold, refer to the chapter on Tooling for suggestions regarding procedure.) Molds for marble will last through the production of many parts and provide maximum performance if good mold maintenance is practiced and good workmanship is used in producing the mold.

A mold maintenance program is essential in a marble shop to ensure the long life of polyester molds. While it sometimes suffices to rewax a mold when it starts pulling hard, Polynt has found that problems such as sticking and polystyrene build-up result from neglect of the mold over time. Polynt suggests a routine mold prep schedule. It is far better to prevent polystyrene build-up with a good, consistent preventive maintenance program than to allow molds to get into bad shape.

To determine the prep schedule:

- Determine how many pulls (parts) it takes for the mold to start sticking.
- Routinely prep and wax the mold before this number is reached. For example, if the mold starts to pull hard and gloss is diminished after seven parts are pulled, then always prep and rewax the mold after pulling the sixth part.

With careful adherence to such a program, molds will last longer and produce better looking parts with less patching.

The mold prep area should be completely enclosed and away from the production area. There should be isolated stalls for grinding and a separate area for gel coating.

Mold build-up should not be confused with what was once referred to as 'wax build-up.' Wax build-up is more correctly stated as 'wax leave-on' because the build-up occurs when excess wax is not buffed off. In fact, mold build-up is styrene (polystyrene) that has come from the production gel coat. It adheres to the mold mainly for these reasons:

- Wax leave-on
- Pulling parts too soon (the more 'green' a part when pulled, the more susceptible it is for styrene to adhere to the mold)
- Too many parts made in the mold without proper maintenance

Normal mold preparation involves machine polishing the mold with a glaze. If the mold is very hazy and has some polystyrene build-up, a coarser compound should be used and followed with the glaze. The mold should be washed and rinsed with cold water to remove compounding dust and compound vehicle.

Some compounds can cause sticking if left on the mold. Six fresh coats of mold wax should follow the water wash. The fish eye and pre-release tendency will always be greater after this fresh wax. However, if the gel coat is sprayed to a thickness of 18-20 mils, the fish eyes should be covered and pre-release tendency is minimized.

If the mold has a lot of build-up, it must be removed by scrubbing with a commercial stripper (toluene, methyl ethyl ketone, ethyl acetate, or 'wax off').

Note: Do not use styrene for cleaning molds.

All of these commercial strippers are flammable and health hazardous. Safety precautions should be observed:

(1) Read the Safety Data Sheet (SDS).

- Wear gloves.
- Wear safety glasses.
- Make sure the area is well ventilated.
- No smoking.

After molds have been stripped, if there is still roughness on the mold surface, then the mold should be sanded with sandpaper no coarser than 600-grit and polished. If roughness or scum is left on the mold, it will permit quicker mold/polystyrene build-up when put back into production. If using a polymer mold release system, follow supplier's instructions. Too much polymer mold release will cause fish eyes in the gel coat.

For more information, please refer to the section Tooling: Mold Maintenance.

Gel Coat Application

Application of gel coat is the most critical aspect of cast polymer production since it provides the ultimate first impression of the product. Also, performance of the finished product is directly related to how well the gel coat is applied. For information on spray equipment and technique, please refer to section Conventional Gel Coat: Application.

Clear marble gel coats, specifically designed for cast polymer, and pigmented gel coats should be used in the production of cast polymer. Typically, gel coat is sprayed in a wet film thickness of 16-24 mils. For parts that are not as critical (for example, wall panels), the minimum wet film thickness is acceptable. For parts with high exposure to water impingement, the maximum wet film thickness is recommended. It is important that the gel coat is applied evenly throughout the part; therefore the use of mil gauges is encouraged.

Film gel time must be long enough to allow leveling and air release but short enough to prevent the styrene in the gel coat from attacking the release barrier between it and the mold surface. If the latter situation occurs, it would cause release impairment leading to cracking and edge peeling or stress and shrink lines. Likewise, if the gel coat thickness is insufficient, the styrene in the marble matrix can penetrate the gel coat into the mold release and cause similar problems. Thin gel coat also may not cure thoroughly.

The gel coat is allowed to partially cure before the marble mix is poured. Cure times are normally 30-90 minutes depending upon plant temperatures, catalyst level, and air movement. Slight air movement speeds cure by moving styrene vapor off the gel coat surface. Styrene vapor does inhibit gel coat cure. Forced air ovens, set at 100-120°F, can reduce the gel coat cure time to a range of 15-20 minutes. Uneven heat, too much heat, extended time, and too little or too much air movement in the oven may cause pre-release.

NOTE: Gel coats are flammable. Ovens used must be designed to accommodate flammable materials.

General Matrix Formulation

Listed are general starting points for each product line. As production continues, the matrix formulation becomes customized to each manufacturer.

A. Cultured Marble

Table 11-3. Base cultured marble formulation.

Material	Quantity
Resin	22 - 26% (1)
$CaCO_3$	74 - 78%
Base Pigment	0.5 - 1.5%
Initiator/Catalyst	0.5 - 3.0% (based on resin content)

- Recommendation based on orthophthalic polyester resin. If using a hybrid based marble resin, the starting resin recommendation is 20-24%.

B. Cultured Onyx

Table 11-4. Base cultured onyx formulation.

Material	Quantity
Resin	26 - 30%
Onyx Grade ATH	70 - 74%
Initiator/Catalyst	1.0 - 3.0% (based on resin content)

Due to the finer particle size of ATH filler, cultured onyx requires higher resin content than marble to wet out and to reduce matrix viscosity to aid in air release. Due to the translucency of this product, it is necessary to release as much air as possible (unlike opaque cultured marble where it is only critical to remove the air from the gel coat surface). The catalyst level is higher than marble due to the lower promoter level of onyx resin.

C. Cultured Granite

Table 11-5. Base granite matrix (granite mixed into the matrix) formulation.

Material	Quantity
Resin	22 - 30%
Granite Effect Filler	70 - 78%
Initiator/Catalyst	1.0 - 3.0% (based on resin content)

Resin content varies greatly with granite effect fillers depending on the particle size and distribution of the granite particulates. The larger the granite chips, the lower the resin content. The finer the granite chips, the higher the resin content. If the mix is too loose (too high in resin content), the larger particulates will fall to the gel coat surface and not achieve the desired appearance. If the mix is too thick, air bubbles will be trapped in the matrix. The initiator/catalyst level will also vary greatly depending on the granite color(s) being cast. It is advisable to keep a log of the initiator/catalyst level versus granite color for reference.

Table 11-6. Base spray granite (granite mixed into the gel coat) formulation.

Material	Quantity
Clear Gel Coat	50 - 60%
Spray Granite Effect Filler	40 - 50%
Initiator/Catalyst	1.5 - 2.0% (based on resin content)

Unlike granite filler mixed into the resin and poured behind clear gel coat, spray granite is granite filler mixed with a specially formulated clear gel coat and sprayed as the gel coat. The standard marble matrix is poured behind it. There is a difference in appearance between these two methods. As above, there is a wide range of gel coat/resin content due to the particle size and distribution of the granite particulates. Please refer to the previous notes on Granite Matrix.

It is a common practice to use marble clear gel coat as the carrier for the spray granite. The advantage is in not having to stock another product. The disadvantage is that gel coat is designed to cure in thin films and therefore is very reactive.

To get the coverage or ‘hide’ of spray granite, 20-30 mils film thickness is required. Depending on granite particle size, thicker film thicknesses may be required. If the layer is too thin, the matrix behind it will show through. At 20-30 mils film thickness, standard gel coat may cure too fast and exotherm too high, resulting in a variety of problems such as pre-release, excessive shrinkage, distorted surface, etc.

Specially formulated gel coat has been developed to resolve this issue. The advantage is that the specially formulated gel coat is very highly thixed to help suspend the granite particulates and will cure at a much lower exotherm than standard clear gel coats. The disadvantage is in having to stock another material.

The typical application process for spray granite is:

1. Apply 10-12 mils of wet clear gel coat to the mold. This will give the finished product a smooth glossy surface and add depth to the finished appearance.
2. Wait for the gel coat layer to dry to a tacky finish, then spray on 25-35 mils of the wet spray granite mix (gel coat or resin plus spray granite effect filler).
3. Wait for the spray granite layer to dry to a tacky finish, and then pour on the marble matrix. It is recommended to pigment the background of the marble matrix the same general color as the spray granite for cosmetic purposes.

There are differences between granite effect fillers intended to be mixed into the matrix versus spray granite intended to be mixed into gel coat. Make sure to specify to the supplier which product is needed.

Matrix Mixing Methods

There are several different methods for mixing the matrix (incorporating the resin, pigment, catalyst, and fillers).

- If possible, add and mix the catalyst to the resin first before adding the filler. Mixing in the catalyst first will ensure even distribution of the catalyst throughout the mix.
- If adding separate fine and coarse fillers, mix in the fine or lightweight fillers first since they are more difficult to wet out before the coarse fillers.
- When using dry pigment, make sure the pigment is well mixed into the resin before adding catalyst. If dry pigment comes into direct contact with catalyst, it creates a gaseous reaction that will leave many air voids in the matrix.

A. **Hand Batching/Small Batching Method**—Materials are manually measured and mixed in a batch mixer, making 100-400 pounds of matrix per batch.

1. Premeasure all ingredients first.
2. Add measured resin into mixing pot.
3. If adding background color, add pigment to the resin. Mix for one minute. Add a small amount of filler to help disperse the pigment.
4. Add catalyst to the pigmented resin. Mix for one minute.
5. If using lightweight filler, add to the mixing pot and mix until all is we tout.
6. If using separate fine and coarse fillers, add fine fillers first. Mix until all is we tout. Then add coarse filler and mix until all is wet out.
7. Scrape down sides and mixing blade for unmixed material.
8. Mix for additional three minutes to ensure thorough mixing.
9. Add veining pigment(s) if desired.
10. Pour onto molds.

B. **Auto-Dispensing Method** — Auto-dispensing equipment is designed to deliver measured amounts of resin and filler into the mixing pot. The primary advantage is that most auto-dispensing units have resin heating capability that allows higher filler loading. This equipment eliminates the labor and time previously required for measuring materials, delivers consistent material quantities, and reduces material costs by heating up the resin to increase filler loading.

Maintenance is critical. As for any machine, calibration should be performed regularly to ensure proper delivery of material amounts.

1. Operator chooses preset formulation and enters batch size into the machine.
2. Heated resin is dispensed into the mixing pot.
3. Catalyst may be added by hand or by machine. Mix for one minute.
4. Add background pigment by hand and mix for one minute. May add small amount of filler to help disperse the pigment.
5. Machine dispenses filler into the mixing pot. Mix until all is wet out.
6. Scrape down sides and mixing blade for unmixed materials.
7. Mix for additional three minutes to ensure thorough mixing
8. Add veining pigment(s) if desired.
9. Pour onto molds.

C. **Auto-Casting Method**—As the name suggests, auto-casting equipment is designed to measure, mix, and dispense the matrix directly onto the mold. The machine is programmed with a formulation. It measures the heated resin, filler, catalyst, and background pigment. The materials are dispensed into a tube called the barrel. In the barrel, there is an auger screw that serves as the mixing mechanism and transports the matrix through the tube. Veining pigment, if desired, may be automatically added as the matrix nears the end of the barrel or may be hand applied to the mold. Once the matrix emerges from the barrel, it falls onto the mold or can be put in a bucket and then hand poured onto the mold.

Like the auto-dispensing equipment, auto-casting equipment has resin heating capabilities which allow higher filler loading. The whole process is automated, reducing the labor force. Matrix output is high, greater than 50 pounds per minute, which increases product output. Finished product should be consistent. No need for measuring materials.

Note: Keeping the machine calibrated is critical.

Veining

Veining is an art that becomes an identifying mark for each manufacturer. Veining techniques vary as widely as the resulting designs. No one method is better than another. It is purely a subjective preference.

Table 11-7 lists some factors that will influence veining results.

Table 11-7. Factors that influence veining results.

Factor	Result
Matrix Viscosity	• Thick matrix will produce crisp sharp veins. • Thin matrix will produce blurred veins.
Temperature	• Hot temperatures will decrease or thin the matrix viscosity. • Colder temperatures will increase or thicken the matrix viscosity
Vibration	• Long vibration time will produce blurred or less defined veins. • Short vibration time will produce crisp, sharp veins. • It is important to keep the vibration time constant in order to maintain consistent appearance.

Pouring Methods

Transferring the matrix from the mixing pot/bucket to the mold can be done using paddles, scoops, gloved hands, or simply pouring out of the bucket. Pouring method, again, is the preference of the manufacturer based on the cosmetic appearance of the product.

In general, the veined matrix is applied on the mold first. Once the vein pattern is established, the remaining matrix is transferred and fills up the mold.

A. **Pouring Vanity Tops/Bowls**

- **One-Pour Method**—The full hat, in this case with a lip that covers the whole mold, is positioned and clamped into place to stop matrix leakage. The rest of the mold is then filled as necessary. Some techniques utilize overfilling of the mold areas, followed by quickly clamping down the hat to force the extra matrix into the bowl area of the hat. Vibration is continued an additional five minutes to ensure air removal.
- **Two-Pour Method**—This method is required with partial hats. It is similar to the one-pour method to the point of adding the hat. Also, the initial pour can be a higher viscosity because the semi-closed mold situation in single pouring, which hampers flow and air release, is not a factor. Crisper veining will result.

  Once the cavities of the deck are filled, along with a matrix cover of ⅛"-¼" on the bowl area, a hat with a 3"-5" lip is positioned around the bowl area only. This may be removable or permanent.

  Once the first pour has gelled and has enough strength to hold the hat in place to prevent leakage, the second mix is made to fill the cavity of the hat. This mix can be lower in viscosity to allow it to flow more easily. It may be any color as it will not show through the first layer of marble.

  The second pour, to fill the hat, may be added shortly after the first pour gels, or it may be delayed until after the first pour has exothermed. Timing of the second pour is important. If either pour shrinks significantly while the other pour is soft, cracking can result. The catalyst level of the second pour may be reduced to delay and lower exotherm development.

B. **Pouring Large Parts (tubs, shower pans, etc.)**—Tub castings can present unique problems because of their mass. The larger the mass, the higher the exotherm during cure. The high exotherm may lead to excessive shrinkage and cracking. Tubs may also vary in wall thickness, which can lead to differential shrinkage and cracking. A thicker area may begin shrinking and create a tear or crack if adjacent to a thinner, less cured area. Tubs are often cast in multiple pours, which are catalyzed at different times.

Table 11-8 shows points to consider in casting tubs:

Table 11-8. Points to consider in casting tubs.

Point	Consideration
Catalyst Level	• Catalyzation should be appropriate for the ambient temperature. • Catalyst levels may range from 0.5% in the hot summer months to 1.25% in the cold winter months. The norm is approximately 0.75% (based on resin content). • Low catalyst levels coupled with variable thickness can contribute to cracking due to low green strength development.
Special Formulated Tub Resins	• Tub resins are high viscosity versions of marble resins. (With higher viscosity, there is less styrene monomer in the resin.) • Lower styrene content reduces the amount of shrinkage during the cure. • Also, it is desirable to have thick matrix viscosity for tubs so that the matrix will adhere to the mold during the mold filling process.
Demolding	• Remove the hat as soon as allowable to dissipate the exotherm. • Suspend the mold so that the part is right-side up one inch above the floor to allow gravity to aid in demolding the part. • Demold the part as soon as possible to alleviate any stress on the matrix.

Vibration

The effect of vibration is a result of time, frequency, and amplitude. Frequency is the rate at which vibration occurs. Amplitude is the power or energy of the vibration. Ideally, vibration causes the mold and matrix to resonate at the vibration frequency. Heavier parts and the mold can dampen the amplitude and make the vibration ineffective. Likewise, the vibrator motor can make loud noises but not actually transfer its power (amplitude) to the mold. It is recommended to periodically check the effectiveness of the vibrator motor.

Vibration is used during the process of filling the mold to help the matrix flow over the mold surface. As the matrix moves, filling the mold, air bubbles are able to come to the surface and break. Once the mold is filled, the vibration continues to help the entrapped air move off the gel coated side and migrate to the back of the part.

Vibration should commence during the filling of the mold and stop several minutes after the mold is filled. Vibration should never continue once the matrix has gelled. Excess vibration can wash out the vein pattern and cause the filler to settle to the mold side, which can contribute to warping. If air bubbles are seen on the gel coated side, it may be due to ineffective vibration or vibration time that is too short.

Demolding

Once the matrix has gelled, the mold should be trimmed. This requires removal of tape, overspray gel coat, and the matrix from the mold flange. This helps the gel coat to release from the mold and reduces the potential problem of edge peel. As the part cures and begins to shrink, it is good practice to remove the back hat (of a bowl), open the back splash, remove inserts, and eliminate other constraints as soon as possible. Note: Do not force these parts off because that will stress and possibly crack the part.

During the curing process, the matrix will release or shrink away from these parts and its removal should be relatively easy.

Demold the part as soon as possible to avoid developing internal stress as the part shrinks on the male mold. In extreme cases, it is possible for the part to shrink and lock itself onto the male mold. As stated before, do not force the part out of the mold. It should release on its own. If it requires too much energy or pressure, then the part is not cured enough to come off. When working with large parts such as tubs, the mold can be suspended upside down to allow gravity to demold the part.

Once the part is demolded, it should be supported on templates or tables to reduce the possibility of warping while it is completing its cure. This is especially critical if the demolded part is still very ‘green’ (flexible or soft).

Finishing

Once the part is cured, it will need to be finished. Typical finishing includes:

- Sanding the edges and the back or bottom of the part (smoothing off the surfaces)
- Polishing the top surface (gel coated side)

- Drilling or smoothing the edges of the faucet and drain holes
- Repairing or patching of surface defects

Before making any repairs to marble, it is important to determine if the part is worth saving. Do not attempt to repair parts under the following circumstances:

- Repairs are needed in the bowl area. Such repairs will compromise the performance of the part.
- If the part has veining, granite, or other distinguishing features that will be difficult or impossible to duplicate in a repair.

Repairs in the deck or back-splash can be made successfully by using the following procedures for gel coat patching. These involve tested and proven methods that will not compromise appearance or performance.

A. Gel Coat - Putty Patching

Putty patches involve small areas, generally no bigger than a pea.

1. Scuff sand the area to be repaired with 220-grit sandpaper. This ensures that the patch will adhere to the patch surface.
    - If the repair is into the matrix, it will be necessary to first patch with fresh matrix, and then cover with gel coat.
2. Catalyze the gel coat with 1.2-3% standard MEKP; 2.5% is preferred.
    - Color and performance will be compromised by catalyzing outside of these ranges.
3. Dab a small amount of catalyzed gel coat into the sanded, recessed void.
4. Place a film of mylar, waxed paper, etc. over the patch to reduce the profile of the patch and seal the surface.
    - This technique will reduce sanding and keep the gel coat from gumming the sand paper.
5. Allow patches to cure for 2 hours minimum before sanding.
    - To reduce the cure time, heat the patch with a hot air gun. Do not allow heat of the gun to exceed approximately 120°F; otherwise, color will be affected.
6. Sand the surface with sandpaper. Gradually use finer and finer sandpaper, beginning with 400-grit and proceeding in increments no greater than 200-grit at a time. i.e., 400, 600, 800, and then 1000-grit sandpaper.
    - Clean the surface with a fresh dry cloth between each grit.
7. Buff to a high gloss and wax.

B. Gel Coat - Spray Patching

1. Scuff sand the area to be repaired with 220-grit sandpaper. This ensures that the patch will adhere to the patch surface.
    - If the repair is into the matrix, it will be necessary to first patch with fresh matrix, and then cover with gel coat.
2. Spray the gel coat directly over the area to be repaired. Feather outwardly to provide enough gel coat thickness for sanding and buffing.
    - Use the gel coat full strength. Do not reduce with acetone, styrene, or wax solution since these will affect performance of the patch. Do not use no more than 3% catalyst.
3. Immediately overspray Spraycure® 970C961 or PVA parting film over the backside, wet-on-wet, to a continuous film.
    - This provides a tack-free surface and makes sanding easier.
4. Allow patches to cure for 2 hours minimum before sanding.
    - To reduce the cure time, heat the patch with a hot air gun. Do not allow heat of the gun to exceed approximately 120°F; otherwise, color will be affected.
5. Sand the surface with sandpaper. Gradually use finer and finer sandpaper, beginning with 400-grit and proceeding in increments no greater than 200-grit at a time. i.e., 400, 600, 800, and then 1000-grit sandpaper. Clean the surface with a fresh dry cloth between each grit.
6. Buff to a high gloss and wax.

Influence of Temperature

Gel and cure of the gel coat and matrix are influenced by many factors. Catalyst levels, catalyst type, humidity, types of fillers, and pigments can shorten or lengthen gel times. Gel and cure rates can be manipulated by variations of catalyst type and level. The use of higher catalyst levels produces faster gel times but will also produce hotter cures. The use of lower catalyst levels produces slower gel times but will also lengthen total cure times.

The most influential factor and the hardest to control is temperature. Often, attention is given to the temperature of the resin, but temperatures of the fillers, mold, and room are neglected. If the resin is warmed to 100°F (38ºC) and it is mixed 75% with filler at 50°F (10ºC), the combined matrix temperature will be approximately 60-70°F (15-21ºC). The gel and cure is further inhibited by pouring the matrix onto a 50°F (10ºC) mold sitting at 50°F (10ºC) ambient temperature.

Heat is another catalyst to the cross-linking reaction. The exotherm generated by the reaction is needed to help drive the cure through. If the ambient temperature and the materials are cold, the exotherm is lost to heating its surroundings. In cold temperatures, the viscosity of the matrix thickens, cure times are extended, and degree of cure issues and air entrapment problems are predominant. As ambient temperatures go up, the matrix viscosity decreases and high exotherms and inconsistent shrinkage become the main problems. As catalyst levels and resin content are lowered to account for the higher temperatures, the green strength development becomes affected, which can lead to cracking or tearing problems.

A crack is characterized by a sharp straight line and is primarily due to excessive shrinkage caused by high exotherms. Cracks can be controlled by reducing the catalyst level and optimizing the filler to resin ratio.

A tear will have a haphazard direction, is ‘whitish’ in color and appears in areas of maximum stress. Tears are primarily due to poor green strength development.

A mix will hold significantly more fillers at higher temperatures. For example, a resin adjusted to 1,500 cps when used in a mix of 23% resin, and 26% fine and 51% coarse fillers has a viscosity of 344,000 cps at 77°F (25°C). The same mix at 99°F (37°) is only 152,000 cps and is too thin to be workable. Often times, mixing viscosity is fine-tuned by adding resin or filler. In this case, adding more filler will bring up the viscosity. As this is done, the resin percentage can drop to the point where green strength development is significantly slower, which can result in edge peel, stressing, and possibly tearing of the part.

A recommended procedure would be to alter the coarse-to-fine ratio to maintain proper matrix viscosity while maintaining the original resin content. It is advisable when using a two-component filler system to increase the percentage of fine filler during the hotter temperatures. A standard mix using a two coarse-to-one fine filler ratio will require 2% additional filler at 99°F (37ºC) versus 77°F (25ºC) to keep the same viscosity. At ambient temperatures over 85°F (29ºC), fine fillers should be increased to a ratio of three coarse-to-two fine fillers. If pre-blended fillers are used, it is suggested to keep bags of fine fillers available for such adjustments.

Another alternative to keeping mix viscosity constant without changing filler ratios at higher temperatures would be to use higher viscosity resins. From the manufacturing side, whatever opportunities available to keep materials as cool as possible should be used. Problem parts should be cast during the coolest point of the day. Starting earlier and finishing earlier for summer hours to take advantage of cooler mornings deserves strong consideration.

11.2.5. Troubleshooting Guide

This section provides some possible causes or explanations for typical problems encountered during the production of cast polymer products.

Filler Particle Packing

Filler particle packing refers to the distribution of the individual filler particles within the matrix. The looser the distribution, the larger the spaces between particles. The tighter the distribution, the smaller the spaces between particles. Use of all coarse or large filler particles results in the loosest distribution of particles. Use of a combination of coarse and fine fillers results in the tightest particle packing. See Figures 11-1 and 11-2 below.

Tight filler particle packing in cast polymer products enhances the performance of the finished part. In cast polymer products, resin fills in the gaps between particles. If the gaps are large enough, the resin may shrink and pull away from the filler particles creating small fissures within the matrix. This is referred to as resin laking. The fissures caused by resin laking may go unnoticed until stress or impact, such as thermal cycling, causes it to open to a visible surface crack.

Filler particle packing and particle size also affect the matrix viscosity. See Figure 11-3 below. Use of all coarse filler particles will result in higher viscosity due to poor packing. Use of all fine particles will result in high viscosity due to poor particle packing and high resin usage. Again a blend of coarse and fine particles is ideal. Use of two parts coarse and one part fine fillers will yield the lowest matrix viscosity.

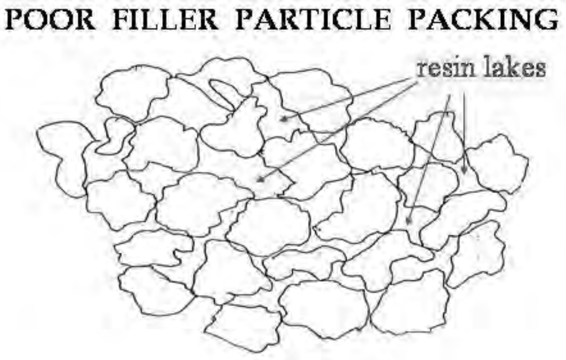


Figure 11-1. Poor filler particle packing.

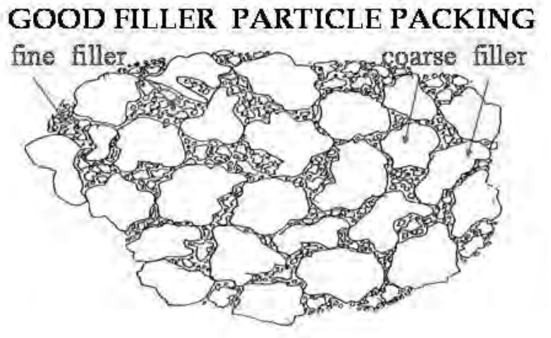


Figure 11-2. Good filler particle packing.

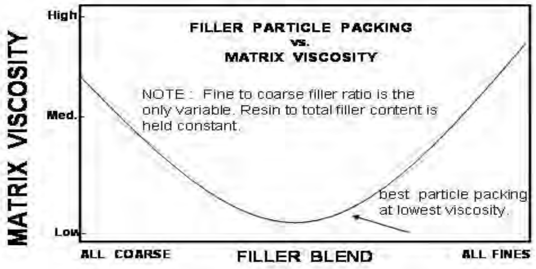


Figure 11-3. Filler particle packing vs. matrix viscosity.

Temperature

Temperature affects the viscosity of the resin which can lead to changes in the resin content of the matrix. The higher the temperature, the lower the viscosity; the lower the temperature, the higher the viscosity. Examples of viscosity versus temperature relationships for two resins are shown in Figures 11-4 and 11-5. Low temperatures affect the viscosity much more dramatically than high temperatures. The higher the original resin viscosity, the more temperature changes will affect the viscosity.

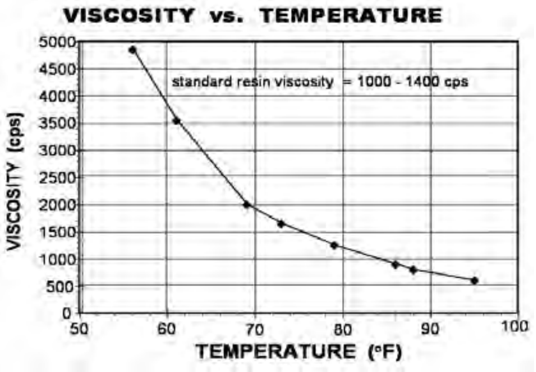


Figure 11-4. Viscosity of poor filler particle packing data.

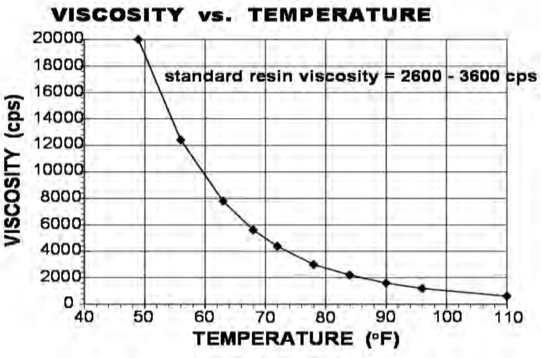


Figure 11-5. Good filler particle packing data.

Temperature also affects the matrix viscosity as shown in Figure 11-6. Starting with resin at 1,260 cps viscosity and blending 25% resin and 75% filler, the resulting matrix has a 200,000 cps viscosity. When the temperature increases to 95°F (35°C), the 1,260 cps resin viscosity can thin down to 600 cps. To get the same 200,000 cps matrix viscosity using the 600 cps viscosity resin, the matrix composition will be about 22.7% resin and 77.3% filler. This is a 2.3% resin reduction in the matrix composition. While 22% resin is acceptable, care must be taken if resin percent gets too low (less than 20%). Too low of a resin content may lower the finished product's performance, such as thermal shock.

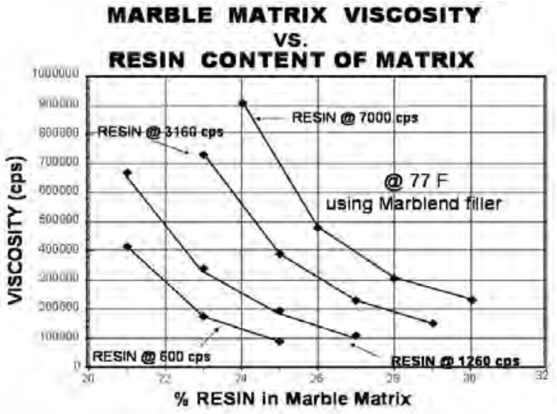


Figure 11-6. Marble matrix viscosity vs. resin content of matrix

Cracking and Tearing

As temperatures increase, cracking and tearing problems will also increase.

Cracks (sharp straight lines) are primarily due to excessive shrinkage caused by high exotherm.

Tears (lines which are haphazard or lack direction, and may have frayed appearance) are primarily due to low green strength (see information below) and will appear in areas of maximum stress.

Cracking and tearing can be avoided by adjusting filler ratios in relationship to increases in temperature.

As temperature increases:

A. DO NOT: Increase filler percent to increase matrix viscosity.
  - Increased filler percent will lower the resin percent.
  - Lower resin percent will reduce green strength* development which can lead to tearing.

B. DO: Maintain resin percent and increase ratio of fine fillers.
  - Standard filler mix is two parts coarse to one part fine.
  - At temperatures over 90°F, a ratio of three parts coarse to two parts fine will maintain original viscosity.

C. DO: Switch to higher viscosity resin.
  - Allows use of standard filler mix (two parts coarse to one part fine).

What is Green Strength?

In a filled polyester system, green strength is the strength development between gelation and the point of peak exotherm (cure rate). This is measured by the time required from catalyzation to a measurable Barcol hardness.

Soon after gelation, the matrix begins to shrink. It is not immediately apparent due to the adhesion of the gel coat to the mold. During the shrinking process, the strength is building up to a point when it is able to sufficiently overcome the adhesion of the gel coat to the mold. Hence, the part releases from the mold. If the shrink rate exceeds the strength development, tearing occurs.

Slow green strength development may be caused by:

- Slow reactive resin
- Cold resin, fillers, mold, shop
- Catalyst level too low or wrong type
- Filler loading too high
- Moisture in the fillers
- Influence of pigment

Gel Coat Delamination

This situation occurs when gel coat adhesion to the mold is so strong that the matrix is not able to pull the gel coat free from the mold as it shrinks; subsequently, the matrix pulls away from the gel coat.

Some possible solutions for gel coat delamination are as follows:

- Improve the mold release application or change mold release type.
- Increase in catalyst level of the gel coat to accelerate the cure time. This will prevent the styrene from dissolving the release agent and improve the cure of the gel coat and increase shrinkage.
- Take care to ensure the gel coat is sprayed on 20- 25 mils wet (cures to 18-20 mils). Thin films cure slowly.
- Use a resin with faster green strength development.

Gel Coat Delamination on Edges of Part

Gel coat delamination on the edges of a part has two primary causes. These causes, along with solutions, are described below.

A. **Gel Coat Overspray**—Overspray tends to be thin and cures at a slower rate. Flange areas typically are not waxed and gel coat does not easily release from the surface. Adhesion of the gel coat to the unwaxed flange area of the mold is stronger than the adhesion of gel coat to matrix at the edge. Thus, upon demolding, the gel coat will peel off the marble matrix edge.

   To avoid this problem, tape the flange areas up to the edge of the marble part. After spraying the gel coat, remove the tape while the gel coat is still wet.

B. **Thin Gel Coat on Vertical Edge**—Gel coat on a vertical edge may be thin, causing it to cure at a slower rate and not shrink away from the mold.

   To check for this problem, measure the mil thickness on the vertical edge to ensure that it is the same as the rest of the part. Also, increase the catalyst level of the gel coat to accelerate the cure time.

Pre-release of Gel Coat on Bowl Perimeter and Edges of Parts

Pre-release of gel coat on bowl perimeter and edges of parts has a number of potential causes. These causes along with solutions are described as follows:

A. **Uneven Gel Coat Thickness**—The gel coat may be too thick in the creases due to drainage. These thicker areas will cure faster and have a higher shrink rate. To avoid this, check gel coat thickness while spraying. Keep spraying as evenly as possible (20-25 mils wet).

B. **Motion**—If using floating bowls which are not secured, movement or vibration will cause the bowl and gel coat to move and release from the mold surface. To avoid this, make sure all mold parts and edges are secured.

C. **Pre-release When Using Clay**—When using clay around the bowl perimeter and edges, oils from the clay can cause pre-release of the gel coat. Potential for this problem is magnified in the summer months, as hotter temperatures soften the clay and release more oils to the surface. These oils serve as mold releasing agents to the gel coat. Take one or more of these steps to avoid this problem:

   - Keep clay as cool as possible. When cold, the oils remain in the clay and are not drawn to the surface.
   - After placing the clay on the mold, lightly sprinkle talc or powder on it to absorb the oils. Be sure to blow off the excess powder.
   - After placing the clay on the mold, put a layer of mold release on the clay. This will help seal in the oils.
   - Before applying the clay onto the mold, draw the oils out of the clay with a microwave oven. Put the clay on an unwaxed paper plate or paper towel and microwave for 30-60 seconds. The oils will come to the surface and be absorbed by the paper.

     CAUTION: If microwaved too long, the clay will become dry and crumble.

Gel Coat Stress Lines

The main cause of stress lines is high gel coat adhesion to the mold which causes incremental release instead of a smooth continuous release.

To avoid, check the following areas:

A. Mold Release

- Make sure molds have a good layer of mold release.
- Be sure mold release is applied properly over the entire mold, including the edges.

B. Gel Coat

- Make sure gel coat is sprayed evenly over part (20-25 mils wet). Remember that thin films cure slowly.
- Catalyze gel coat to get reasonably fast gel and cure. Slow gel times will allow gel coat to dissolve release agents. Overcatalyzing will cause too much shrinkage.
- Check catalyst line of spray gun to make sure catalyst is not ‘spitting’ and making hot spots. Thick films will cure and shrink more.

C. Matrix Shrink Rate Greater than Gel Coat Shrink Rate

- Reduce catalyst level of matrix to slow down gel and cure rate.
- Use lower shrinkage resin.
- Reduce lightweight filler amount. Lightweight filler increases peak exotherm, causing higher shrink rate.

  - Increase filler loading.
  - Check fine to coarse filler ratio. Too much coarse filler will increase number of resin lakes between fillers and increase shrinkage.

Cracking and Delamination of White Gel Coats

White gel coats (as opposed to clear gel coats) are more heavily promoted and contain titanium dioxide (TiO_2-white pigment). TiO_2 inhibits (slows) the gel time; therefore, higher catalyst levels are required.

Higher catalyst levels can lead to higher exotherm which leads to exothermic cracking. On the other hand, if the catalyst level is not sufficient, the gel coat will cure very slowly. Upon curing of the matrix, insufficiently cured gel coat may tear due to low green strength and fail to release from the mold.

Once the gel process has occurred, because of higher promoter levels and extra catalyst, the cure rate is quicker than with clear gel coats. If the gel coat has overcured, the matrix will not bond well. Delamination will be further enhanced by the TiO_2, which reduces the surface tack of the gel coat.

To avoid this problem, be sure to:

- Determine the appropriate catalyst level.
- Be aware of the cure rate of the gel coat.
- Pour the matrix at the appropriate time.

Gel Time Too Fast or Too Slow

There are three main factors that can promote too fast or too slow of a gel time.

These influencing factors are:

A. Influence of Fillers and Pigments

  - Change of filler sources.
  - Change from coarse to fine particle ratios (the more fine particles, the slower the gel time).
  - Moisture in filler (or resin) which will inhibit gel time.
  - Change in pigment colors and concentration. Dark colored pigments and TiO_2 inhibit gel time.

B. Influence of Temperature

  - As a rule of thumb, a resin temperature increase of 18°F (-8°C), will cut the gel time in half. A decrease of 11°F (-12°C) in temperature will double the gel time.
  - Temperature of filler. If resin is warm and filler is cold, matrix is cold.
  - Mold temperatures. Cold molds will cool off a warm matrix.

C. Influence of Catalyst

  - Change in catalyst supplier.
  - Change of catalyst ratio.
  - A change from or blend of MEKP catalyst to 2,4-pentadione peroxide (2,4-PDO) catalyst, (i.e., Azox Trigonox-44). A 2,4-PDO catalyst will have a slower gel time but a faster relative cure.

Too Fast or Too Slow Cure Times

Too fast or too slow cure times have two primary causes. These causes along with solutions are described below.

A. Influence of Pigments, Fillers, Temperature, and Catalyst

  - Any influence of the above factors that affect gel time will also affect cure time.

    NOTE: Gel and cure times are directly related. The faster the gel time, the faster the cure time.

  - Use of lightweight fillers tends to increase peak exotherm and cause a faster cure rate.

B. Casting Size and Thickness (the larger and thicker the part, the faster it cures and the higher the peak exotherm)

  - Lower the catalyst level or use a 'cooler' catalyst.
  - Remove or open molds as soon as possible.
  - Use air or water to dissipate the heat from the surface of the part.

Warpage

Warpage has two basic causes. These cause, along with solutions, are described below.

A. **Filler Settling**—This produces resin-rich backs, which cure, shrink, and pull inward causing the parts to warp upward in the mold. Solutions include:

  - Increase fine filler particles to increase or thicken the matrix viscosity.
  - Increase total filler loading to increase or thicken the matrix viscosity.
  - Reduce vibration time to reduce the chance of filler settling.
  - Increase the catalyst level to shorten the gel time.

B. **Excessive Shrinkage**—Excessive shrinkage causes warpage on the decks around the bowl. Solutions are described as follows:

  - Increase filler loading. The lower the resin content in the composition, the lower the peak exotherm and shrinkage.
  - Check fine to coarse filler ratio. Too much coarse filler will increase the number of resin lakes and increase shrinkage.
  - Reduce the catalyst level. The longer the gel time, the lower the peak exotherm.
  - If back-pouring the bowls, reduce the catalyst level in the second pour. The exotherm of the first pour will help catalyze the second pour.
  - Remove the parts from the mold while still warm and support it right side up to counter the warpage.
  - Check mold release application to make sure it's not a pre-release problem.

C. **Post Demold Warpage**—Warpage of parts after demolding due to lack of full cure can be avoided by the following:

  - Lay the part down so that it is better and fully supported until cured.
  - Increase the catalyst level to quicken the cure or try a secondary curing catalyst such as a 2,4-pentadione catalyst (Azox Trigonox-44, etc.).
  - Check the mixing procedure and make sure the catalyst amount is both measurable and a large enough quantity to ensure a good even distribution throughout the matrix.

Cracking

Cracking is mainly caused by unrelieved cure shrinkage stress which exceeds the green strength of the resin. Solutions to this problem include:

A. Reduce Matrix Shrinkage

  - Increase filler loading.
  - Use lower shrinkage resin.
  - Cure matrix slower by reducing or changing catalyst.
  - For tubs and shower pans, use higher viscosity resin.

B. Increase Matrix Crack Resistance

  - Increase green strength by doing one of the following:
    - Use hotter catalyst or increase catalyst level.
    - Use 2,4-Pentadione type catalyst.
  - Increase matrix elongation.
    - Use higher elongation resin.
    - If using lightweight fillers, try using lightweight fillers with added elongation or glass fibers (e.g., R. J. Marshall Thermolite 100).
  - Relieve stress by allowing the part to move as it shrinks.
    - Remove hats, open back splashes.
    - Check mold release.
    - Check gel coat gel and cure.
    - Check mold design.

Air Bubble Entrapment

Air bubble entrapment has three possible causes. These causes and suggested solutions follow.

A. Matrix Viscosity Too High

  - Check temperature of resin, fillers, shop, and mold. The colder it is, the thicker the matrix.
  - Check for high concentration of fine filler particles. The higher the quantity of fine particles, the thicker the mix.
  - Increase the resin ratio of the mix.
  - Use lower viscosity resin.
  - Add wetting and air release agents to the resin.

B. Ineffective Vibration

  - Check for sufficient and uniform vibration force around the table.
  - Lower catalyst level to decrease gel time and allow more time for vibration.

C. Catalyst Reaction with Pigment and/or Filler Generating Gas Bubbles

  - Mix catalyst thoroughly into resin before adding dry pigment and filler.
  - Make sure all dry pigment and fillers are thoroughly dispersed (no lumps) before addition of the catalyst.

Soft Spots

Soft spots are caused by resin that has not gelled or cured evenly. Possible solutions are:

- Increase catalyst levels, using lower-strength catalyst and increasing volume.
- Mix catalyst to resin thoroughly before adding filler.
- Check for moisture in filler (wet filler tends to clump; water retards gel and cure).
- Check for pockets of unmixed pigment.

Blurred Vein Lines

Blurred vein lines are caused by matrix mix that is too low in viscosity. This problem can be resolved as follows:

- Increase filler ratio.
- Increase catalyst level.
- Reduce vibration time.
- **‘Guesstimating’ Resin Gel Time**

Temperature versus resin gel time is an exponential relationship (see Figure 11-7).

For example, if a resin gel time at 70°F (21°C) equals 15 minutes, what would the gel time be at 60°F (15°C) or 80°F (27°C)?

The formula is:

- Gel time at 60°F (15°C)

  Use 60°F – 70°F = -10°F

  Multiplying factor for -10 = 1.90 (see Table 11-9)

  15 minutes x 1.90 = 28.5 minutes

  Gel time at 60°F (15°C) = 28.5 minutes.
- Gel time at 80°F (27°C)

  Use 80°F – 70°F = +10°F

  Multiplying factor for +10 = 0.68 (see Table 11-9)

  15 minutes x 0.68 = 10.2

  Gel time at 80°F (27°C) = 10.2 minutes.

As a general rule of thumb, for every 11°F (-12°C) decrease in temperature, the gel time doubles (2x).

For every 18°F (8°C) increase in temperature, the gel time halves (0.5x).

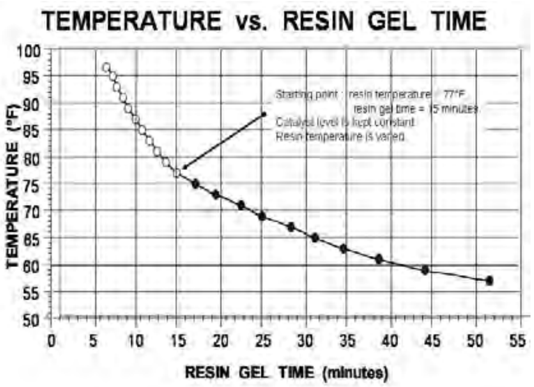


Figure 11-7. Temperature vs. Resin Gel Time

Table 11-9. Resin Gel Time Guestimator

Temperature Difference	Multiplying Factor	Temperature Difference	Multiplying Factor
-2	1.15	+2	0.92
-4	1.31	+4	0.85
-6	1.51	+6	0.79
-8	1.67	+8	0.73
-10	1.90	+10	0.68
-12	2.09	+12	0.62
-14	2.31	+14	0.58
-16	2.59	+16	0.53
-18	2.95	+18	0.50
-20	3.46	+20	0.45

Catalyst Ratio

Remember that increased temperatures can cause high exotherms and increase shrinkage, which will result in cracking. When temperatures increase:

A. DO NOT: Reduce the catalyst level.

  - Catalyst amount may be too small to disperse thoroughly in the mix.
  - This will slow green strength development.
  - Full cure may not be achieved.

B. DO: Change to a lower strength catalyst.

  - This allows an increase in catalyst amount for better mixing and to ensure full cure.

C. DO: Switch to a longer gel time resin.

  - Allows an increase in catalyst percent.
  - Maintains ‘normal’ catalyst percent.

The general rule of thumb for catalyst ratio is that the level should be maintained between 0.5-3%. As the catalyst level moves outside this range, change, as appropriate, to a cooler or hotter catalyst type.

11.2.6. Supplies for Marble Production

Polynt Composites supplies gel coats, resins, and cleaners for cast polymer production. Other resources are listed here.

Mold Manufacturers

Gruber Systems
25636 Avenue Stanford
Valencia, CA 91355-1117
Ph: 800-257-4070
661-257-4060
Fax: 661-257-4791
www.gruber-systems.com

J. R. Composites Inc.
1251 GoForth Road
Kyle, TX 78640
Ph: 800-525-3587
512-268-0326
www.JrComposites.com

Ken Fritz Tooling & Design, Inc.
1945 Puddledock Road
Petersburg, VA 23803
Ph: 800-426-1828
804-862-4155
Fax: 804-748-2561

Filler Suppliers

Alcan Specialty Aluminas
6150 Parkland Blvd.
Suite 220
Cleveland, OH 44124
Ph: 440-460-2600
Fax: 440-460-2602
www.Riotinto.com/riotintoalcan

Imerys
100 Mansell Court East, Ste 300
Roswell, GA 30076
Ph: 888-277-9636
770-645-3700
Fax: 770-645-3384
www.imerys-perfmins.com

R. J. Marshall Company
26776 W. 12 Mile Road
Southfield, MI 48034
Ph: 800-338-7900
248-353-4100
Fax: 248-948-6460
www.rjmarshall.com

ACS International
4775 South 3rd Avenue
Tucson, AZ 85714
Ph: 800-669-9214
520-889-1933
Fax: 520-889-6782
www.acstone.com

Huber Engineered Materials
1000 Parkwood Circle Ste 1000
Atlanta, GA 30339
Ph: 678-247-7300
Fax: 678-247-2797
www.hubermaterials.com

Sanco Inc.
207 Brookhollow Industrial Blvd.
Dalton, GA 30721
Ph: 800-536-5725
706-279-3773
www.sancosystems.com

Dry Pigment and Pigment Dispersion Suppliers

American Colors
1110 Edgewater Drive
Sandusky, OH 44870
Ph: 419-621-4000
Fax: 419-625-3979
www.americancolors.com

BroCom Corp.
2618 Durango Drive
Colorado Springs, CO 80910
Ph: 888-392-5808
719-392-5537
Fax: 719-392-5540
www.marblecolors.com
Plasticolors Inc.
2600 Michigan Ave.
P.O. Box 816
Ashtabula, OH 44005
Ph: 888-997-5137
440-997-5137
Fax: 440-992-3613
www.plasticolorsinc.com

11.3. Solid Surface

Overview

- **Introduction**
- **Materials**
- **Manufacturing Process**
- **Matrix Formulation**
- **Postcuring**

11.3.1. Introduction

Solid surface is a specialized casting application characterized by its homogenous composition and the absence of gel coat. Homogeneity is required for fabrication of solid surface parts since installation may include routing, cutting, surface sanding, creating inlaid designs, and edge shaping. As a result, each side of a solid surface part is potentially a finished side, including the cut edges. Solid surface parts can be pigmented or veined and are slightly translucent or have a granite appearance.

One of the main defects found in solid surface parts are voids. If the matrix contains voids, some will likely be exposed during the installation/fabrication process. Exposed voids become visible defects and are susceptible to staining. Materials used, matrix mixing procedures, and matrix formulation all influence void content.

11.3.2. Materials

Solid surface resins are based on ISO/NPG polyesters similar to those used in gel coats rather than the orthophthalic type resins used in gel coated casting applications. This higher grade matrix resin is required since it must provide all the protection that would have been provided by the gel coat. For additional information on resin chemistry, see section FRP Composites: General Chemistry of FRP Composites Resins

As with cultured onyx, clarity and low cured casting color are very important factors. Solid surface resins are highly promoted to achieve reasonable cure rates while using the fine particle size of ATH fillers. However, the promotion system differs from cultured marble in that the cured casting color is not as dark.

Air release and wetting agents are typically added to help release air bubbles/voids from the mix. UV stabilizers are added to improve UV stability. MMA (methyl methacrylate) may be added to improve UV and water resistance.

Aluminum trihydrate (ATH) is the preferred filler for solid surface products. Solid surface grade ATH has a much finer particle size than onyx grade. Its size is measured in units called microns. The finer or smaller the particle size, the whiter the cured casting color and the tighter the particle packing. Tighter particle packing leads to increased surface hardness and a smoother, glass-like surface. ATH is also chemical resistant which adds to the stain resistance properties of the part. Because of the ATH particle size, there is a high resin demand to wet out the fillers.

Also, specially formulated granite effect fillers are available for solid surface.

Catalysts/initiators used in solid surface production are similar to those used in cast polymer applications.

11.3.3. Manufacturing Process

The general fabrication process for solid surface production is shown in Table 1.

1. Weigh out the ingredients.
2. Add resin to the mixing pot.
3. Add catalyst to the resin and mix well for 1 minute or add catalyst at a later step.
4. Add pigment and mix well. May add a small amount of filler to help disperse the pigment.
5. Add filler and mix well.
6. Stop mixer and scrape down sides and mixing blade for unmixed material.
7. Mix well for additional 3 minutes.
8. Apply vacuum. Vacuum should be maintained for at least 5 minutes once 25-27 mmHg is reached.
9. If catalyst has not already been added in Step 3, add catalyst to the mix.
10. Mix for 30 seconds without vacuum to blend in catalyst.
11. Apply vacuum and maintain for 5 minutes.
12. Pour into molds.

Use of a vacuum mixer is recommended to aid in eliminating entrapped air in the matrix and voids in the finished part. Vacuum mixers have been specifically designed for manufacturing solid surface. A vacuum with 25-27 mmHg is recommended. Less than 23 mmHg vacuum is not effective, while more than 28 mmHg will cause monomers in the resin to vaporize. Monomer vaporization would result in millions of microscopic air bubbles in the matrix that would be impossible to eliminate.

11.3.4. Matrix Formulation

With solid surface, resin content is much higher than other casting forms due to the fine grind of the solid surface ATH filler and the necessity to release air bubbles. Also, because of the fine grind of the ATH filler, a higher catalyst level is needed. A typical solid surface matrix formulation is shown in Table 1.

Table 1. Typical solid surface matrix formulation.

Material	Quantity
Resin	38-45%
Solid Surface Grade ATH	55-62%
Base Pigment	1.0-1.5%
Initiator/Catalyst	1.0-3.5% (based on resin content)

11.3.5. Postcuring

To postcure is to expose a room temperature cured part to an elevated temperature for a period of time. The theory of postcuring is that the elevated temperature will increase the amount of cross-linking of the polyester resin. All cast polymer products are cured at room (ambient) temperature; however, the room temperature will change depending on the season. If the ambient temperature is cold, the polymer reaction will slow down, resulting in longer gel and cure times. The longer the cure time, the harder it is for the part to reach a complete cure. Even in warmer ambient temperatures, there are numerous factors that will prevent the part from achieving a full cure. Postcuring ensures that all parts consistently achieve a complete cure.

Postcuring is a necessity for solid surface products. Postcuring will optimize the physical properties which are critical to meeting standards and certification testing. Studies have shown that physical properties, such as flexural and tensile strengths and heat distortion temperatures, improve with postcuring. Also, chemical resistance, water resistance, and UV stability of the final product are enhanced. Postcuring also reduces the amount of residual styrene left in the part.

The recommended post-cure temperature is 180-200°F for two to four hours. Do not allow temperatures above 225ºF since this approaches the temperature at which solid surface begins to degrade and discolor. It is important that the elevated temperature is uniform in the postcuring area. If there are ‘hot spots,’ there is a risk that a part or a portion of a part will degrade or discolor. Postcuring is more beneficial when parts are postcured immediately after demolding (i.e., while the part is still warm and coming down off the peak exotherm) than postcuring a part that has completely cooled to room temperature. While being postcured, the part should be well supported. No matter when a part is postcured—after demolding, the next day, or later—the benefits of postcuring will always exceed not postcuring.

11.4. Flexible Casting Resins

Overview

- **Introduction**
- **Materials**
- **Processing Information**
- **Formulations for Flex Trim Molding**

11.4.1. Introduction

Flexible resin is a special polyester resin formulated to achieve its flexible property. There are several uses for flexible resins.

A. **Decorative Trim Molding**—Flex resin is mixed with various types of fillers and pigments, typically cast in long strips. Required properties for trim molding products include:

   - **Flexibility**—Strips of molding are rolled for packaging. Trim needs to bend around structural curvatures.
   - **Nailability**—Nails are used to secure molding in place.
   - **Paintability**—Once installed, moldings are painted.

B. **Safety Glass**—Flex resin is poured between glass plates to prevent the glass from shattering upon breaking.

C. **Blending Resin**—The most popular usage of flexible casting resins is in blending with another rigid polyester resin to increase the tensile elongation (flexibility) of the rigid resin. The blending ratio is dependent upon the desired flexibility. Increasing the flexibility will improve the ‘toughness’ by decreasing the ‘brittleness’ of the part.

General characteristics of flexible resins are as follows:

- Very low shrinkage
- Tacky surface finish
- High tensile elongation
- Low heat distortion temperature (HDT)
- Low Barcol hardness
- Poor UV resistance

Flexible resin by itself or blended in high ratios is not recommended for use in structural parts or for use with gel coats. The high tensile elongation, low heat distortion temperature, and low Barcol hardness will not provide structural integrity. Gel coat is typically rigid and can crack if there is too much movement in the matrix or laminate behind it.

11.4.2. Materials

Flex resins are available in pre-promoted and unpromoted versions. The pre-promoted versions require only the addition of catalyst to start the curing process. The curing process can be started for unpromoted versions by either use of heat and a heat-activated catalyst or use of catalyst and promoters at room temperature.

Catalysts

Benzoyl peroxide (BPO) catalyst is the most commonly used heat-activated catalyst and is typically used at temperatures above 200°F. BPO is a paste and therefore less convenient to use than methyl ethyl ketone peroxide (MEKP).

BPO may also be used to cure polyesters at room temperature, provided an amine promoter is used. Examples would include diethylaniline (DEA) or dimethylaniline (DMA). DMA yields shorter gel times than DEA. More amine speeds up both gel and cure rates. Castings cured this way tend to be more flexible. Instances where this cure system might be used are in two-pot systems where catalyzed resin and promoted resins are mixed just before or during usage.

The most common system used for room temperature cure is MEKP catalyst with a cobalt promoter. Use of a co-promoter amine is frequently desirable to provide faster gel and cure rates for production needs. Typical concentrations would include 0.15-0.25% of a 12% cobalt solution and 0.025-0.25% DMA. Additional inhibitor may be added to achieve a specific gel time, once the right cure rate has been determined.

CAUTION: When promoting polyester resins, promoters and catalysts must not come into direct contact with each other because rapid and violent decomposition may result. The resulting by-product may pose serious health and fire hazards.

Fillers

Fillers are used to extend the resin, thereby lowering raw material costs. Fillers impart color and opacity to a casting. Many inorganic fillers are white to light gray in a resin system. Organic fillers produce brown colors.

Pigments can also be used to produce any desired color.

A. **Inorganic Fillers**—Typical inorganic fillers are calcium carbonate, talc (magnesium silicate), and aluminum trihydrate. The two primary reasons for using this type of filler are low cost and availability. Some fillers affect the final cured properties and need to be checked by the end user for acceptable results. Since these are heavy fillers, parts will reflect higher densities. Use of this type of filler makes a part harder and less flexible. Aluminum trihydrate can reduce the flammability characteristics of the final casting.

B. **Organic Fillers**—Organic fillers are usually composed of agricultural by-products that are ground to various particle sizes. Because they are agricultural by-products, availability and consistency may vary relative to geographic area. Typical fillers include ground pecan or walnut shells. Parts made with organic fillers result in a wood-like finish and can be painted.

   Careful selection of organic fillers is necessary. Many organic fillers inhibit gel and cure, in some cases, very severely. Sawdust is a common material that is not recommended.

C. **Lightweight Fillers**—Use of lightweight fillers can reduce cured densities close to that of wood. Lightweight fillers are hollow spheres that displace weight but not volume and thereby effectively reduce the part's density. There are various lightweight filler compositions available as well as pre-blended mixtures with calcium carbonate.

   Be aware that some types of lightweight fillers are fragile and readily break. Once broken, these lightweight fillers become fine particles and their lighter weight advantage is lost.

Reinforcements

Chopped fiberglass, milled fibers, wood, or metal rods can be used to reinforce structural parts. Fibers are mixed into the resin to produce a higher physical strength part. Wood, such as particleboard or plywood sheets, can be used as a back support. It is important to make sure the wood is dry. Metal rods inserted into the casting will impart stiffness.

11.4.3. Processing Information

Molds must be flexible and strong for long life and ease in removing the cast part. In addition, they must be resistant to solvents and styrene. Mold materials must be capable of duplicating every detail from the master. Typical mold-making materials are RTV silicone rubber, urethane elastomers, and latex or vinyl rubber.

NOTE: Latex must be non-sulfur based. Sulfur based latex will inhibit the gel and cure of polyester resins.

Castings pulled from the mold usually will have a slightly tacky surface. This tackiness is mostly unreacted styrene monomer. Hot soapy water or solvent wash will easily remove it. Castings can then be sanded, buffed, and polished to a variety of surface finishes from glossy to matte. Castings can also be painted, stained, lacquered, or varnished.

11.4.4. Formulations for Flex Trim Molding

Typical properties of Polynt STYPOL® flexible resin are shown in Table 1.

Table 1. Typical properties of Polynt STYPOL® flexible resin.

Properties	
Viscosity (Brookfield)	80 cps
Gel Time at 77ºF	3.5 minutes
Cure Time	10 minutes
Peak Exotherm	330°F (166°C)
Weight per Gallon	9.4 pounds

The following formulations in Table 2 are starting guidelines.

Table 2. Starting guidelines for various parts.

	Flexible Parts	Semi-Rigid Parts (nailable)	Lightweight Parts (semi-rigid and nailable)	Rigid Parts
Resin	91.3%	80.0%	73.0%	57.8%
Pecan Shell	2.2%	20.0%	19.0%	42.2%
Calcium Carbonate	6.5%	-	-	-
Lightweight Filler	-	-	8.0%	-
Pigments	-	as needed	as needed	as needed
Promoters	as needed	as needed	as needed	as needed
MEKP	1% minimum	1% minimum	1% minimum	1% minimum

11.5. Thermal Shock Testing

Overview

- **Thermal Shock Testing**
- **Factors Affecting Thermal Shock Performance**
- **Thermal Shock Test Protocols**

11.5.1. Thermal Shock Testing

Thermal shock is an accelerated test designed to measure the longevity of cast and solid surface parts when exposed to water conditions of a typical home. Parts tested for thermal shock are typically kitchen sinks and bathroom sinks and tubs. Thermal shock testing is a required protocol of ANSI standards Z 124.3 for plastic lavatories and Z 124.6 for plastic sinks.

During the thermal shock test, the part is exposed to cycles of extreme hot and cold water. The time exposure, rate of flow, and water temperatures are specific to each standard or test method. During the hot water exposure, the part will expand or contract. Then the cold water will shrink or constrict the part. As a result, the part will continuously ‘move’ by contracting and constricting throughout the test period.

Eventually, the part will reach a point of fatigue and fail as indicated by the visible appearance of a crack. If the test is permitted to continue, the crack will grow longer and deeper and other cracks can appear. Results are generally reported as the number of cycles to failure, along with a description of the failure, including whether the failure occurred in the gel coat or in the matrix. Thermal shock testing results have not been correlated to the actual real time performance of the product.

11.5.2. Factors Affecting Thermal Shock Performance

Although thermal shock testing results can be influenced by the quality of materials used to fabricate the part, the manufacturing process used to fabricate the part is the main factor influencing results.

If thermal shock testing is being performed to qualify a new raw material, two parts should be made, one with the ‘new’ material and one with the ‘old’ material, using the same manufacturing process. The results should be compared only to each other. If the results differ, then the difference is most likely influenced by the raw material. However, very significantly different results would indicate a possible manufacturing defect in the part with the lower result. If both results are equal but are very low (not meeting required number of cycles), a manufacturing process issue is indicated.

When performing thermal shock testing to become qualified to a standard, it is assumed that the tested sink or tub is a typical representative of the manufacturer’s product. Failure during thermal shock testing can occur in either the gel coat or the matrix. Descriptions of each of these failure modes and possible causes for failure follow.

A. **Gel Coat Failure**—Short cracks or crazing only in the gel coat layer indicate gel coat failure. If testing continues after gel coat failure has occurs, water will eventually seep under the crazed areas of the gel coat and cause it to peel. The exposed matrix will eventually crack. Gel coat failures can be caused by porosity in the gel coat, or by thick, thin, or uneven gel coat thickness.

  - **Porosity**—When exposed to hot water, porosity or entrapped air in the gel coat layer expands more than the surrounding gel coat. Because the gel coat is such a thin layer, it does not require many cycles of hot water before a crack appears. The size of the air bubble will also make a difference in how quickly the failure occurs.
  - **Thick or Thin Gel Coat**—If the gel coat layer is too thin, failures typically occur because the gel coat lacks the strength to withstand the stress of the contraction. It the gel coat layer is too thick, performance is better; however, as a result of the excess thickness, increased movement during contraction/constriction can fatigue the part and cause premature cracking.
  - **Uneven Gel Coat**—If the gel coat is not applied evenly, areas of thin and thick gel coat will contract and constrict at differing rates causing the interfaces where thick and thin areas meet to become high stress areas.

B. **Matrix Failure**—Cracks resulting from matrix failure are deeper, longer, and most often wider than gel coat failure cracks. Typical matrix cracks radiate straight out from the drain because the drain is the thickest section of the bowl. Matrix failure can be caused by matrix composition, reactivity of the back pour, porosity, misalignment of back (bowl) hats, or improper placement of the overflow tube.

- **Matrix Composition**—During the thermal shock test, the resin is the only material in the matrix composition that contracts and constricts. If the matrix is resin-rich, there will be an excessive amount of movement in the contraction and constriction. If the matrix is resin-poor, it will not hold together.
- **Reactivity of the Back Pour**—Frequently, matrix resin content is increased for the back pour to make it easier to fill in the hats. High matrix resin content coupled with the thicker mass of the bowl will cause the exotherm of the back pour/hat to be very high. The higher the exotherm, the greater the possibility of building in stress fractures in the matrix during the curing process. The stress fractures will grow during the thermal shock test and eventually become visible on the surface.
- **Porosity**—If there is entrapped air in the matrix near the gel coat interface, the hot water exposure can heat the air within the void causing it to expand. This expansion can cause a crack in the matrix which then radiates to the surface.
- **Misalignment of Back (Bowl) Hats**—Misalignment of back (bowl) hats will shift the mass of the matrix. The result will be even greater differences between thick and thin matrix areas. Just like uneven gel coat thickness, there is a difference in the rate of contraction and constriction between thick and thin matrix areas, with the stress being at the interface between the areas.
- **Improper Placement of Overflow Tube**—The space under the overflow tube should be consistent from the drain to the connection near the bowl’s edge. Matrix fills the gap between the bowl and the tube. If the space under the tube is not consistent, thickness variations will occur and cause failure as described above.

As stated previously, thermal shock testing is an indicator of how well the part was manufactured. It is an accelerated method of testing with harsh and extreme conditions designed to push the performance of the part. If results are good, then the manufacturer has the peace of mind of knowing that the production process is working well. If results are poor, then it is important information in defining the issues that need to be addressed and corrected in the manufacturing process.

11.5.3. Thermal Shock Test Protocols

Testing protocols for the two most common standards, ANSI Z 124.3 and ANSI Z 124.6, are shown below.

A. **ANSI Z 124.3 (Bathroom)**—The standard test uses 150ºF (66°) and 50°F (10°C) water. A cycle consists of the following:

   - 90 seconds of 150°F (66°C) water flowing at one gallon per minute.
   - 30 seconds of drain time.
   - 90 seconds of 50°F (10°C) water flowing at one gallon per minute.
   - 30 seconds of drain time.

   To pass this test, a minimum of 500 cycles without cracks or blisters is required. Typically, bowl tests are run until at least two cracks are observed. The bowl is then cut. The cracks are inspected and the gel coat thickness is measured.

B. **ANSI Z 124.6 (Kitchen)**—This test uses 190°F (88°C) and 70°F (21°C) water flowing at 1 gallon per minute without pause between cycles. The passing requirement is 250 cycles minimum without cracks or blisters.

12. Tooling

Overview

- **Introduction**
- **The Master Model**
- **Master Model Preparation**
- **Applying Release Wax**
- **Building a Mold**
- **Mold Surface Distortion**
- **Mold Break-In Procedures**
- **Mold Maintenance**
- **Mold Repair**
- **Mold Storage**
- **Special Precautions**

12.1. Introduction

Fiber reinforced plastic (FRP) parts are molded to the design shape using a tool (commonly called a mold) and a molding process. At minimum, a mold consists of a mold skin, or molding surface. This surface's qualities will be reflected in the molded part made in the tool. If the part requires a smooth, high gloss finish, then the molding surface needs to be a smooth high gloss finish.

Figure 12-1. Example of a large mold.

The molding process has a large impact on the tool design. When a molding process involves high pressures, or when any mold deflection must be limited, bracing is used to reinforce the mold skin. This can be accomplished with any combination of increased thickness, the use of cores, and/or shaped stiffener elements such as hat-section or c-section laminates. Each case of bracing can be unique in its design.

When a mold skin is larger than a few square feet, a framing system is also used to provide a means of handling the mold skin without causing it to be deformed or fractured. A framing system can be one of two types. The simplest framing system supports the dead weight of the mold and concentrates it on a few load points. The more complex frames also provide structural support to resist molding forces and restrict mold deformation. Both systems provide a means of grabbing the mold for lifting and transport operations.

Most mold skins used to produce FRP parts are fashioned from FRP-type materials. For high production runs, a metal mold skin can be the most economical, but at a higher up-front cost.

A FRP-type mold skin is produced using a master model, also known as a pattern or plug. This master model is a full-scale representation of a part design that incorporates all of the geometry for one of the part surfaces. A model may be geometrically equivalent to the part image or it can be a mirror image of the part's external surface.

There is no quick or easy way to produce quality FRP tooling. Good tooling is a precise, painstaking craft. It begins with careful preparation of the master model and continues through the final building of the production mold. Any defects on the master model will translate onto each subsequent piece of tooling and require extra effort to remove. The highest quality production mold begins with an even higher quality master model.

The terms master model, patterns and plug are sometimes used interchangeably. Due to advancements in computer numerically controlled (CNC) routers, the term pattern generally describes a master model that is machined from a blank constructed of a single material or material type. In contrast, the term plug generally describes a master model that is constructed from a variety of materials and shaped manually.

Neither a pattern nor a plug is particularly durable and is suitable for producing only one, or a small number of moldings. When two or more molds are required to meet production requirements, a master mold is used to produce the production molds. This master mold is a durable, robust, full-scale representation of a part image design and is constructed in the same manner as a production mold.

12.2. The Master Model

Overview

- **Introduction**
- **Number of Moldings**
- **Generation**
- **Master Mold Base Preparation**
- **S320LS "Blue Lightning" Tooling Paste**
- **Surface Quality**

12.2.1. Introduction

A wide variety of materials can be used to construct the master model. Some examples are:

- Plaster
- Polyester resin
- Epoxy resin
- Urethane foam
- Polyvinyl chloride (PVC) foam
- Body filler
- FRP materials
- Wood coated with epoxy or polyester resin
- Medium-density fiberboard (MDF)
- Certain laminated Melamine®-faced sheet materials such as Formica® or bathroom wallboard
- Tooling board
- Machinable tooling paste

Base structure requirements for the master model will vary greatly based on size. Smaller patterns may be constructed from foam encapsulated with sealing resin. Mid-size patterns may be constructed from foam encapsulated with sealing resin and mat. Very large patterns, such as boat hulls, may be constructed on wood/plywood substructures, covered in mesh, polyurethane foam, and glass mat or chopped glass.

Tooling board is a foam board available is various densities. For lower end plugs, 10-15 lb. /cubic foot is often used. For higher end aerospace applications, 20-30 lb. /cubic foot can be used. Higher density tooling board is harder to machine, but provides better plug stability.

Machinable tooling pastes, like Polynt Composites' "Blue Lightning", can be sprayed or troweled on. They can be milled or routed to create the desired mold shape.

Figure 12-2. Example of a mold made from wood, Styrofoam®, and Polynt's S320LS "Blue Lightning" tooling paste pumped. It has not been machined yet.

12.2.2. Number of Moldings

The number of moldings expected from the master model will influence the choice of materials and construction methodology. Plaster or foam board type patterns or plugs constructed from numerous materials will seldom survive one pull without incurring some damage. If several molds are needed, it is best to build a master mold using FRP materials. A master mold is robust and can be used to produce a large number of production molds.

12.2.3. Generation

The term generation refers to the number of successive moldings between the master model and the production part. If a production mold is made on the master model, it is a first-generation production mold. If a production mold is made from a master mold that is made from the master model, it is a second-generation production mold. A second-generation mold requires a master model geometry that is a mirror image of the part design surface as described in Figure 12-3. Each subsequent generation can be slightly smaller than its predecessor. The exact amount will depend upon the materials and processes involved.

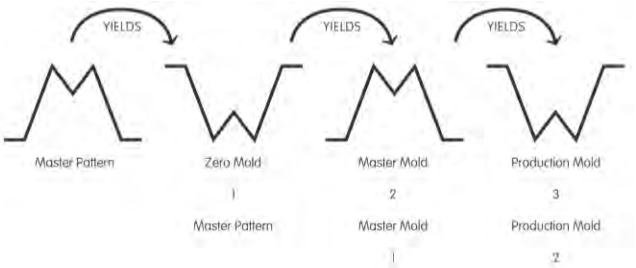


Figure 12-3. Mold generations. A master pattern can also be referred to as a master model.

Producing a master mold from the geometry of a master model that is identical to the part design surface requires an intermediate piece of tooling. This intermediate piece is made from the master model and is called a zero mold. The zero mold is used to manufacture the master mold. The master mold yields the production molds one, two, etc. Here, the zero mold is a first-generation mold, the master mold is from the second generation, and all of the production molds (one, two, etc.) are from the third generation.

Some materials used in the master mold may leave witness lines in the subsequently molded FRP part. This cosmetic defect, known as mark-off, happens due to a combination of molding exotherm, substrate heat capacity, substrate thermal expansion, cure shrinkage, and softening in the gel coat, both on the model and molding.

The zero mold presents an opportunity to remove these witness lines by wet sanding, buffing, and polishing. This is particularly true for outside edges and corners on the zero mold (convex, or ‘male’ type features). Outside features are more easily sanded than inside edges and corners (concave, or ‘female’ type features). Defects at these inside edges and corners are more easily corrected on the next piece of tooling, the master mold, when they become outside edges and corners.

12.2.4. Master Mold Base Preparation

Regardless of which materials are selected for the master model, the rough base needs to be milled or routed to approximately ½" under the finished net size. Smaller patterns may need to be milled or routed to as little as ⅜" under the net size.

Glass is generally added for stability, particularly if standing or walking on the base is required. Always allow for the addition of any glass.

Polynt does not recommend small stepover when rough machining. The rougher and wider the distance between passes provides better traction for material later in the process.

Urethane foams, although not attacked by polyester resin as much as Styrofoam® base structures, will benefit from the application of suitable Styrofoam® safe resins. The application of these products will not only protect foam products affected by styrene, but also will penetrate deeper into the foam surface, providing improved strength at the interface of the foam and following applications of material.

12.2.5. S320LS “Blue Lightning” Tooling Paste

Polynt Composites’ S320LS “Blue Lightning” (60F050) polyester resin based machineable putty (PMP) is intended for the fabrication of master model facing using CNC routing or milling. When applied to a substructure, this product provides a machineable, stable pattern surface for the creation of molds and prototypes.

Figure 12-4. Example of “Blue Lightning” application.

The advantages of “Blue Lightning” are:

- Pumpable with standard polyester putty equipment from 5 or 45 gallon systems
- Applies in a uniform thickness horizontally or vertically without sagging
- Non-porous surface is suitable for vacuum bagging
- Low shrinkage
- Machineable in less than 24 hours
- Machines as shavings creating little or no dust
- Easy to sand
- Up to 30% higher yields over sprayed systems
- 50% less labor intensive than sprayed systems
- Low wear on cutting tools
- Repairable
- Compatible with most surface finishes

Figure 12-5. “Blue Lightning” shavings.

“Blue Lightning” is used to produce master models with excellent and consistent surface quality, and significant time and labor savings. This product may be applied as thick as ¾" in one application. It is generally applied to an undersized base pattern and machined back to a net surface.

When using “Blue Lightning”, attention to process details is a key element for success. This product is sensitive to plant airflow, cooling conditions, erratic operating conditions and inconsistencies in application. Best results are obtained by using “Blue Lightning” in a controlled environment with near ideal process conditions. Although “Blue Lightning” is a low shrink material, it does still shrink slightly.

Application of “Blue Lightning” should be performed at ambient shop temperatures between 70-78°F (20-25°C). Temperatures outside this range are not recommended due to the high likelihood for poor cure, excessive shrinkage or expansion, and the resultant substandard cosmetic quality.

Prior to building each model, small test samples should be prepared to demonstrate suitable process conditions and application techniques.

A uniform thickness of ¾" is recommended. The thickness and catalyst level can be adjusted for variations in ambient temperature. Obtaining an exotherm temperature of 130-160°F (54-71°C) produces optimum results.

“Blue Lightning” quality control testing is performed using Syrgis Norox® MEKP-9 initiator. Chemical equivalents, such as Arkema Luperox® DDM-9, can also be used. Under ideal conditions at 77°F (25°C), use MEKP-9 at 1.0% based on resin weight. Consult a Polynt representative for other specific catalyst recommendations.

If the “Blue Lightning” turns light blue within 60 minutes of catalyzation, it is most likely properly gelled. When used with MEKP catalysts containing a disappearing red color, this product changes from a light mauve color, indicating the presence of catalyst and proper mixing, to the light blue color. Serviceable cure time will range from overnight to a week due to temperature and catalyzation. If it does not change to the light blue color or is not uniform, it is most likely poorly cured. Reconstruction should be performed under more ideal conditions. Avoiding the need for reconstruction is best accomplished by building test samples prior to full-scale mold building activities. Heat can also be added to complete cure.

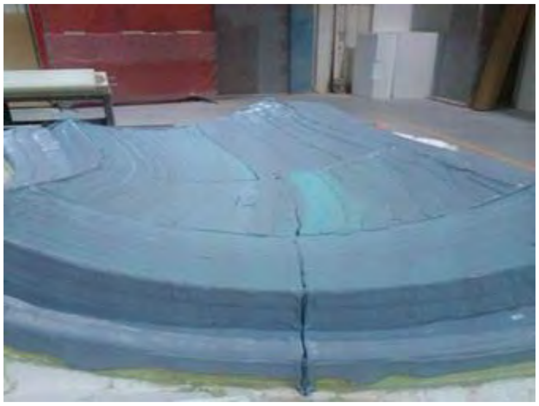


Figure 12-6. Master model made with “Blue Lightning” pumped over a foam base (80 sq. ft.). The pattern cured for 8 hours. It was milled, sanded, primed, resanded, and ready for mold making in less than 24 hours.

“Blue Lightning” is compatible with 5 and 45 gallon ram fed putty systems. Polynt recommends Magnum Venus Plastech (MVP) equipment. Flow rates and technique will vary based on individual projects but here are a few basic equipment settings for startup:

- Air Pressure: 100 psi dry air; use a ¾" I.D. hose to equipment
- Pump Pressure: 40-60 psi

  Note: More pressure is required with increased hose length.
- Material Delivery Rate: approximately 1-1.5 gallons per minute
- Follower Plate Pressure: 20-40 psi

Pump and follower plate pressures may be modified as required to speed up or slow down material delivery. Always consult the manufacturer’s equipment data and representative for set up and equipment training.

The “Blue Lightning” master model construction procedure is described below.

A. Before Applying

1. Ensure that material is at ambient shop temperature of 70-78°F (20-25°C).
2. Set the catalyst level at 1%. The recommended catalyst is Syrgis Norox® MEKP-9 with disappearing red dye.
    - Catalyst changes beyond the recommended parameters, including type and level, should be reviewed with Polynt Composites.
3. Start up the equipment. Follow manufacturer guidelines for bleeding catalyst lines, priming, etc.
4. Use the shortest practical length of disposable ¾” I.D. hose for putty application to reach all areas of the model. Move equipment as required.
    - Disposable or “hot” line is used for several reasons:
        - Less acetone required for clean-up.
        - Material application requires a lighter and more flexible line than conventional heavier material.
        - The ability to customize equipment for specific jobs.

B. Application

1. Apply the putty to the desired thickness, allowing a slight overlap.
    - This overlap forces the putty to “meld” together and therefore prevent air entrapment between lines of material.
    - The applicator nozzle has a standoff which aids in controlling the material depth during extrusion.
2. Note the color of the putty as it comes out of the nozzle. It should be an off blue to mauve color, indicating the presence of catalyst.
    - A color change to light blue during application of material indicates a catalyst blockage, requiring an equipment check before continuing. The color should fade to light blue, indicating gel.
3. Allow for stress relief to prevent surface cracking during application. A good starting point is as follows:
    a. Apply 36-38" (9-10 square feet) of putty.
    b. Leave a ½" to 1" gap or use a tool to break through the putty to the base creating a grid or “tiled” appearance.
4. After the putty gels and the pattern cools from exotherm during cure, apply putty to fill the gaps.
5. Allow at least 12 hours after gelation before rough machining. Allow several days if higher tolerances are required. Post cure the pattern at 140°F (60°C) for several hours to improve stability more rapidly.
    - Larger patterns may continue to shrink slightly over time.
6. For repairs and touch ups, follow the recommendations below.

C. Milling And Routing

These guidelines are based on a 10 HP router and should serve a good general baseline for roughing:

- Cutter Style: ½" depth, ½" radius two flute cutter made of solid carbide
- Feed Rate: 150-200 fpm
- Depth of Cut: Approximately ⅜"
- Stepover: Approximately ¼"
- RPM: Approximately 15,000 rpm

Cutter style, feed rate, depth of cut and horsepower vary tremendously from shop to shop.

D. Filling And Touch Up

Before filling gaps or touch ups of any kind, “Blue Lighting” requires surface preparation.

1. Sand and wash areas with acetone or styrene.
    - The best bonding results are achieved if solvent wash is applied prior to putty application.
2. Backfill areas as required.
    - Large areas may be pumped with equipment.
    - Areas, such as voids, may also be filled with hand mixed putty. If hand mixing, use a higher catalyst level (2% MEKP-9 is recommended). This method is recommended for a minimal thickness of ¼".
3. For thin areas, feather edges and pinhole repairs, use a fairing compound, like Polynt’s F206LF fairing compound.
    - “Blue Lightning” is not formulated to cure well in very thin cross sections.

E. Finishing

“Blue Lightning” is compatible with most standard finishing materials.

1. Sand with a 120-grit sandpaper maximum.
2. Clean surface with acetone prior to apply sanding primer.
3. Apply finish materials.

12.2.6. Surface Quality

The surface quality of the master model is its most important feature for most molded FRP parts. It should be hard, glossy, and free of defects. The molding process will reproduce and worsen any defects on the master model. Polynt tooling gel coat makes an excellent final coating for the master model. When properly applied, tooling gel coat provides the most foolproof surface. Refer to Polycor® 945 & 965 Series Tooling Gel Coat data sheets for specific information.

Resin shrinkage during the molding process will result in a part that is smaller than the master model. For some parts that require precise dimensions, the master model may be made slightly larger to offset this shrinkage. The exact amount will depend on the type of resin and its inherent shrinkage, the glass content, process temperatures, and the number of generations between the master model and the production part. A general rule of thumb for conventional room-temperature cured polyesters is 1/32" of shrinkage per linear foot when reinforced with 25 weight percent glass content.

Gel coat shrinks more than fiber-reinforced resin, resulting in parts that are more concave on the gel coat side. For this reason, any large, flat areas should be crowned in a convex shape to prevent dishing in the reverse direction. A crown of ¼ inch per linear foot is typical for small panels.

12.3. Master Model Preparation

Overview

- **Sanding**
- **Polishing and Buffing**
- **Test for Gloss**

12.3.1. Sanding

A master model should be surfaced with tooling gel coat that is well-cured and sanded smooth. At a minimum, sanding should be accomplished by using finer grit sandpapers until no scratches are present that are deeper than those made by 600-grit paper. For a higher gloss with less buffing, 800, 1000, 1200 and 1500-grit papers are available. Each grit should be used at a 90° angle to the direction of the preceding grit, until all of the crossing scratches are removed. A water-insoluble dye such as steel layout fluid (Dykem® from ITW) or a dry guide coat can be used to increase the visibility of larger grit scratches, which should be sanded until they are eliminated before changing to the next finer grit paper.

When wet sanding, a small amount of dish soap helps to suspend sanding particles in the water. This water should be changed whenever moving to a finer grit paper to avoid subsequently scratching the model surface with the sanding particles from the coarser grit.

12.3.2. Polishing and Buffing

After sanding, the model surface should be polished and buffed using a polishing compound that is formulated for polyesters. Careful attention is needed in this operation. Poor polishing caused by the high heat of the buffing pad can result in orange peel, fiber print, and burn-through. After polishing, wash the model with dish soap and water to remove residues from the buffing compound or polishing medium.

12.3.3. Test for Gloss

After final polishing, check to see if the tooling gel coat has a finished shine once all the compounding materials have dried and been stripped. Using a rag lightly dampened with acetone or other suitable solvent, wipe the gel coat surface to remove any residue. The solvent should remove some of the residual compound oil, but the surface should still have a high gloss. If the tooling gel coat dulls down a great deal, a lack of original gloss is indicated because the compound oil has produced an artificial (false) gloss by wetting the surface and smoothing over any imperfections.

To prevent damage to the tooling gel coat, do not allow acetone or other solvents to puddle upon or to remain in contact with the model's surface.

Mold release wax should not be used to increase gloss on a mold surface. Waxes will raise the gloss of the mold surface, but once coated with the gel coat can haze and are not durable.

The mold surface should be sanded and polished until the tooling gel coat has the degree of gloss that is required for the molded part.

Once the master model has been surfaced, sanded, buffed, polished, and washed with soap and water, a mold release system should be applied.

12.4. Applying Release Wax

Overview

- **Types of Mold Release**
- **Application of Paste Wax**
- **Additional Release Protection**
- **Troubleshooting**

12.4.1. Types of Mold Release

The best results for tooling are achieved by using a good grade of paste wax formulated for FRP. It is imperative that the master model or mold be thoroughly waxed to avoid any sticking during demold of the part. At least six coats of wax should be applied to the master mold to ensure a complete release of the subsequent molded part.

Polymer based or semi-permanent mold releases are not suggested for mold making. They are designed for high volume, production parts making where their improved release is excellent for fast mold turns (i.e., demold). If a polymer-based or semi-permanent mold release system is used, follow the specific directions from the manufacturer. These systems usually include a surface cleaner and a sealer that fills in the microscopic porosity and scratches.

In mold making, molds often take several days to several weeks to be completely finished, thus the less efficient wax based releases are the preferred mold release materials. In mold making, any pre-release will lead to poor surface finish and require a great deal of sanding and post finishing of the mold to match the non-released areas for surface finish and gloss.

It is always a good idea to build a small test panel to be sure the system will produce moldings with the required quality.

12.4.2. Application of Paste Wax

To apply the paste wax:

1. Apply the first coat of release wax in a circular motion, taking care not to apply the release wax too heavily.
2. Wait the amount of time recommended by the manufacturer for the wax to haze (spew) and the solvents to flash off (evaporate).
3. Polish thoroughly by hand using clean, soft, lint-free cotton cheesecloth or terry cloth towels.
    - Always use two rags for wax buffing. The first rag is used to remove the bulk of the wax. The second rag is used for final polishing.
    - Avoid using fibrous paper products because they can scratch the surface and remove the wax release layer.
    - Do not use a machine buffer for polishing, as it may burn through the waxed surface and leave bare areas.
4. Allow the coat of release wax to dry sufficiently. Refer to the manufacturer’s instructions for details.
5. Apply the remaining coats as described above.
    - To help avoid leaving unwaxed areas, begin and end each coat at a different place on the mold.
    - Always wait for hazing before buffing and always wait between coats.
6. After the final coat has dried sufficiently, hand wipe the entire surface with cheesecloth to remove any dust and dirt.

Figure 12-1. Applying paste wax to mold.

12.4.3. Additional Release Protection

To further ensure successful release from a master or plug, a film-forming material that creates a physical barrier can be used in addition to the six coats of wax release. Poly Vinyl Alcohol (PVA) is a water/alcohol solution of water-soluble, film-forming materials. PVA is particularly recommended as an additional release agent on new molds, and when molds are resurfaced, repaired or sanded and buffed. Since it is water-soluble, it is not recommended as a release film for gel coats or resins that contain water or emit water during cure. The PVA film does impart some degree of surface roughness to the molded article, so some post-molding sanding may be required to meet cosmetic requirements. Upon part removal, the PVA should readily dissolve and wash from the molding with water. If the PVA adheres to the mold rather than the part, the film was probably too thin.

To apply the PVA:

1. Upon completing the release wax procedure, apply two coats of a non-silicone paste wax such as, Partall® Paste #2, Meguiar's Maximum Mold Release Wax (M0811), or TR108. The non-silicone paste wax will help prevent fish eyes and allow the PVA to flow more smoothly.
2. Apply several thin coats of PVA.
    - Best spray results are obtained with as fine a spray as possible. Use high air pressure (80-100 psi) and low PVA fluid flow. Normal spraying distance is 12"-20".
3. Follow with a 'heavier' wet coat to a film thickness of approximately 2-4 mils.
    - One gallon will cover approximately 400 square feet.
4. When dry, the PVA film should be tack-free, very smooth and glossy. Drying time is 15-30 minutes, depending on the temperature, humidity, air movement and film thickness.
    - Do not apply tooling gel coat over wet PVA.
5. The spray gun should be cleaned with water and then flushed with solvent to remove the residual water.

When using PVA, refer to Table 12-1 on Troubleshooting PVA Application for suggestions.

12.4.4. Troubleshooting

Table 12-1. Troubleshooting PVA application.

Observation	Suggestion
Air bubbles in the PVA film	• Air pressure too low; use at least 80 psi dynamic at the gun.
Film solution runs	• Film sprayed on too wet and too thick.
Dull spots in the film caused by PVA overspray	• Spray dried PVA film with water to cause re-wetting and flow out.
Entire film is dull and hazy, grainy looking	• Film not thick enough. • Film not sprayed to a "wet" coat.
Surface on part is rough and dull	• Spray dried PVA film with water to cause re-wetting and flow out. • Film not thick enough. • Film not sprayed to a "wet" coat.
Film won't wet out evenly or fish eyes form	• Contaminated surface. Do not use release wax that contains silicone.
PVA etch (a dull, textured pattern on both mold and part surface)	• PVA film too thin (dust coat).
Hard, white build-up accumulates on the mold	• Laminate too hot or PVA too thin.
Part sticking	• PVA film too thin.
PVA stays with the mold, not the part	• PVA film too thin.

12.5. Building a Mold

Overview

- **Introduction**
- **Mold Design**
- **Mold Building Materials**
- **Tooling Gel Coat**
- **Barrier Coats in Tooling Applications**
- **Skin Coat**
- **Conventional Bulking Materials**
- **OPTIMOLD® II Low Profile Tooling Products**
- **OptiPLUS® Low Profile Tooling Products**
- **OptiPLUS® for Infusion**
- **Bracing**
- **Framing**
- **Thermoforming Tooling Gel Coat**

12.5.1. Introduction

There are several aspects to consider before building a mold.

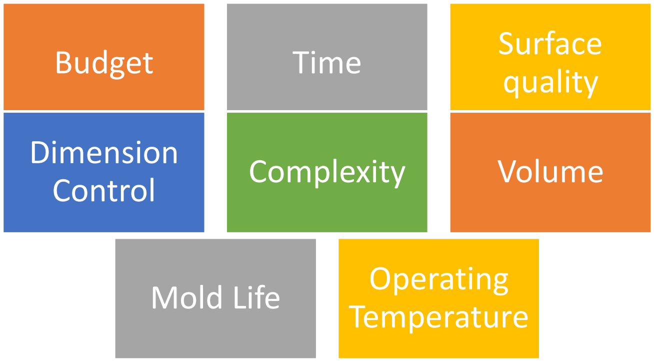


Figure 12-8. Aspects of mold building.

These aspects are used to determine the material(s) selected for mold building.

Molds can be made out of many materials including silicone, coated wood, plaster, metal, epoxy, orthopolyester, isopolyester, vinyl ester and hybrids, and shrink-controlled polyester (filled and unfilled). Table 12-2 shows the advantages and disadvantages of some of these materials.

This section will discuss the building of FRP molds.

Table 12-2. Mold material comparisons.

Metal		Epoxy	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Machined and highly polished surfaces • Dimensionally stable • Long life expectancy • Can be repaired and modified (except nickel) • Accurate temperature control • Excellent for automation and process control • High volume capability	• Cost • Weight • Takes 16-20 weeks to manufacture • Not practical for very large parts • Not practical for low volume parts • Not practical for fast turnarounds	• Lightweight • High strength • Dimensionally stable • Relatively fast to build compared to metal • Excellent life expectancy	• Cost • Takes weeks to manufacture • Low gloss mold surfaces • Ramped post cure required for high Tg and HDT • Increased oven and energy costs

Table 12-2. Mold material comparisons (continued).

Orthopolyester		Isopolyester	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Lowest cost FRP material • Light weight • Relatively fast to build compared to epoxy • Easy to manufacture	• Takes 1-2 weeks to build • Very poor heat resistance • Very poor dimensional stability • High shrinkage requiring oversized master mold • Poor surface retention (fiber print) as mold ages • Very limited mold life • No longer recommended	• Low cost • Light weight • Relatively fast to build compared to epoxy • Improved heat resistance compared to orthopolyester	• Mediocre to good heat resistance • Mediocre dimensional stability • High shrinkage requiring oversized master mold • Poor surface retention (fiber print) as mold ages • Limited mold life • Takes 1-2 weeks to build

Vinyl Ester and Blends	
Advantages	**Disadvantages**
• Improved heat resistance compared to orthopolyester and isopolyester • Low cost • Light weight • Relatively fast to build compared to epoxy	• Limited heat resistance • Moderate dimensional stability • Moderate shrinkage requires oversized master mold • Reduced surface retention (fiber print) as mold ages • Costs more than isopolyester • Takes at least 1-2 weeks to build

Table 12-2. Mold material comparisons (continued).

Shrink-Controlled Polyester (Filled)		Shrink-Controlled Polyester (Unfilled)	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Improved heat resistance (212°F (100°C) range) compared to orthopolyester, isopolyester, and vinyl ester • Very good dimensional control • Warpage resistance • Reproduces the master mold for surface and size • Very limited fiber print as mold ages • Extended mold life; similar to epoxy • Takes days to build mold	• Increased weight compared to orthopolyester, isopolyester, and vinyl ester • Reduced mechanical strengths and low glass fiber content • Brittleness • Potential thermal shock issues, especially during winter • More difficult to repair • Harder to establish secondary bonding with older material • Trapped air • Sensitive to cure conditions (heat and thickness)	• Improved heat resistance over epoxy • Excellent dimensional control • Reproduces the master mold's surface and size • Very limited fiber print as mold ages • Extended mold life; better than epoxy • Build molds in hours to days • Excellent mechanical properties	• Sensitive to cure conditions • Sensitive to laminate thickness (exotherm) • Sensitive to master mold construction (soft tooling)

12.5.2. Mold Design

FRP molds are usually produced using the open molding method. The mold building process must be scheduled and fabricated within a controlled time frame. Gel coat is applied and allowed to cure. Subsequently, layers are applied and bonded to the previously cured gel coat and additional layers. This bond is a secondary bond and a source of potential weakness. For this reason, the gel coat or laminate should never be allowed to cure completely before applying the next layer of material.

12.5.3. Mold Building Materials

Mold laminates should be fabricated from materials specially designed or recommended for tooling. There are several options to consider. A mold laminate can consist of as little as two components: tooling gel coat and a bulk laminate. The tooling gel coat provides a surface that is hard, with a natural shine, and a very smooth, glossy surface. The bulk laminate serves as the structural portion. Additional components, such as barrier coat, skin laminate, and coring materials, can be added to enhance mold performance. Figure 12-9 shows the layers of a mold.

The laminate reinforcement can be any reinforcing fiber. Chopped gun roving or chopped strand mat (CSM) are commonly used. Higher strengths can be achieved using continuous reinforcement, but print-through and distortion will be greater. CSM contains a binder resin that can cause dimples on the gel coat surface. Typically, there is less binder on one side of the CSM. This side should be placed against the gel coat layer. For the best cosmetics, any CSM splices in the part area should employ tear joints at the edges of the CSM.

A skin coat laminate is used to avoid air entrapment next to the gel coat. The entrapped air can lead to subsequent flaws in the gel coat layer. A skin laminate is generally a thin layer, 0.030"-0.090", of chopped gun roving at 33 weight percent reinforcement. This corresponds to between one and three ounces per square foot (300-900 grams/square meter).

Figure 12-9. Layers of a mold.

Notes: (1) Use layers to reach the desired bulk laminate thickness. (2) The coring material should be placed in the middle of the bulk laminate layers.

The bulk laminate is usually made with one of four resin materials: Stypol® conventional isophthalic laminating resin; Stypol VSXH vinyl ester blend; OPTIMOLD® II (alumina trihydrate filled controlled-shrink) laminating resin; or OptiPLUS® (unfilled controlled-shrink) laminating resin.

Total mold thickness depends upon the size and shape of the mold. A thickness of ¼" for up to 10 linear feet, with an extra ⅛" for each additional five linear feet, is a very loose rule of thumb. Flat molds may need more thickness than complex molds to achieve the same stiffness. The style and type of framing, as well as the mechanical and physical properties for the laminating materials, also influence design thickness.

Structural considerations are addressed with bracing and framing. Bracing is an element that is integral to the mold laminate. Large molds usually incorporate balsa core materials. A shaped stiffener element, like a hat or blade, can also be incorporated. Framing is a structure that surrounds and supports the mold from the back side. Generally, steel is used for framing, although wood is commonly used.

For open molding, the frame is a cradle that loosely supports the mold laminate, by design, by lightly tabbing the laminate to the structural frame. Light tabbing can easily be repaired if damaged. Heavy tabbing will transfer thermal shock to the mold surface.

For high pressure resin transfer molding, the frame is a structural reinforcement for the laminate that defines the mold cavity. Care should be taken to float bracing material off the mold's backside to avoid hard spots that could transfer to the mold's surface. Cardboard or wood shims are suggested and should be removed after the frame is tied to the mold skin.

Once the mold's design and construction methodology are selected, one or more small test panels should be produced to demonstrate suitable process conditions and application techniques. Performance of these tests prior to building a mold is very prudent and leads to the highest quality mold for the lowest cost.

12.5.4. Tooling Gel Coat

Isophthalic polyester tooling gel coats provide the highest gloss, but with a modest strength and heat distortion temperature (HDT). Vinyl ester gel coats provide the highest strength and HDT, but with a modest loss of gloss. Refer to the Polycor® 945 and 965 Series Tooling Gel Coat data sheets for specific material, equipment, and application information.

Before using tooling gel coat to fabricate molds, a gel coat sprayout test panel should be prepared as shown in Figure 12.10. The sprayout should be made under the same conditions as those that will be used while spraying the actual mold. After evaluation, the sprayout should be retained along with other data as part of the mold's historical record.

Figure 12-10. Gel coat sprayout test panel.

The first coat of the tooling gel coat is the most critical, since this will be the surface that defines the final surface quality. If porosity is evident after the film is gelled, the coat should be removed and the problem corrected. Once the film is clean, with no porosity, pits, or pinholes, the second coat can be applied. Some tool builders use different colors for the first and second gel coat layers. The color contrast provides a visible indication of how much gel coat is being removed during finishing, maintenance, and repair operations.

To produce a quality sprayout panel:

1. Apply mold release wax to a clean glass plate.
   - A common size is 12"x12".
2. Spray a properly catalyzed film of gel coat using the same techniques that will be used on the production mold, using the same equipment, as well as the same lot of gel coat and catalyst.
3. Use a wet-film gauge to ensure that the gel coat is applied in three passes to achieve a total thickness of 18 ± 2 mils (450 ± 50 microns) wet.
4. Once cured, the gel coat film should be laminated or backed with masking tape for demolding.
5. The gel coat surface should be visually inspected for imperfections. Sand the surface with 400-grit sandpaper. Wipe with a contrasting dye to reveal any surface and/or internal porosity.
6. If the sprayout panel looks satisfactory, use the same material lots, equipment and application techniques to produce the mold. If the panel does not look satisfactory, spray adjustments should be made until a high quality panel is produced that is porosity-free with no surface imperfections.

Most of Polynt's tooling gel coats are formulated for air atomized and airless air-assist spray application. When using air atomized (pressure pot) spray equipment, a material flow rate of 1.5-2.5 pounds per minute is recommended. An air atomization pressure of 60-75 psi (at the gun with the fan full open) utilizes 17 CFM of air and normally ensures excellent atomization of the gel coat. When using airless air-assist equipment, the material flow rates and tip sizes in Table 12-3 are recommended. Excessive material flow rates can create sags, pinholing, porosity, excessive orange peel, and should be avoided.

Table 12-3. Airless air-assist recommendations.

	Flow Rate	Tip Size
Intricate Parts, Small Parts, and Decks	1.5-3.0 lbs/minute	0.018 inch
Large Parts, Open Molds, and Flat Panels	1.5-4.0 lbs./minute	0.021 inch

The tooling gel coat should be applied in one or two smoothly sprayed coats of 18 ± 2 mils wet for each coat. Each coat should be developed through three spray passes, with each pass at a right angle to the previous pass.

The first coat should be allowed to gel and cure only to the point where it will not alligator when the second coat is applied. Normally, this time period is 90 minutes at 77°F (25°C) and 1.8% catalyst, depending on the tooling gel coat and conditions. Spraying tooling gel coat at temperatures lower than 77°F (25°C) can result in undercure that appears later as distortion and/or dulling of the mold surface.

The second coat can be a different color and act as a warning when the first coat has been sanded through during the mold's service life. Figure 12-11 shows two layers of tooling gel coat, orange and then black, sprayed for a tub/shower combination mold. Barrier coat can also be used as a substitute for the second coat of tooling gel coat, applied at the same thickness as the tooling gel coat.

Figure 12-11. Tub/shower combination mold sprayed with orange and black tooling gel coat.

Lamination should begin only after the second layer of tooling gel coat, or barrier coat, has cured for 60-90 minutes or up to three hours. The time element is dependent upon room temperature, air movement, humidity, catalyst type, and concentration. If the gel coat cures too completely, it may shrink and pull away from the master (pre-release). The gel coat should be covered with at least a skin laminate on the same day it is sprayed to avoid gel coat pre-release. Excessive delays can also result in dust or dirt accumulation that can prevent proper laminate adhesion.

12.5.5. Barrier Coats in Tooling Applications

A vinyl ester barrier coat can be used as a print blocker to provide a smoother gel coat surface. This translates into a mold that yields parts with improved cosmetics. A black or white barrier coat also provides a visual aid for detecting air bubbles during skin coat lamination. Barrier coat can also be used as a substitute for the second layer of tooling gel coat, as shown in Figure 12-12. Do not use barrier coat with thermoforming tooling gel coat.

Figure 12-12. Barrier coat applied in place of second layer of tooling gel coat.

The barrier coat material is applied in the same manner as a gel coat to a thickness of 18 ± 2 mils (400-500 microns). This buildup should done in three passes, with each pass at a right angle to the previous pass.

Vinyl ester barrier coats, like the ArmorGuard® 967, do have some porosity and should not be used as a molding surface. The porosity is intrinsic to vinyl ester based barrier coats and does not present a problem when applied behind a full layer of tooling gel coat.

For ArmorGuard® 967, quality control is performed with Arkema Luperox® DDM-9. The ideal catalyst level is 1.8% at 77°F (25°C) and should always be between 1.2-2.5% for proper cure. This generally requires ambient temperatures in the 70-95°F (21-35°C) range. Successful usage is possible at temperatures slightly outside this range, but at an increased risk of pre-release or poor cure.

Normally, the barrier coat film is ready for lamination within 60 minutes. This time interval is dependent upon material temperature, room temperature, humidity, air movement, and catalyst concentration.

12.5.6. Skin Coat

A chopped glass skin coat laminate using unfilled tooling resin is required when bulking with filled, shrink-controlled resins, such as OPTIMOLD® II. The skin coat is optional for OptiPLUS® systems. It is strongly suggested for complex geometries. A skin coat provides the best opportunity to prevent air voids behind the gel coat surface. The skin coat also provides good mechanical properties and impact resistance, directly improving mold life.

Either STYPOL® 040-4339 isophthalic skin resin or ArmorStar® VSXH-2210, a higher performance, epoxy-modified polyester skin resin, can be used in the skin laminate.

Any defects in the skin coat, such as blisters, voids, contamination, and/or foreign objects will transfer through to the gel coat surface. These imperfections will not always be visible on a new mold, but can appear as the mold is used in production. Repairing these defects is time-consuming and will detract from the overall mold surface quality. Removing a skin coat defect by grinding can result in scratches, nicks, or gouges on the underlying mold or pattern surface. It is often more economical to start over than it is to repair gouges on a fiberglass master mold or production mold. Removing skin coat defects by grinding should not be entrusted to untrained and/or unskilled personnel without accepting the risk of damage to high value assets.

In general, a skin coat should contain 31-35% chopped glass fiber by weight. The nominal thickness should fall in the range of 30-90 mils. A chopped glass skin coat at 1 ounce per square foot (osf) glass will measure about 30 mils; 1.5 osf will measure about 45 mils; 2 osf will measure about 60 mils; and 3 osf will measure about 90 mils. A laminate thickness gauge should be used to verify that the correct thickness is applied. Since an air-free skin coat is easier to apply thinly rather than thickly, use multiple passes to apply this layer.

Figure 12-13 shows a skin coat laminate being applied to a test panel. Figure 12-14 shows a Barcol hardness test.

Figure 12-13. Skin coat application.

Figure 12-14. Barcol hardness test of skin coat.

Controlled-shrink resins such as OPTIMOLD® II or OptiPLUS® should not be used as skin coat resins. These resins require a sufficient mass to produce the exotherm heat needed for shrinkage control. Proper rollout and removal of all air voids becomes very difficult at the thicknesses required for shrinkage control.

For molds that will experience thermal cycling or shock, the glass content should be lower in the layer adjacent to the gel coat than it is in the rest of the laminate. For the greatest durability, a glass veil with a weight of 25-50 grams per square meter should be brush laminated right against the gel coat. The glass content should be 10-15% by weight. The same type of resin used for the skin coat should be used for saturating the glass veil. Due to the thin nature of a veil layer, the catalyst level should be at the high end of the recommended range for good cure. This resin-rich veil layer should be followed by a more typical 30% chopped glass skin coat. The low-fiber-content veil layer provides a transition from the high thermal expansion characteristics in the gel coat layer to the much lower thermal expansion characteristics in the structural laminate. This reduces the stresses imposed by the thermal cycle or shock between the gel coat and laminate, thus extending mold life.

Woven or stitched cloth materials should not be used in a skin coat. The resin shrinkage usually results in weave print (print-through) that is visible on the final mold surface. The severity of this weave print depends upon the fiber architecture in the material. For example, woven roving has large bundles that undulate (move up and down) at bundle crossovers. This results in a large resin-rich area as a bundle crosses under another. The resin shrinkage at these points will easily telegraph through to the mold gel coat surface. This can be so pronounced that the difference between 18 osy (ounce per square yard) and 24 osy WR (woven roving) will be discernible. This weave print may not be visible when the mold is first produced, but may appear as the mold experiences production cycles.

12.5.7. Conventional Bulking Materials

A conventional bulking material is a thixotropic laminating resin with a high heat distortion temperature (HDT). Historically, an isophthalic polyester resin has been the industry standard. This type, like most laminating resins, shrinks when it cures. This shrinkage causes an overall dimensional change in the mold and cosmetic flaws known as distortion, print-through and mark-off. Distortion is the surface waviness visible on the panel surface when light is reflected off the gel coat surface. Print-through is more severe and can mimic the architecture of the fiber forms used in the underlying laminate. Mark-off is a cosmetic defect that can appear when something, such as a piece of steel framing, presses against the laminate back side. It can be avoided by floating the bracing and framing materials during the tabbing.

Shrinkage occurs because of two mechanisms: curing shrinkage and cooling shrinkage. The first mechanism, curing shrinkage, occurs in two stages: during cure (before demold) and during postcure (after demold). Curing shrinkage is due to a volume change in the resin that accompanies the cure. This curing shrinkage is inevitable. It is best when all of it occurs prior to demolding from the master. When some portion of the cure occurs after demolding, the additional shrinkage causes cosmetic flaws to appear on the surface. This is commonly called postcure, but it is really distortion caused by the additional shrinkage that occurs during postcure.

The second mechanism, cooling shrinkage, is due to thermal expansion (actually contraction) when the laminate cools from its stress-free temperature. The stress-free temperature is related to the temperature that is seen by the laminate when the resin solidifies. The greater the difference between the stress-free and ambient temperatures, the more cooling shrinkage occurs. Therefore, the cooling shrinkage can be managed by minimizing the exotherm temperature during the laminate cure. Postcure shrinkage is minimized by achieving a complete cure and may require elevated temperatures. Cooling shrinkage is minimized by lower exotherm temperatures and minimal exposure to elevated temperatures. As a result, the optimum cure profile is very strongly dependent on the laminate exotherm temperature and resin area weight.

Minimizing shrinkage provides the best cosmetics. Completing the cure prior to demolding provides the most stable cosmetics. For conventional bulking materials, this is achieved by single-ply laminations, one 1.5 oz. CSM (or equivalent if glass choppings) per day, with a resin that is specifically designed to cure in a single ply.

Due to the extended nature of this lamination sequence, the secondary bonding window becomes important for scheduling purposes. Usually, a mold is started early on a Monday and lamination proceeds throughout the week. When lamination pauses for more than 24 hours, such as over a weekend, it is best to enhance secondary bonding with thorough mechanical abrasion, in addition to normal surface deburring. For the best cosmetics, the completed mold laminate should be allowed to cure for an additional 5-10 days prior to demolding. A new mold should always be demolded prior to any elevated temperature postcure.

The most common single ply lamination is 45 mils (1.5 ounces per square foot or 450 grams per square meter) at 30 weight percent reinforcement. Exotherm temperatures will run 5-15°F (9-15°C) above ambient and seldom reach as high as 140°F (60°C).

Slight concessions in cosmetic quality occur when single-ply laminations are applied twice per day (such as morning and evening). Additional concessions in cosmetic quality occur when double-ply laminations are applied. These concessions are worse for laminations closer to the gel coat surface.

Skin coat resins like STYPOL® 040-4339 or ArmorStar® VSXH-2210 are designed for single-ply lamination. Optimum cosmetics for double-ply or thicker laminations may require a slightly different resin such as STYPOL® 040-2989 isophthalic polyester tooling resin, which is designed to cure in thicker laminates.

12.5.8. OPTIMOLD® II Low Profile Tooling Products

OPTIMOLD® II resin is a two component, low profile resin system that incorporates alumina trihydrate (ATH) filler. The two resin components are STYPOL® 040-8060 and 040-8070. When mixed, the OPTIMOLD® II resin is a pre-promoted, thixotropic, shrinkage-controlled laminating resin. OPTIMOLD® II resins cure at room temperature with a high-dimer MEKP catalyst such as United Initiators Norox® MEKP-925, Arkema Luperox® DHD-9, or Pergan Hi-Point® 90.

OPTIMOLD® II is used to produce molds with outstanding cosmetic quality and significant time and labor savings. Laminate thickness can be added quickly with minimal surface distortion. This surface quality is achieved via minimal resin shrinkage during the cure process. The minimal resin shrinkage provides a mold with dimensions nearly identical to the master model. Unlike conventional isophthalic tooling resins, the cosmetic quality is very stable over the life of the mold.

The advantages of OPTIMOLD® II are:

- Excellent cosmetic stability due to controlled-shrinkage technology.
- Faster mold building than with conventional isophthalic tooling resin.
- Fire retardant characteristics due to the ATH filler.
- Good mechanical properties.
- Pre-promoted in pre-weighed packages.

When using OPTIMOLD® II to laminate molds, attention to process details is a key element for success. OPTIMOLD® II products are sensitive to plant airflow, cooling conditions, erratic operating conditions and inconsistencies in application. Best results are obtained by using OPTIMOLD® II in a controlled environment with optimal process conditions.

OPTIMOLD® II is packaged in a short-filled, open-head drum with a companion pail. This allows the filled mix to be prepared in the drum.

To mix a 500 pound batch at the proper mix ratio:

1. Add one (1) companion pail of STYPOL® 040-8070 to the drum of STYPOL® 040-8060 and mix.
    - The drum contains 255 pounds of STYPOL® 040-8060.
    - The companion pail contains 45 pounds of STYPOL® 040-8070.
2. Add 200 pounds of ATH filler (four 50 pound bags) to the STYPOL® mixture in the drum slowly under gentle agitation using a large paddle mixer.
    - Recommended ATH fillers are either R. J. Marshall A-208 (www.rjmarshall.com) or J. M. Huber SB-432 (www.huber.com).
    - High shear mixing is not required or desired.
    - Over mixing increases the tendency to sag.
    - Avoid mixing air into the batch by using the least amount of turbulence possible.
    - A bunghole mixer will not adequately mix in the filler, resulting in clumps of unmixed (dry) filler on the mold.
    - Air bubbling should never be used for mixing. It is not effective and only serves as a potential for water or oil contamination.
    - Use of the mix prior to complete filler wetting can result in localized, soft, filler-rich areas in the laminate.
    - If the material is allowed to sit without proper agitation, the filler will settle to the bottom and be very difficult to redisperse.
3. After the filler appears to be mixed in, scrape the sides of the container to remove dry filler.
4. Continue mixing for 30 minutes to allow small particles of filler to completely wet.

To prevent filler settling, the mixture should be kept under gentle agitation until it is completely used.

The mixture should be used within 2-3 days. After three days, increased viscosity, extended gel time, and loss of shrinkage control may result. It is best to use the entire batch on the same day it is mixed.

To mix smaller batches (ratio by weight):

1. Add nine (9) parts of STYPOL® 040-8070 to 51 parts of STYPOL® 040-8060 and mix.
2. Add 40 parts of ATH filler to the STYPOL® mixture slowly under gentle agitation using a large paddle mixer. Follow the mixing suggestions listed in step 2 for a 500 pound batch.
3. Follow steps 3 & 4 above.

Prior to building each mold, small test laminates should be prepared to demonstrate suitable process conditions and application techniques.

Laminating with OPTIMOLD® II should be performed at temperatures between 75-90°F (24-32°C). Successful application is possible at temperatures outside of this range, but will require specific adjustments in laminate thickness and catalyst level to keep exotherm temperatures within specification. Temperatures of all materials and process items should be between 75-90°F (24-32°C). This includes the master mold, resin, and glass roving, in addition to the ambient room temperature. When temperatures are outside this range, the likelihood of poor cure, excessive shrinkage or laminate expansion and the resultant substandard cosmetic quality is increased.

For OPTIMOLD® II tooling resins, glass content should be between 22-28% by weight. The ideal glass content is 25% by weight. Lower glass content will result in excessive exotherm temperatures and could cause expansion of the laminate. Higher glass content will result in lower exotherm temperatures and may cause poor cure or excessive shrinkage.

Nominal uniform laminate thickness of 3/16" (188 mils) per lamination is recommended. The laminate thickness and catalyst level can be adjusted for variations in ambient temperature. The laminate thickness can range from 0.170-0.220" (170-220 mils). Obtaining a laminate exotherm temperature between 110-140°F (43-60°C) produces optimum results.

OPTIMOLD® II quality control testing is performed using United Initiators Norox® MEKP-925 catalyst. Chemical equivalents, such as Arkema Luperox® DHD-9 or Pergan Hi-Point® 90, can also be used. Cumene hydroperoxide (CHP) and MEKP blends are not recommended. Consult a Polynt representative for other specific catalyst recommendations.

Under ideal conditions at 77°F (25°C), use MEKP-925 at 1.5% based on resin mix weight. For colder temperatures, as much as 1.75% can be used. For warmer temperatures, as little as 1.25% can be used. Catalyst levels slightly outside the range of 1.25-1.75% may be necessary at the temperature extremes, but this can lead to substandard results and is not recommended.

A standard resin pump with a catalyst slave pump provides catalyst adjustments based upon volume, not weight. Since the OPTIMOLD® II is filled with ATH and ATH is non-reactive, the true catalyst ratio by weight is different from the volume ratio marked on the equipment. Table 12-4 provides a cross reference between the catalyst percentage by volume and the true catalyst percentage by weight for the OPTIMOLD® II system.

If the laminate turns uniformly white within 60 minutes of catalyzation, it is most likely properly cured. If the laminate is amber in color or spotty white and not uniform, it is most likely poorly cured. Reconstruction should be performed under more ideal conditions. Avoiding the need for reconstruction is best accomplished by building test laminates.

Table 12-4. OPTIMOLD® II catalyst correction.

Catalyst % by Volume	Catalyst % by Weight
0.90	1.27
0.95	1.34
1.00	1.41
1.05	1.48
1.10	1.55
1.15	1.62
1.20	1.69
1.25	1.77

Most chopper guns configured for filled resins can be used to spray OPTIMOLD® II resins. Standard laminating equipment may require specific adjustments to ensure proper application. An increased spray pressure and/or larger tip orifice size may be required due to the viscous nature of an ATH-filled resin.

When using fluid impingement equipment, refer to the manufacturer's recommendations for filled systems.

The glass content should be demonstrated by measuring prior to building a test laminate. The test laminate is then used to verify catalyst level and laminate thickness. Mold building should commence only after a test laminate is successfully produced.

The OPTIMOLD® II lamination procedure is:

1. Apply a mist coating of resin to the work zone.
    - A typical work zone ranges from 25-100 square feet, depending upon the number of laminators and ambient temperature conditions.
2. Apply 0.040" (40 mils) of gun chop to the work zone for the first lamination pass against the skin coat.
3. Roll the first pass to eliminate all air.
4. Once rolled and before gelation, apply another pass of 0.130-0.170" (130-170 mils) of gun chop to the work zone.
5. Roll this second pass for consolidation.
    - A slow-motion rolling approach with a light touch helps to consolidate the material and helps to avoid just pushing the material around.
6. Cover neighboring work zones in a similar manner, maintaining a 'wet edge' between work zones.
7. Allow this nominal 0.190" (190 mil) thick lamination to gel and cure, approximately 30-60 minutes from application to each work zone.
8. The laminate should exotherm at 110-140°F (43-60°C) and turn uniformly tan-white in approximately 75 minutes.
    - Times in excess of 90 minutes suggest a reduced or poor cure, and subsequent warpage and postcuring of the mold may occur.
    - An infrared thermometer should be used to monitor laminate exotherm, both for the test and mold laminates.

9. Apply additional OPTIMOLD® II laminations until the design mold thickness is achieved.
    - Each lamination can begin once the mold temperature returns to near ambient temperature (comfortable to touch).
    - Subsequent laminations do not require the 0.040" (40 mil) pass, although applying material in two passes does facilitate rolling and accuracy of laminate thickness.
    - The entire 0.190" (190 mil) laminate thickness can be applied after the mist coating of resin for each subsequent lamination.

For best results, the entire OPTIMOLD® II mold laminate should be applied on the same workday. Spotty interlaminar adhesion may result if one lamination is allowed to cure too completely. When delays are required, a commercially available two component urethane or adhesion promoter should be used to achieve a good secondary bond. Follow the manufacturer’s directions.

12.5.9. OptiPLUS® Low Profile Tooling Products

OptiPLUS® resins are used to produce molds with outstanding cosmetic quality. This surface quality is achieved with minimal resin shrinkage during the cure process. Unlike conventional isophthalic tooling resins, the cosmetic quality is very stable over the life of the mold. OptiPLUS® resins are pre-promoted, thixotropic, shrinkage-controlled laminating resins that do not require the addition of fillers or additives. OptiPLUS® resins cure at room temperature with conventional MEKP catalysts.

Figure 12-15. Boat hull mold sprayed with OptiPLUS®.

The advantages of OptiPLUS® are:

- Excellent cosmetic stability due to controlled shrinkage technology.
- Faster mold building than conventional isophthalic tooling resin. See Table 12-5 for an example.
- Lower weight molds than OPTIMOLD® II (ATH-filled) tooling resin.
- Excellent mechanical properties.

When using OptiPLUS® to laminate molds, attention to process details is a key element for success. OptiPLUS® products are very sensitive to plant airflow, cooling conditions, erratic operating conditions and inconsistencies in application. Best results are obtained by using OptiPLUS® in a controlled environment with near ideal process conditions.

Prior to building each mold, small test laminates should be prepared to demonstrate suitable process conditions and application techniques.

Laminating with OptiPLUS® should be performed at temperatures between 75-95°F (24-35°C). Successful application is possible at temperatures as low as 60°F (15°C) or as high as 100°F (54°C), but will require specific adjustments in laminate thickness and catalyst level to keep exotherm temperatures within specification.

The temperatures of all materials and process items should be between 75-95°F (24-35°C). This includes the master mold, resin, and glass roving, in addition to the ambient room temperature. Temperatures outside this range are not recommended due to the high likelihood for poor cure, excessive shrinkage, or laminate expansion and the resultant substandard cosmetic quality.

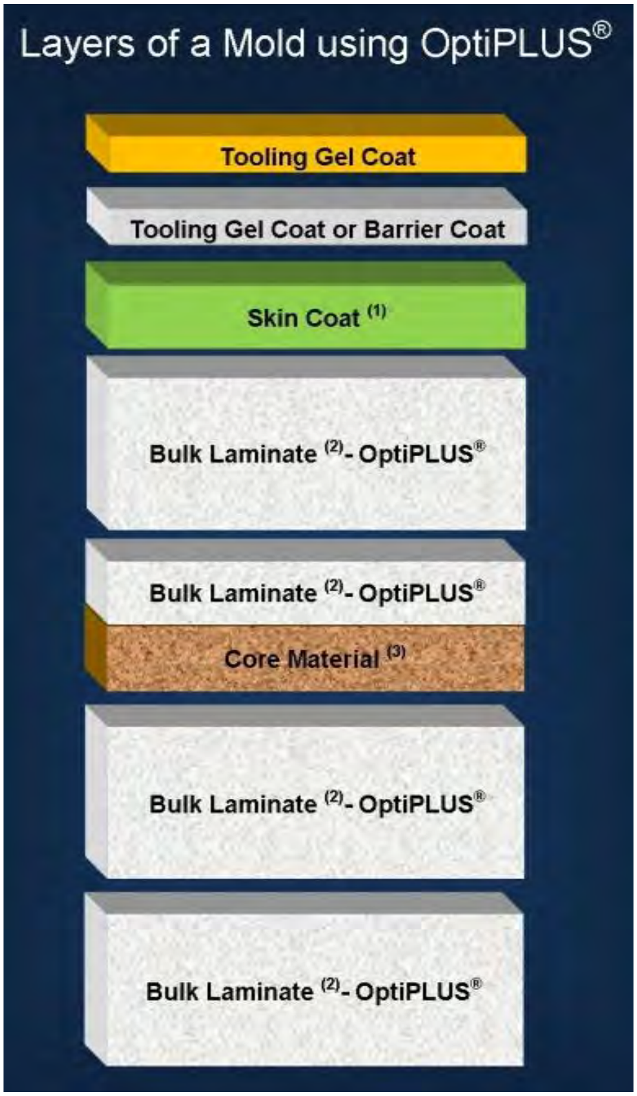


Figure 12-16. Layers of a mold using OptiPLUS®.

Notes: (1) Optional, but highly recommended for complex geometries. (2) Use OptiPLUS® layers to reach the thickness. (3) The coring material should be placed in the middle of the OptiPLUS® layers.

For OptiPLUS® tooling resins, glass content should be between 37-41% by weight. The ideal glass content is 39% by weight. Lower glass content will result in excessive exotherm temperatures and could cause expansion of the laminate. Higher glass content will result in lower exotherm temperatures and may cause poor cure or excessive shrinkage. Newer, high efficiency glass fiber rovings, like OCV's OptiSpray™ F, should be run at 40-45% fiber content to prevent draining and looking too wet.

A uniform laminate thickness of 0.180 inches (180 mils) per lamination is recommended. The laminate thickness and catalyst level can be adjusted for variations in ambient temperature. Obtaining a laminate exotherm temperature between 135-160°F (57-71°C) produces optimum results.

Table 12-5. Example comparison of molds built using conventional bulking materials versus OptiPLUS®.

Day	Conventional	OptiPLUS®
1	Tooling Gel Coat Tooling Gel Coat / Barrier Coat Skin Laminate	Tooling Gel Coat Tooling Gel Coat / Barrier Coat Skin Laminate Layer of Bulk Laminate - OptiPLUS®
2	Single layer of Bulk Laminate	Layer of Bulk Laminate - OptiPLUS® (as needed)
3	Single layer of Bulk Laminate	Layer of Bulk Laminate - OptiPLUS® (as needed)
4	-	Layer of Bulk Laminate - OptiPLUS® (as needed)
5	Double layer of Bulk Laminate	-
6	-	-
7	-	-
8	-	-
9	Double layer of Bulk Laminate	-
10	-	-

OptiPLUS® quality control testing is performed using United Initiators Norox® MEKP-9 catalyst. Chemical equivalents, such as Arkema Luperox® DDM-9, can also be used. Under ideal conditions at 77°F (25°C), use MEKP-9 at 1.5% based on resin weight. For colder temperatures, as much as 2% can be used. For warmer temperatures, as little as 1.2% can be used. Catalyst levels outside the range of 1.2-2% can lead to substandard results. High dimer peroxide catalysts, such as United Initiators Norox® MEKP-925, Pergan Hi-Point® 90, or Akzo Nobel Cadox® L-50a, can be used, but will provide longer gel times. Cumene hydroperoxide (CHP) and MEKP blends may also be used if the CHP is less than 35% of the blend. Suitable cure should always be tested. Consult a Polynt representative for other specific catalyst recommendations

If the laminate turns uniformly white within 60-75 minutes of catalyzation, it is most likely properly cured. If the laminate is amber in color or spotty white and not uniform, it is most likely poorly cured. Figure 12-17 shows examples of poorly cured OptiPLUS®.

Figure 12-17. Examples of poorly cured OptiPLUS®.

Reconstruction should be performed under more ideal conditions. Avoiding the need for reconstruction is best accomplished by building test laminates prior to full-scale mold building activities. Heat can also be added to spots to complete cure.

Most laminating spray equipment can be used to spray OptiPLUS® resins. The equipment may require specific adjustments to ensure proper glass content. Two strands of glass roving, reduced spray pressure, and/or reduced tip orifice size may be required. For fluid impingement equipment, an orifice of 0.040" with a 40-50° fan pattern at 40 psi is suggested.

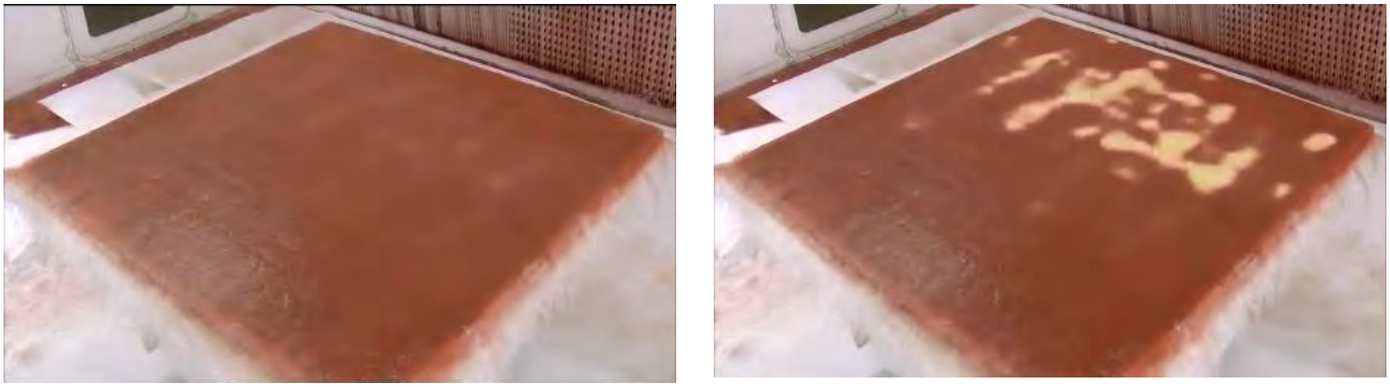
The glass content should be demonstrated by testing prior to building a test laminate. The test laminate is used to verify catalyst level and laminate thickness. Mold building should commence only after a test laminate is successfully produced.

The OptiPLUS® mold laminate construction procedure is:

1. Apply a mist coating of resin to the work zone.
    - A typical work zone ranges from 25-100 square feet, depending upon the number of laminators and ambient temperature conditions.
2. Apply 0.060-0.090" (60-90 mils) of gun chop to the work zone for the first lamination pass against the gel coat (Figure 12-18).
3. Roll the first pass to eliminate all air at or near the gel coat surface (Figure 12-18).
4. Once rolled and before gelation, apply another 0.090-0.120" (90-120 mil) pass of gun chop to the work zone for a total of 0.180" (180 mils) (Figure 12-18).
5. Roll this second pass for consolidation.
    - A slow-motion rolling approach with a light touch helps to consolidate the material and helps to avoid just pushing the material around.
6. Cover neighboring work zones in a similar manner, maintaining a ‘wet edge’ between work zones.
7. Allow this 0.180" (180 mil) thick lamination layer to gel and cure, approximately 30-60 minutes from application to each work zone.
8. The laminate should exotherm at 135-160°F (57-71°C) and turn uniformly tan-white at approximately 60-75 minutes (Figure 12-19).
    - Times in excess of 90 minutes would suggest a reduced or poor cure, and subsequent warpage and postcuring of the mold may occur.
    - An infrared thermometer should be used to monitor laminate exotherm, both for the test laminates and the mold laminates (Figure 12-18).
9. Apply additional OptiPLUS® laminates until the design mold thickness is achieved.
    - Each lamination can begin once the mold temperature returns to near ambient temperature.

- Subsequent laminations do not require the 0.060-0.090" (60-90 mil) thick pass, but is suggested for thickness control.

Figure 12-18. OptiPLUS® mold laminate construction steps.



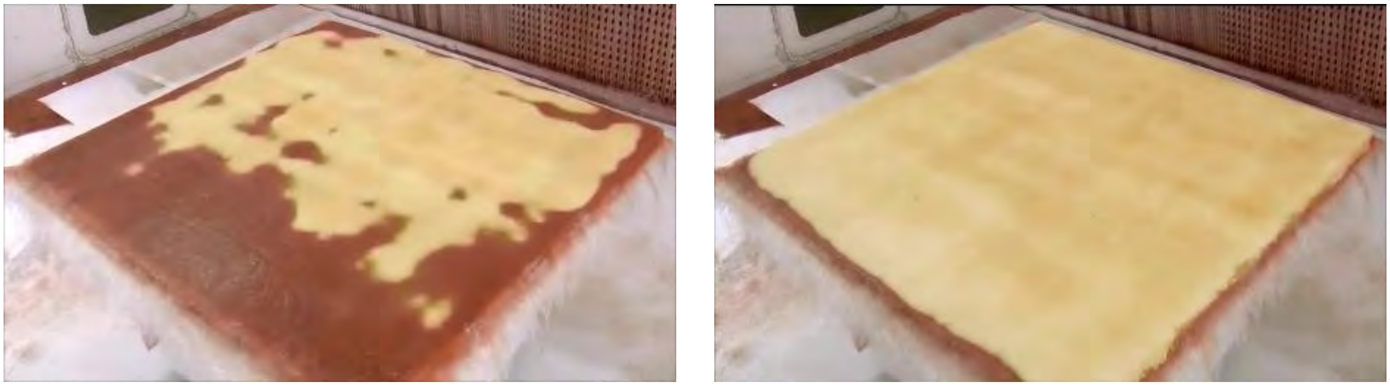


Figure 12-19. Time lapse of OptiPLUS® curing.

12.5.10. OptiPLUS® for Infusion

OptiPLUS® Infusion resins, 040-8079 and 040-8091, are used to produce molds with outstanding cosmetic quality. This surface quality is achieved with minimal resin shrinkage during the cure process. Unlike conventional isophthalic tooling resins, the cosmetic quality is very stable over the life of the mold.

These resins can replace isophthalic, vinyl ester, and epoxy resins in the following tooling application processes:

- Conventional molding - Hand lay-up, spray-up, and infusion
- Resin Transfer Molding (RTM) and Vacuum Assisted Resin Transfer Molding (VARTM)
- Reaction Injection Molding (RIM)
- Thermoplastic Vacuum Forming

OptiPLUS® Infusion resins are pre-promoted, thixotropic, shrinkage-controlled laminating resins that do not require the addition of fillers or additives. OptiPLUS® Infusion resins cure at room temperature with conventional MEKP catalysts.

The advantages of OptiPLUS® Infusion are:

- Excellent cosmetic stability due to controlled shrinkage technology.
- Faster mold building than conventional isophthalic tooling resin.
- Lower weight molds than OPTIMOLD® II (ATH-filled) tooling resin.
- Excellent mechanical properties.
- Very high heat resistance.
- High fiber content laminates (65-70% typically).

An example comparison of open versus vacuum infusion molding lamination layers is shown in Table 12-6.

Table 12-6. Example of open mold versus vacuum infused lamination layers.

Open Mold	Vacuum Infused
• Tooling Gel Coat • Tooling Gel Coat or Barrier Coat • Skin Laminate • Bulk Laminate • Bulk Laminate • Bulk Laminate • Bulk Laminate	• Tooling Gel Coat • Surface Veil • Bulk Laminate

When using OptiPLUS® Infusion, attention to process details is a key element for success. OptiPLUS® Infusion products are very sensitive to plant airflow, cooling conditions, erratic operating conditions and inconsistencies in application. Best results are obtained by using OptiPLUS® Infusion in a controlled environment with near ideal process conditions.

Prior to building each mold, small test laminates should be prepared to demonstrate suitable process conditions and application techniques.

Infusing with OptiPLUS® should be performed at temperatures between 70-95°F (21-35°C). Successful application is possible at temperatures as low as 60°F (15°C) or as high as 100°F (54°C), but will require specific adjustments in laminate thickness and catalyst level to keep exotherm temperatures within specification.

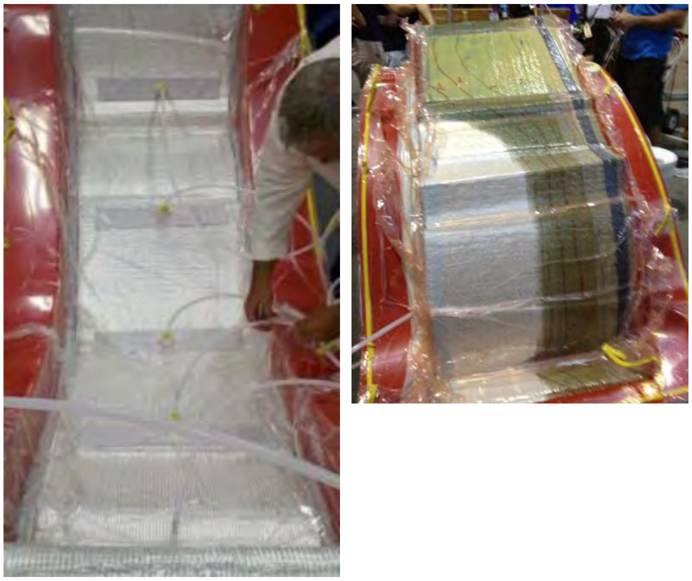


Figure 12-20. Examples of infusion.

Temperatures of all materials and process items should be 70-95°F (21-35°C). This includes the master mold, resin, and glass roving, in addition to the ambient room temperature. Temperatures outside this range are not recommended due to the high likelihood for poor cure, excessive shrinkage, or laminate expansion and the resultant substandard cosmetic quality.

For OptiPLUS® Infusion tooling resins, glass content should be between 60-70% by weight. The ideal glass content is 65% by weight. Lower glass will result in excessive exotherm temperatures and could cause expansion of the laminate and damage master molds. Higher glass content will result in lower exotherm temperatures and may cause poor cure or excessive shrinkage.

The 0.25-2.0" laminate thickness is determined during laminate design and largely controlled by the laminate schedule. The laminate thickness and catalyst level can be adjusted for variations in ambient temperature. Obtaining a laminate exotherm temperature between 150-180°F (65-82°C) produces optimum results. Exotherms above 200°F (93°C) should be avoided to protect the tooling gel coat and plug.

OptiPLUS® Infusion quality control testing is performed using United Initiators Norox® MEKP-9 catalyst. Catalyst levels outside the range of 0.9-2.4% can lead to substandard results. Acetylacetone peroxides (AAP), such as United Initiators Norox® Azox, or AAP blends, such as United Initiators Anodox® SHP-90, should be considered for thin, high glass content laminates or in cool temperatures for thicker infused laminates. Cumene hydroperoxide (CHP) and MEKP blends, such as United Initiators Norox® MCP-75, may also be used while maintaining the 150-180°F exotherm temperature. Suitable cure should always be tested. Consult a Polynt representative for other specific catalyst recommendations

If the laminate turns uniformly white within 60 minutes of catalyzation, it is most likely properly cured. If the laminate is amber in color or spotty white and not uniform, it is most likely poorly cured.

Reconstruction should be performed under more ideal conditions. Avoiding the need for reconstruction is best accomplished by building test laminates prior to full-scale mold building activities.

Heat can also be added to spots to complete cure if applied within the initial cure time, usually within the first 90 minutes. Temperature extremes above 200°F (93°C) should be avoided and can be controlled by passing compressed air over the backside mold surface if 200°F (93°C) temperatures are observed.

The glass content should be demonstrated by testing prior to building a test laminate. The test laminate is used to verify catalyst level and laminate thickness to achieve the 150-180°F exotherm temperature. Mold building should commence only after a test laminate is successfully produced.

12.5.11. Bracing

A mold reinforcing element, bracing is a continuation of the mold skin laminate. For open molding, bracing is used to react all molding forces, including those resulting from demolding. Modest thickness increases result in large increases in bending stiffness, and therefore, robustness.

Sandwich construction using a core material, such as balsa or plywood, is the simplest form of bracing. Sandwich construction provides the added benefit of preventing damage to the mold surface from backside impacts.

Shaped stiffener elements can also be formed over foam, cardboard or wood pattern materials. The most common shapes are hat and vertical blade stiffeners.

When open molds develop cracks, the best solution is usually to add bracing in the local areas. Bracing with laminate materials and structural cores does not introduce thermal stresses as large as those possible with steel framing.

12.5.12. Framing

Framing is a mold reinforcing element outside the mold skin that falls into two different categories. For high pressure molding, framing must be used to react molding forces. These high pressure processes include conventional RTM and sometimes SMC. For low pressure molding, framing primarily serves as a cradle to distribute the mold weight onto concentrated load points such as casters. The frame also provides a means of grabbing the mold for lifting and transport operations without introducing loads at concentrated points that can lead to laminate fracture.

Most mold frames are made from mild steel tubing. The tubing may be square or round with a wall thickness of approximately 60-120 mils. Wood can also be used and usually takes the form of deep-section blade stiffeners cut from plywood. When using wood, care must be taken to avoid moisture variations that can cause the wood to swell and contract and should be avoided for all but small or temporary molds.

The differences in thermal expansion between a steel frame and an FRP mold skin are very significant. A parameter known as the linear coefficient of thermal expansion (CTE) is used to quantify a material's response to a temperature change. The coefficient is defined as the change in unit length for a unit change in temperature at a given temperature. For laminated composites, there are three distinct coefficients:

- Alpha XX - coefficient in the panel's x direction
- Alpha YY - coefficient in the panel's y direction
- Alpha ZZ - coefficient in the panel's z thickness direction

The thermal expansion coefficient for a gel coat or unreinforced resin is between 31-55 micro-inches per inch per degree Fahrenheit, while a chopped glass laminate is between 11-18 micro-inches per inch per degree Fahrenheit in the laminate plane. For comparison, this laminate CTE is similar to aluminum, which is 13 micro-inches per inch per degree Fahrenheit. Steel, on the other hand, ranges from 5.5-9.5 micro-inches per inch per degree Fahrenheit.

Example

Consider a temperature change from 70°F (21°C) to 0°F (-40°C). A 20-foot long piece of steel will contract:

(20 feet long) x (12 inches per foot) x (7.5E-6 average inches per inch per degrees Fahrenheit) x (70°F temp. change) = 0.126" (525 microstrain)

As a laminate, that same 20-foot span will contract:

(20 foot long) x (12 inches per foot) x (14.5E-6 average inches per inch per degrees Fahrenheit) x (70°F temp. change) = 0.244" (1015 microstrain)

The fiberglass panel contracts 1.94 times as much as the steel structure. Structurally tying the two materials together and forcing them to become the same length causes significant thermal stresses. Adding more steel simply compounds the problem.

When thermal stresses are developed rapidly due to a rapid change in temperature, one material can reach its new dimension much more quickly than the other. Within the same material, the same thing can happen at different spots, depending on exactly how quickly it changes temperature and where. This is a rate-dependent, worst-case type of thermal stress known as thermal shock. This is especially true when using hollow steel tubes that will heat or cool significantly faster than a ¾" thick glass fiber reinforced laminate.

To minimize thermal shock effects, the steel frame must be designed to expand and contract at a rate that is different from the mold laminate without forcing the mold skin to crack. Therefore, the cradle and mold laminate must not be structurally coupled. This is best done by leaving a gap between the steel frame and mold laminate. The gap is bridged using a low-stiffness tie (tab) made from a single piece of two osf chopped strand mat and a resin with a low inherent shrinkage. This is often a production resin such as a DCPD (which has a low inherent shrinkage) that will cure in a thin laminate. Isophthalic tooling resin can also be used, but at a higher cost and with higher shrinkage. Controlled-shrink resins like OPTIMOLD$^{®}$ II and OptiPLUS$^{®}$ should never be used as a frame tie resin because they will not cure properly at the desired tie laminate thickness. Figure 12-21 shows an example of tabbing on a mold.

The open mold frame is usually fabricated on the laminated mold once the design mold thickness has been applied and cured. Sections of tubing are cut and bent to fit while maintaining a gap between the tubing and mold skin. Thick cardboard or crushable foam (two to four pounds per cubic feet urethane or PVC) is good to use for a spacer. Either material is soft and can crush without marking the mold gel coat surface.

Figure 12-21. Example of tabbing and framing.

Once positioned, the pipe sections are welded together into a single unit and can be fitted with casters and provisions for lifting. One advantage of the OPTIMOLD® II system when welding is the flame retardancy provided by the ATH filler. For unfilled systems, careful attention while welding is important to avoid accidentally setting the mold on fire.

When laminating the ties between the frame and mold skin, exercise care to avoid saturating the offset spacers with resin, which will harden and defeat the spacers' purpose. Once the ties are cured, the spacers should be pulled out to prevent the future possibility of mark-off.

Spacing between frame elements depends on the tubing size and the thickness of the mold laminate. Small molds, less than 20 feet long, will commonly use a laminate thickness of ½" and a tubing diameter of 1.25"-2". Frame spacing is set to provide an unsupported panel length of 12-15 inches. For larger molds, 2"x4" or larger rectangular tubing is used, oriented with the longer direction perpendicular to the mold laminate. Sandwich construction with 1" balsa core will commonly separate two ⅜" thick skins. For this heavier panel section, the unsupported panel length may be as large as 20-24". These are loose rules of thumb and should not be construed as better than any frame design that is tried and tested true.

Frame spacing and laminate thickness must also consider the mechanical and physical properties of the mold materials. For instance, the OPTIMOLD® II system utilizes lower glass loadings and a high filler content that produces a heavier mold skin with lower mechanical properties than a conventional isophthalic tooling system. The frame spacing must be smaller and the mold skin must be thicker because of these features.

The frame must be rigid compared to the mold laminate. One way to evaluate frame rigidity is to jack up one caster and see if the frame deforms. Another way is to position the mold so that one caster is hanging over the edge of a loading dock. If it droops down noticeably, the frame is not rigid and probably not supporting the mold properly. If the frame is not rigid, picking up the mold can cause it to bend and twist, increasing the chance for mold cracks to occur during normal handling and demold operations.

Wherever a steel frame is in direct, hard contact with a mold laminate, a mark-off may appear on the mold gel coat surface. This mark-off may merely witness the contact and will lead to gel coat cracking due to point loading. Regardless, frame contact should be avoided for low-pressure molding applications.

For high-pressure molding applications, a steel frame must contribute to the reacting molding forces. Any gaps between the steel frame and mold skin are often filled with a high-compression strength syntactic putty after the frame is constructed. For this reason, rectangular tubing is used instead of round tubing. The frame is then structurally tied to the mold skin by laminating with a heavy material such as woven roving stitched to mat.

When steel framing is structurally coupled to a mold skin and used to react molding forces, normal thermal shocks experienced by moving molds, from outside to inside and back into cold climates, can result in extensive mold cracking. Additional steel framing does not improve the situation.

The only practical solution is to create conditions that slowly change temperature. The mold is moved into the space and the outer door is closed. The inner door is opened somewhat. The space is allowed to slowly come back to the shop temperature, with the mold also slowly increasing temperature. The absolute worst case scenario is to place a very cold mold directly under a big, forced-air or infrared heater that runs continuously. Unfortunately, these heaters are usually located near the door where cold molds are first brought inside and left until the snow and ice melts from them.

12.5.13. Thermoforming Tooling Gel Coat

Thermoforming is the shaping of a polymer sheet by the use of heat. The manufacturing process is described in the Open Molding – Lamination: Acrylic Bonding section. The four types of thermoforming molds are wood patterns, cast aluminum, machined aluminum, and composite molds.

Wood patterns are generally the first step in building a thermoforming mold. They are relatively inexpensive and allow the design changes to be made easily. Typically, wood patterns are used to determine general functionality of both the part and the thickness of the material. The wood pattern is then used to create a regular production mold once the part specifications have been met.

Cast aluminum molds are cast at a foundry. They typically have temperature control lines running through them to regulate the heat of the plastic being formed, as well as speed up the production process. Cast aluminum molds are more expensive to produce than composite molds.

Machined aluminum molds are cut out of a solid block of aluminum using a CNC machine that uses CAD software. This type of mold is typically is used for shallow draw parts made out of thin gauge material. Applications may include packaging, such as trays. Cast or machined aluminum molds are more expensive to produce than composite molds.

Aluminum molds can be male or female in nature. They can also be used in pressure forming applications.

Composite molds are typically made with high HDT resins, such as Stypol® VSXH-2210 or OptiPLUS®. These molds produce high quality parts for a long time. Composite molds are suitable for all but the highest volume production and strictest tolerances. These molds can run nearly as fast as cast and machined aluminum, even though they are not temperature controlled.

Due to the extreme temperatures involved in thermoforming (if 400-450°F), care must be taken in choosing which gel coat to use or if one is used. It must be capable of handling the thermoshock. Polynt specifically designed Polycor® 965BK228 tooling gel coat for use in thermoforming applications. Refer to the paragraphs on Tooling Gel Coat in this section for application information. Do not apply a barrier coat.

12.6. Mold Surface Distortion

Overview

- **Types of Cosmetic Flaws**
- **Causes**
- **Summary**

12.6.1. Types of Cosmetic Flaws

There are three types of cosmetic flaws that can develop on a gel coat surface. The extent of these flaws can vary from minimal distortion to major fiber print.

A. **Distortion**—Distortion is the waviness seen in light reflected off the mold surface.

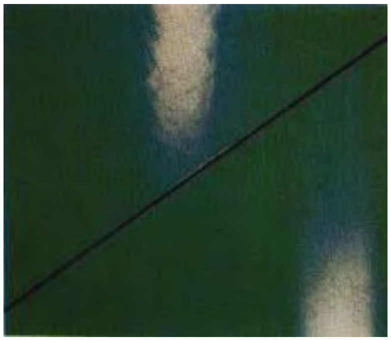


Figure 12-9. The top half of this panel shows distortion.

B. **Print-through**—Print-through is a pattern that mimics the construction architecture of a fibrous reinforcement. Print-through can appear as a fiber bundle known as fiber print or it can appear as the weave construction known as weave print.

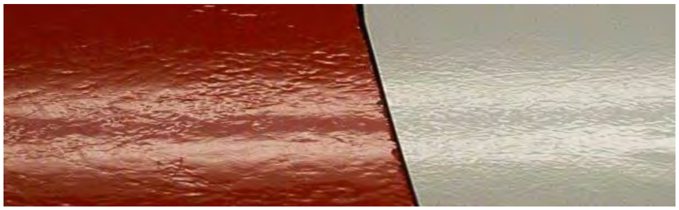


Figure 12-10. This panel shows print-though and distortion.

C. **Mark-off**—Mark-off is a visible witness caused by differences in stiffness and hardness at the boundary from one material to another. This boundary is usually present in the mold or pattern and transfers to the molded article. A common example is a plug constructed using a fiberglass laminate and body filler. The body filler can be softer and can have a lower glass transition temperature than the fiberglass laminate. They also differ in thermal expansion and heat capacity characteristics. Both the heat from exotherm and the forces due to resin shrinkage apply stresses. These stresses are supported and reacted differently by the different regions. At the boundary between them, a mark-off can result.

Mark-off can also occur when a mold frame element is in contact with the back side of the mold.

12.6.2. Causes

The gel coat surface often displays these cosmetic flaws. The root causes, however, are not due to any properties or characteristics of the gel coat layer. By itself, a gel coat film properly cured on a flat, polished master will exhibit high gloss and visual smoothness. The gel coat matches the smoothness and gloss of the mold surface. There is some loss of gloss and smoothness in the molded part.

Even when resin is cast behind the gel coat film, the resulting surface will be very glossy, smooth, and free from these cosmetic defects. Cosmetic flaws are caused by how resin shrinkage is affected by different materials. These flaws will magnify when the gel coat is either thin or under cured.

When a laminate is cured against the gel coat layer, cosmetic flaws will appear. Their severity is directly related to the amount of resin shrinkage experienced during its cure. A resin that shrinks a lot will produce cosmetic flaws to a greater extent than a resin that shrinks less. These flaws are also influenced by the nature of the reinforcing fiber and the architecture of the fiber form in the underlying laminate.

Lack of shrinkage of a fiber does not lead to cosmetic flaws. Instead, the flaws result when the fiber resists the resin's shrinkage. Different fibers resist resin shrinkage to different degrees according to the fiber's transverse stiffness. Transverse to the fiber axis, glass fiber has a stiffness of about 10 msi (million pounds per square inch). Resin has a stiffness of about ½ msi, which is a factor of 20 less than glass. As the resin shrinks and tries to squeeze the glass fiber, the glass offers 20 times more resistance to being squeezed than the resin can deliver. This results in the image of the fiber being visible on the gel coat surface because the resin-rich areas shrink away from the gel coat surface, while the fiber-rich areas resist shrinkage away from the gel coat surface.

Carbon, graphite, and polymer fibers achieve a high stiffness in the axial direction due to molecular orientation imparted during the fiber manufacturing process. As a result, their transverse stiffness is low and can be ½-2 msi. The lower the fiber transverse stiffness, the less impact the fiber has on cosmetic flaws because it cannot prevent the resin from shrinking. Consequently, polymer fiber print blockers provide better cosmetics than glass fiber veils.

In a textile construction, such as woven roving, the bundle weave (overlaps and underlaps) results in resin pockets that alternate with fiber bundles. The unrestrained shrinkage in the resin pockets contrasts markedly with the restrained shrinkage in the fiber bundle, causing the weave print to appear on the surface. Thus, the architecture of the fiber form has a distinct impact on cosmetics.

Resin shrinkage, fiber transverse stiffness and the architecture of the fiber form are the root causes of cosmetic flaws. For a given fiber and form, such as chopped glass, cosmetic flaws vary in their severity according to resin shrinkage. Most resin shrinkage occurs during the molding process, known as the curing operation. Any additional curing that occurs after demolding is called postcure. Postcure results in additional shrinkage. This postcure shrinkage causes cosmetic flaws to develop.

Normal room temperature does not provide enough energy to completely cure an unsaturated polyester resin. At some point in the cure, the cross-link density becomes high enough that the curing reaction stalls. Further curing requires temperatures that are closer to the resin’s glass transition temperature. This further curing pushes the resin’s glass transition temperature closer to its maximum, resulting in a complete cure. Once the cure is complete, no additional cure shrinkage will occur, and the cosmetic quality will stabilize. Usually, the final stages of curing occur when the mold experiences exotherm heat during production of the first few parts.

Instead of allowing the postcure to occur when the mold is exposed to the exotherm heat generated by parts during production, a new mold can be subjected to a special postcure operation. The postcure temperature should be chosen to be 20°F (7°C) above the expected production exotherm temperatures or the expected maximum glass transition temperature for the gel coat and resin used to manufacture the mold, whichever is less. Four hours at temperature is generally sufficient to complete the cure and achieve the maximum glass transition temperature. Isophthalic tooling gel coats have a maximum glass transition temperature of 221°F (105°C), while vinyl ester gel coats have a maximum of 248°F (120°C).

Any elevated temperature postcure should always be accomplished with the mold in the free standing condition, supported to prevent warping due to its own weight. If a mold is postcured at elevated temperatures while it is still on the master, differences in thermal expansion due to geometry will cause mark-off to appear in various places on the gel coat surface, on both the master and the mold. For best cure results, any elevated temperature postcure operation should be scheduled within three days of the initial cure.

Wet sanding and buffing will remove cosmetic flaws that develop on a mold surface due to cure and postcure. This should sensibly be performed only after the mold has reached its final cure state. Once the cure is complete, no cure-related shrinkage will occur regardless of the temperature a mold experiences.

If the mold temperature is near or above its glass transition temperature, however, the mold materials will soften and can acquire a mark-off due to stresses caused by the shrinkage in a production part. If a part contains woven roving, the weave print on a part can transfer to the mold surface when the molding temperatures are near or above the mold’s glass transition temperature. If the part is made with a controlled-shrink resin, the part does not put shrinkage stresses on the mold surface, and minor excursions above the mold glass transition temperature do not cause print to transfer from the part to the mold surface.

12.6.3. Summary

In summary:

- Molds will develop cosmetic flaws due to resin shrinkage during cure and postcure.
- The cosmetic flaws can be sanded out, but may return if the mold is not yet fully cured.
- Parts made with conventional unsaturated polyester resin can print or distort a fully cured mold if the exotherm temperatures approach or exceed the mold glass transition temperature.
- Low profile resins will produce less severe cosmetic flaws because these systems shrink negligibly compared to conventional unsaturated polyester resin.
- Distortion (sometimes called orange peel) only appears on a gel coat surface when there is a laminate behind the gel coat. It is caused when a fiber’s transverse stiffness is great enough to resist the resin shrinkage. Distortion is not caused by the

gel coat’s backside roughness because a smooth draw-down of tooling gel coat develops the same degree of distortion as a sprayed film that features back side orange peel.

- If a tooling gel coat has a maximum glass transition temperature of 221°F (105°C), postcuring the mold above this temperature will not improve its distortion resistance.

  A ‘harder’ tooling gel coat does not resist distortion any better. It may polish to a higher gloss, but will exhibit a greater tendency to crack.

12.7. Mold Break-In Procedures

Overview

- **Introduction**
- **Conventional Mold Release Waxes**
- **Semi-Permanent Mold Release Systems**
- **Poly Vinyl Alcohol (PVA)**
- **Mold Seasoning Procedures**

12.7.1. Introduction

A proper conditioning or break-in procedure maximizes the mold's value by preventing part sticking, promoting gloss retention, and lessening fiber print-through. Once the break-in procedure is complete, the mold is considered seasoned and can be treated with normal mold maintenance procedures.

Any mold can, at any point in its life, become permanently bonded to a production part. Inadequate reapplication of the mold release system is the most common reason for part sticking. Porosity in the mold gel coat surface is the second most common reason for sticking. The porosity allows the part to mechanically attach to the mold. This usually occurs after a mold has been sanded and buffed because these operations can expose subsurface porosity.

Gel coat surface porosity and micro-porosity are the reasons that a new mold has a higher likelihood of sticking than a seasoned mold. Porosity that is visible essentially guarantees part sticking. Micro-porosity, which takes at least 60x magnification to see, can be addressed by the proper usage of a mold sealer. Most molds have some degree of micro-porosity. During the break-in procedure, mold release gradually fills mold surface porosity, bonding permanently in place. This is a gradual process that takes several production cycles. Once complete, the mold is considered seasoned.

A new mold, or a mold that has been sanded and buffed, should be inspected for porosity and micro-porosity before determining the appropriate break-in procedure. It may be necessary to repair the porosity before proceeding. Whenever porosity is visible, the use of a Poly Vinyl Alcohol (PVA) film-forming barrier should be used on the first few parts. If porosity is found on a new mold, the mold fabrication history data should be reviewed. In particular, the gel coat spray-out panel described in the Building a Mold section of Chapter 12 should be re-examined. The cause of the porosity should be determined and procedures to avoid porosity should be implemented in future mold-making activities.

There are a number of approaches to breaking in a mold. The first, 'wax it and go,' is not recommended for best results. Even though it works much of the time, the costs of failure are too great. In most instances, sealing and waxing the mold is adequate. Best results are realized by also applying a gel coat layer as a 'blow coat' (also known as 'strip coat' or 'peel coat'). To maximize chances for successful break-in, particularly on a porous mold surface, a film-forming barrier should be used on the first few parts, but this imparts some texture on the molded part surface.

The three categories of release systems are:

- Conventional mold release waxes
- Semi-permanent mold release systems
- Poly Vinyl Alcohol (PVA)

12.7.2. Conventional Mold Release Waxes

Long used in the industry, mold waxes contain carnauba as the release agent. The carnauba must bond to the mold surface and be driven down into the mold pores. Carnauba is the hardest and most expensive of waxes in the wax family. In pure form, it is very hard. The melting point of carnauba is 183-187°F (84-86°C), whereas the melting point of paraffin (sometimes used as a release wax) is 117-150°F (47-66°C).

Typically, mold release waxes contain a mix of carnauba, paraffin, and silicone (very few release waxes are silicone-free). The carnauba serves as the release agent, the paraffin softens the carnauba, and the silicone serves as a lubricant so the carnauba/ paraffin can be easily wiped on and off. The chemical makeup and proportioning of the carnauba, paraffin, silicone, and solvent content is proprietary and varies not only by manufacturer, but within each manufacturer's line of products.

A sealer glaze should always be used to close mold pores and seal new or reconditioned molds before applying conventional paste wax.

12.7.3. Semi-Permanent Mold Release Systems

Usually wiped onto the mold surface, these leave a cured resinous film bonded to the mold surface. This film serves as the barrier for release. A semi-permanent mold release should not be poured onto the mold surface and subsequently wiped with a rag. This results in an overly thick polymer film that leaves a visible mark-off at the puddle edge. It may be necessary to polish the mold surface to remove this type of mark-off.

Semi-permanent mold release systems should always be used with a compatible surface sealer. On porous mold surfaces, a compatible surface primer should also be used. Surface primers generally produce a much thicker film that is chemically bonded to the mold surface. Primers should always be applied sparingly. Primers generally have no release properties and must always be followed with a sealer first and then the release layers. Semi-permanent release system manufacturers claim many more releases can be completed between update events.

A secondary advantage is the ability to tailor the release system to the type of release motion. Release motion describes the physical motion of the two surfaces involved in the release event. For perpendicular release, the surfaces move apart in a purely perpendicular fashion. For parallel release, the surfaces move apart with some component of dragging between the two. This release motion occurs on parts that have a deep draft and benefits from more ‘slippage’ in the release system than does a purely perpendicular release.

High slip release systems are microscopically thicker, which allows for some amount of release film erosion. The high slip film’s greater thickness provides a corresponding decrease in finished part gloss. In contrast, a semi-permanent release film that produces a high gloss is thinner and microscopically smoother and wears more quickly on deep-drafted parts.

Semi-permanent mold release systems seem to cause more fish eyes and pre-releases than waxes, particularly on the first pull, and are not recommended when building molds and masters. As always, read and follow the semi-permanent release manufacturer’s surface preparation and usage instructions.

12.7.4. Poly Vinyl Alcohol (PVA)

Poly Vinyl Alcohol (PVA) is a film-forming barrier. Refer to the Tooling: Applying Release Wax section. When applied correctly, PVA forms a physical barrier between the mold and the part. A barrier film is only good for one release event and will have to be applied for each part. It should be sprayed on rather than brushed or wiped. The PVA film will have an orange peel texture. This texture will transfer to the part, so some part rework may be required to meet cosmetic requirements.

12.7.5. Mold Seasoning Procedures

The following seasoning procedures should be followed on new molds and whenever a mold surface has been sanded and buffed.

A. Conventional Systems

1. Wash the mold surface with a mild detergent solution, such as dish soap and water. Allow the surface to dry thoroughly.
2. Inspect the mold surface for porosity and micro-porosity.
3. Apply a mold primer/sealer. Two coats of a sealer-glaze should be machine buffed in opposite directions.
4. Apply the mold release system. Allow each coat to cure. Six coats of paste wax are generally sufficient.
5. Spray a blow coat with a hot pot.
    - This is preferred over slave pumps or catalyst injection, where uneven catalyzation is possible.
    - It is best to spray tooling gel coat catalyzed at the high end of the recommended catalyst range and the wet-film thickness range.
    - For large molds, divide the area into work zones and work on one section at a time.
6. Strip the blow coat from the mold when it reaches the ‘firm gel’ stage. If there is no sticking, proceed with step 7.
    - In case of sticking, the mold must be repaired and completely prepared again.
    - Do not let the blow coat cure without peeling it from the mold.
7. Update the mold release system after the blow coat has been stripped. Two coats of paste wax are generally sufficient.
8. Spray production gel coat with a hot pot.
    - This is preferred over slave pumps or catalyst injection, where uneven catalyzation is possible.
9. Laminate the first production part.
10. If the first part pulls adequately, update the mold release system. If the part does not pull adequately, the mold must be repaired and completely prepared again. Two coats of paste wax are generally sufficient.

11. Build three more production parts. After each part, update the mold release system. One coat of paste wax is generally sufficient after each part.
12. Build two production parts without updating the mold release system. After the second part is pulled, update the mold release system. One coat of paste wax is generally sufficient.
13. Evaluate the release performance for the second pull in step 12. If the part pulls adequately on the second pull, gradually increase the number of parts built between update events.
    - The number of parts between updating can vary from 1-10 or more. The exact number depends on a variety of factors such as part geometry, solvent content in the gel coat layer, the gel time of the gel coat, exotherm heat generated in the laminate, the degree of cure of the gel coat and laminate, etc.
14. Once the release system update interval is known, begin the normal mold maintenance procedure. Monitor the mold for ease of pulling and dullness or haze.
    - A non-abrasive build-up remover and a machine buffer will remove the haze without breaking the surface seal. Two additional coats of paste wax are generally sufficient to return the mold to serviceable condition.

B. Semi-Permanent Systems

1. Wash the mold surface with a mild detergent solution, such as dish soap and water. Allow the surface to dry thoroughly.
2. Inspect the mold surface for porosity and micro-porosity.
3. Apply a mold primer/sealer. Follow the specific recommendations from the release system manufacturer.
4. Apply the mold release system. Allow each coat to cure. Follow the specific recommendations from the release system manufacturer.
5. Spray a blow coat with a hot pot.
    - This is preferred over slave pumps or catalyst injection, where uneven catalyzation is possible.
    - It is best to spray tooling gel coat catalyzed at the high end of the recommended catalyst range and the wet-film thickness range.
    - For large molds, divide the area into work zones and work on one section at a time.
6. Strip the blow coat from the mold when it reaches the 'firm gel' stage. If there is no sticking, proceed with step 7.
    - In case of sticking, the mold must be repaired and completely prepared again.
    - Do not let the blow coat cure without peeling it from the mold.
7. Update the mold release system after the blow coat has been stripped. Follow the specific recommendations from the release system manufacturer.
8. Spray production gel coat with a hot pot.
    - This is preferred over slave pumps or catalyst injection, where uneven catalyzation is possible.
9. Laminate the first production part.
10. If the first part pulls adequately, update the mold release system. Follow the specific recommendations from the release system manufacturer. If the part does not pull adequately, the mold must be repaired and completely prepared again.
11. Build three more production parts. After each part, update the mold release system. Follow the specific recommendations from the release system manufacturer.
12. Build two production parts without updating the mold release system. After the second part is pulled, update the mold release system. Follow the specific recommendations from the release system manufacturer.
13. Evaluate the release performance for the second pull in step 12. If the part pulls adequately on the second pull, gradually increase the number of parts built between update events.
    - The number of parts between updating can vary from 1-10 or more. The exact number depends on a variety of factors such as part geometry, solvent content in the gel coat layer, the gel time of the gel coat, exotherm heat generated in the laminate, the degree of cure of the gel coat and laminate, etc.

14. Once the release system update interval is known, begin the normal mold maintenance procedure. Monitor the mold for ease of pulling and dullness or haze.
    - It is important to update the mold release system before a part sticks, but maximum mold life is obtained by updating the release system at the first sign of dullness or haze.

12.8. Mold Maintenance

Overview

- **Protocol**
- **Procedure**

12.8.1. Protocol

Properly constructed molds will produce many thousands of parts. Maximum value, however, will only be achieved if a good mold maintenance protocol is followed. Lack of discipline when executing a mold maintenance protocol always results in excessive costs for reworking, repairing, or refinishing the mold.

A preventive maintenance program is essential to ensure long mold life. The preventive approach is proactive and prevents damage from occurring to a mold surface. Updating a mold release system after a part sticks is not considered a preventive, proactive approach and always leads to lower quality and higher costs.

12.8.2. Procedure

The mold maintenance area should be completely enclosed and away from the production area. In order to control dust and overspray, there should be isolated stalls for grinding and gel coating.

Residue that forms on a mold surface is not what was once referred to as wax buildup. True wax build-up is more correctly described as wax leave-on because this build-up occurs when excess wax is not buffed off. Residue build-up is due to styrene (polystyrene) which has come from the production gel coat and adheres to the mold usually for one of these reasons:

- Paste wax leave-on or over application of the semi-permanent release agent.
- Inadequate cure of the release system.
- Pulling parts too soon. The greener a part is when pulled, the more susceptible it is for styrene (polystyrene) to remain on the mold.
- Micro-porosity in a mold surface that has not been adequately sealed.

If the mold is used beyond the proper mold release update interval, the residue will accumulate more rapidly. Eventually, the build-up will require sanding to remove.

Colors appear to haze a mold more (or sooner) than a white or off-white gel coat. This phenomenon has been observed with all gel coats and is not limited to generic types or those from various manufacturers. Colors differ in formulation because of solids and pigmentation. Any dark-colored pigments will tend to be more visible than light-colored pigments when trapped in the polystyrene build-up. The hazing is usually noticed because colors are used as a striping accent (side by side) next to the white or off-white base coat. Hazing in and of itself is not damaging to the mold, although its removal can reduce mold life. Premature hazing can occur when an undercured gel coat film is followed by hot laminate that is too green when pulled.

When using conventional paste wax, light residue and haze can be removed by:

1. Machine polish the mold with a build-up remover such as TR-502 Wax Build-Up Remover.
    - This will not break the surface seal in the release system.
2. Perform this cleaning every three to five pulls for deep draft parts and every six to nine pulls for shallow draft parts to eliminate most problems with haze.
3. Apply two coats of fresh paste wax to return the mold to its serviceable condition.

When using a semi-permanent release system, follow the specific cleaning recommendations from the manufacturer.

If the mold is very hazy and has some textured build-up:

1. Use a coarser compound.
2. Wash with a mild detergent solution.
    - Some compounds, if not removed by a detergent wash, will cause sticking by preventing the mold release system from bonding to the mold surface.
3. Rinse with cold water.
4. Complete the mold seasoning procedure described in the Tooling: Mold Break-In Procedures section.
    - Compounding will break the surface seal in the release system.

If the mold has considerable residue build-up, it will have to be removed by scrubbing with a commercial stripper. When using conventional paste wax, toluene, methyl ethyl ketone, or ethyl acetate can be used as a stripper. When using a semi-permanent release system, follow the specific stripping recommendations from the manufacturer. These stripper materials can be flammable and have potential health hazards. Refer to the appropriate SDS sheets for all safety precautions. In general, always wear gloves and safety glasses, and ensure the area is well-ventilated. Do not use styrene for cleaning molds because it initiates and promotes the process of polystyrene build-up on the mold surface.

For molds that have been extensively neglected, removing the polystyrene residue will require dry and wet sanding, followed by compounding and buffing. This erodes a significant portion of the tooling gel coat layer, thus greatly reducing the life of the mold. Performing the entire mold seasoning procedure will return the mold to its serviceable condition, albeit minus some of the gel coat layer.

12.9. Mold Repair

Overview

- **Introduction**
- **Gel Coat Cracks**
- **Laminate Cracks**
- **OPTIMOLD® II Cracks**
- **OptiPLUS® Cracks**
- **Steps to Resurface a Mold**

12.9.1. Introduction

Mold repair is a process that occurs on a regular basis. Generally, flange areas and tight draws may be areas where cracks or mold wear may occur. Additionally, regular usage may result in various defects, such as cracks, print through/distortion, and scratches.

Mold resurfacing is a relatively rare practice. It is often preferable from an efficiency and quality standpoint to produce a new mold from an existing plug rather than resurfacing an existing mold.

However, with the exception of a two coat resurfacing, mold repair and mold resurfacing require the same techniques. The first step in performing a repair is to properly diagnose the extent of the repair required and prepare the part appropriately.

12.9.2. Gel Coat Cracks

To repair a crack in the gel coat:

1. Remove only as much material as is necessary to remove the crack.
2. Fill the crack with putty made from tooling gel coat and fumed silica. The crack should be overfilled.
3. Allow this to cure.
4. Post-cure with a heat lamp or hot air gun.
    - It is recommended to pre-heat the patched area rather than heating the patch itself.
    - Do not heat a repair over 120°F. This will cause distortion.
    - The heated area is too hot if you can't hold your hand on the area.

    NOTE: Overheating may cause blistering and poor color matching.

If this is done before the surface is sanded smooth, the cure shrinkage won't cause the repair to sink below the surrounding surface.

12.9.3. Laminate Cracks

To repair a crack in the laminate:

1. Grind away each layer that contains a crack several inches from either side of the crack, with the edges tapered back to the undisturbed laminate thickness.
2. Apply additional laminate bracing on the mold back side in the damaged area.
    - This is imperative because the mold was not strong enough and stiff enough to resist the cracks initially.
3. Replace the front side laminate once the laminate is properly braced on the back side.
4. Allow the laminate to cure at least 24 hours. Scuff sand the laminate repair with 80-grit or coarser sandpaper to enhance mechanical adhesion of the gel coat repair.
5. Follow the steps outlined at the end of this section in Steps to Resurface a Mold.

12.9.4. OPTIMOLD® II Cracks

To repair a crack in the OPTIMOLD® II laminate:

1. Grind the repair area to remove all damaged material using coarse sandpaper, such as 80-grit or rougher.
    - Finer sandpaper, for example, 120-grit and finer, does not provide the mechanical keyway needed for good bonding.
2. Feather the area at the edges to taper the repair area thickness.
3. Apply a two component urethane adhesion promoter to the substrate for improved secondary bond performance.
4. Fill the area with the materials listed below:
    - If the repair thickness is 0.15" or less, use ArmorStar® VSXH-2210 (vinyl ester blend) with enough layers to fill in the repair area. Assume 0.045" thickness per layer of 1.5 oz. (450 grams) chopped strand mat (CSM). Allow enough depth after repair for 2-3 layers of 0.02" of tooling gel coat to fill in and finish the mold repair. Remember to over fill the area to allow for sanding and polishing the repaired area.

- If the repair thickness is 0.15"-0.30", use one 0.15" thick layer of OPTIMOLD® II. Use one layer of ArmorStar® VSXH-2210 or STYPOL® 040-2989 at a time to make up the difference.
- If the repair thickness is greater than 0.30", apply OPTIMOLD® II in several layers. Each layer should be 0.15-0.2". Allow enough depth after repair for 2-3 layers of 0.02" of tooling gel coat to fill in and finish the mold repair. Remember to over fill the area to allow for sanding and polishing the repaired area.

5. Add at least one 0.15-0.20" lamination of OPTIMOLD® II to the laminate backside. Add as much thickness as needed to stiffen the area to eliminate cracking. A rule of thumb is: Add half as much as the original laminate.
   a. Sand up the surface with 80-grit sandpaper or coarser.
   b. Apply a two component urethane adhesion promoter to the substrate for improved secondary bond performance.
   c. Apply the OPTIMOLD® II in layers. The first OPTIMOLD™ II layer should be the largest. Each additional layer should be one inch smaller all the way around. The smallest layer should extend at least 6 inches beyond the front side repair area. Do not taper the OPTIMOLD® II thickness at the edge of the added laminate.
6. Once OPTIMOLD® II and/or ArmorStar® VSXH-2210 lamination is completed, post cure the laminates with a heat gun or lamps while maintaining a temperature of 150°F maximum for 2-4 hours to force post cure prior to applying the tooling gel coat to finish the repair.
7. Apply POLYCOR® tooling gel coat over the area. Use POLYCOR® Patching Thinners (945CJ007 or 965CJ036) for the first sprays and Patchaid® for the last spray only. Post-cure with heat lamps or hot air guns, to complete the cure before doing the final sanding. Temperatures of 150°F for 4 hours are sufficient.

12.9.5. OptiPLUS® Cracks

To repair a crack in the OptiPLUS® laminate:

1. Grind the repair area to remove all damaged material using coarse sandpaper, such as 80-grit or rougher.
   - Finer sandpaper, for example, 120-grit and finer, does not provide the mechanical keyway needed for good bonding.
2. Feather the area at the edges to taper the repair area thickness.
3. Apply a two component urethane adhesion promoter to the substrate for improved secondary bond performance.
4. Fill the area with the materials listed below:
   - If the repair thickness is 0.15" or less, use ArmorStar® VSXH-2210 (vinyl ester blend) with enough layers to fill in the repair area. Assume 0.045" thickness per layer of 1.5 oz. (450 grams) chopped strand mat (CSM). Allow enough depth after repair for 2-3 layers of 0.02" of tooling gel coat to fill in and finish the mold repair. Remember to over fill the area to allow for sanding and polishing the repaired area.
   - If the repair thickness is 0.15"-0.30", use one 0.15" thick layer of OptiPLUS®. Use one layer of ArmorStar® VSXH-2210 or STYPOL® 040-2989 at a time to make up the difference.
   - If the repair thickness is greater than 0.30" apply OptiPLUS® in several layers. Each layer should be 0.15-0.2". Allow enough depth after repair for 2-3 layers of 0.02" of tooling gel coat to fill in and finish the mold repair. Remember to over fill the area to allow for sanding and polishing the repaired area.
5. Add at least one 0.15-0.20" lamination of OptiPLUS® to the laminate backside. Add as much thickness as needed to stiffen the area to eliminate cracking. A rule of thumb is: Add half as much as the original laminate.
   a. Sand up the surface with 80-grit sandpaper or coarser.
   b. Apply a two component urethane adhesion promoter to the substrate for improved secondary bond performance.
   c. Apply the OptiPLUS® in layers. The first OptiPLUS® layer should be the largest. Each additional layer should be one inch smaller all the way around. The smallest layer should extend at least 6 inches beyond the front side repair area. Do not taper the OptiPLUS® thickness at the edge of the added laminate.
6. Once OptiPLUS® and/or ArmorStar® VSXH-2210 lamination is completed, post cure the laminates with

a heat gun or lamps while maintaining a temperature of 150°F maximum for 2-4 hours to force post cure prior to applying the tooling gel coat to finish the repair.

7. Apply POLYCOR® tooling gel coat over the area. Use POLYCOR® Patching Thinners (945CJ007 or 965CJ036) for the first sprays and Patchaid® for the last spray only. Post-cure with heat lamps or hot air guns, to complete the cure before doing the final sanding. Temperatures of 150°F for 4 hours are sufficient.

12.9.6. Steps to Resurface a Mold

Mold resurfacing is an expensive proposition. Gel coat sprayed onto the existing mold surface will have an orange peel texture. This texture must be sanded smooth in much the same way that a master pattern is sanded and polished. When the resurfaced area is large, the labor required to finish the mold can cost more than building a new mold from the polished master.

The following procedure describes the steps to resurface a mold. Prior to resurfacing, repair all cracks in the tooling gel coat or laminate to prevent them from reoccurring on the resurfaced mold. Depending the on cause of the crack, additional bracing may also be needed to prevent reoccurrence.

1. Sand the surface with a very coarse grit to help remove any release agent and also to provide a point for mechanical adhesion. Use sandpaper between 60 and 100-grit.
2. Blow off the mold with compressed air.
3. Wash the mold with acetone (or equivalent) until there are no smear streaks left on the mold.
    - Use several clean cloths so that wax and dust are removed.
    - Review the precautions for solvents.
4. Set up the gel coat spray equipment to produce as fine a spray as possible.
    - Typically, lower flow rates and higher atomizing pressure will produce less orange peel on the new gel coat surface.
5. When spraying with air atomized (pressure pot) or airless air-assist equipment, use any Polycor® 945 or 965 Series Tooling gel coat.
    - For multi-coating, the first coat must not contain wax or surfacing agent solutions.
        - Use patching thinner to reduce the gel coat viscosity and improve leveling. Use Polycor® 945CJ007 for Polynt's 945 series polyester based tooling gel coats. Use Polycor® 965CJ036 for Polynt's 945 and 965 series vinyl ester based tooling gel coats. A suggested starting point for gel coat to thinner ratio is 50:50. However, this ratio can be altered to suit individual needs.

          Note: Dilution with patching thinner will reduce the hiding power of the tooling gel coats.
        - Catalyze at 1.5-2.4% depending on temperature.
        - Spray the gel coat in three passes to a wet film thickness of 18 ± 2 mils.
        - Allow this coat to cure. Typical lay-up time is approximately 90 minutes at 77°F (25°C).
        - Follow with the top coat.
    - For the top coat:
        - Combine the tooling gel with PATCHAID® containing wax or surfacing agent. Recommended PATCHAIDS® are 970XJ037, 970X900, 970XJ166 and 970XA014. A suggested starting ratio for gel coat to PATCHAID® is 70:30.
        - Catalyze at 1.5-2.5% percent depending upon temperature.
        - Spray in three passes to a wet film thickness of 18 ± 2 mils.
        - Allow this to cure at least overnight.
        - Postcure with a hot air gun or heat lamp to ensure that all shrinkage is complete prior to finishing. Temperatures of 150°F for 4 hours are sufficient.
6. Eliminate orange peel using should sandpaper no coarser than 320-grit. Finish by wet sanding up through 1000 to 1500-grit sandpaper.
7. Compound and polish using a machine buffer.
8. Wash the mold patch with a mild detergent solution such as dish soap and water.

This mold should now be seasoned as if it were a new mold.

12.10. Mold Storage

Overview

- **Preferred Storage Environment**
- **Condition of the Mold**
- **Outdoor Storage**
- **Returning a Mold to Production Use**

12.10.1. Preferred Storage Environment

Most molds will eventually be stored for use at a later time. As with a classic car, the best storage conditions result in the least wear and tear during the storage period. The ideal storage conditions for FRP molds are indoors, heated during periods of extreme cold, and covered with a sheet, such as painter's plastic, to avoid dirt and grime accumulation.

For a mold, temperature and humidity climate control is an unnecessary expense, but shelter from the outdoor elements is essential to maintaining quality during storage. Uncovered, outdoor storage may be the least expensive from a capital standpoint, but always results in greater rework and mold maintenance costs.

12.10.2. Condition of the Mold

Any dirt and dust that accumulates on the gel coat surface can cause surface scratches and abrasion that lead to loss of gloss if removed while dry. Best results, when removing dirt and grime, are obtained using a mild detergent solution such as dish soap and water. The solution lifts the abrasive dirt particles off the surface, preventing scratching and loss of gloss.

Rainwater should never be allowed to stand in a concave mold feature. Standing water provides a breeding ground for mosquitoes, but worse, leads to blistering of the tooling gel coat layer. Gel coat blistering requires complete replacement of the gel coat layer in the affected areas and can be more costly than building a new mold from a polished master. In addition, if the water freezes, its expansion can cause the mold to fracture.

Direct sunlight will cause the gel coat surface to lose gloss, develop chalk, and craze. Tooling gel coats are formulated for long-term gloss retention and release performance, not resistance to ultraviolet radiation. Tooling gel coats based on vinyl ester chemistry are particularly prone to chalking.

Applying a gel coat layer and skin coat can provide some protection from the elements. If the laminate releases, however, liquid water can accumulate between the gel/skin and the mold surface, leading to blistering.

12.10.3. Outdoor Storage

If outdoor storage is unavoidable, best results are obtained by orienting the molds upside down on wooden pallets, covered with a light colored tarp above and open to the air below. Dirt and grime will accumulate on the mold surface and require removal with a mild detergent solution, but blistering and ultraviolet degradation will be largely eliminated.

If the backside of the mold will be exposed to sunlight during storage, a layer of white production gel coat will reflect the sun's energy, lowering the temperatures it reaches in summertime. This layer should be applied to the mold's back-side just prior to installing its frame. After the frame ties are glassed, PVA can be sprayed over the entire construction to ensure good surface cure.

12.10.4. Returning a Mold to Production Use

Once it has been determined that a mold in storage is needed in production, care must be taken in preparing the mold for use. If the mold will see a transition in temperature of more than 20°F, it is critical that the temperature change occur gradually, ideally no more than 10°F every 3 hours. The greater rigidity of the tooling gel coat, as well as the dissimilarity between laminate materials and bracing, may lead to thermal cracks if this practice is not followed.

Hollow metal tubing, a common framing material, will heat and cool much faster than a ½-¾" thick glass fiber laminated mold. This is especially true if a mold is heavily tabbed between the skin and any metal supportive structure. This is not suggested, but is seen often. The thermal expansion differences between materials will be seen dramatically as the mold's gel coat cracks, or under severe conditions well into the mold laminate itself, if care is not taken to control thermal shock exposure. This is true for either going from a warm, heated production floor to cold, outdoor storage or from cold storage to a heated production facility. The thermal expansion of framing materials is discussed under Framing in the Tooling: Building a Mold section of this chapter.

Tabbing between frames and mold surfaces should be minimal. Any damage resulting from molds being bumped in production or damaged from freeze or thaw will occur in the tabbing area only. Heavily tabbed molds will transfer stresses from the framing to the mold skins and should be avoided.

Figure 12-X. Example of tabs on a mold.

If a tab is broken, production resins and several inch wide mats (1-3 oz. CSM, woven roving or lightweight engineered fabrics) can be used to repair the broken tabs in a production environment. If heavy tabbing (in coverage area or in total thickness) is used and a mold is impacted or thermally shocked to the point that the loads are transferred into the mold and to the mold surfaces, then the mold repair department will need to get involved. This generally will take the mold out of service for days to weeks, subject to mold repair activity and scheduling. For these reasons, tabs should be light and only enough to provide support to the mold skin to avoid deflection of the mold while being moved, walked on, or handled in a production environment. For mold repair information, refer to the section on Tooling: Mold Repair section of this chapter.

12.11. Special Precautions

Overview

- **Introduction**
- **Precautions**

12.11.1. Introduction

There is an economic advantage to producing a quality long lasting mold that requires little or no subsequent finishing. This requires strict quality control methods in the application of both tooling gel coat and the mold laminate.

The approach to designing and building molds requires a different mind-set than the approach to building production parts. During production, certain short cuts can provide recurring savings. However, during mold fabrication, short cuts can provide recurring costs because mold flaws translate directly into part flaws on each production part. Extra care and effort during mold fabrication reduces part re-work costs, providing a recurring savings. Many gel coat and laminating defects result from conditions that can easily be corrected.

12.11.2. Precautions

Please note the following:

A. **Do not use more than 2.4% catalyst in the tooling gel coat.** Excess catalyst can cause excessive shrinkage of the gel coat. This leads to pre-release from the master surface. For adequate cure, do not use less than 1.2% catalyst.

   Disperse catalyst thoroughly in the gel coat. Poor distribution causes uneven cure, color variation and premature release before layup.

   While mixing by hand, the material should be poured from one container into another to facilitate top-to-bottom dispersion.

   Best results are obtained with a small mixer attached to a variable speed pneumatic motor.

   Best cure is obtained when the ambient, material and mold temperatures are between 70-90°F (21-32°C).

   Refer to the Tooling: Building a Mold section.

B. **Tooling gel coat should not be left to cure overnight** before at least a skin coat lamination is applied. Excessive film cure results in a loss of tack and reduced bond quality between the gel coat and laminate. In addition, the likelihood for pre-release is greater.

   Refer to the Tooling: Building a Mold section.

C. **Install oil and water traps** on the air line leading to the spray gun. These traps will remove lint, rust, oil, other contaminants, and liquid water.

   A water trap will not catch moisture in the form of water vapor. Therefore, the compressed air should be cool when it enters the water trap or else water vapor will pass right through the trap. To check for water:

   1. Use a 50-foot hose and a tool that consumes a lot of compressed air.
      - A spray gun will not show this fault because the spray gun is designed to atomize high molecular weight gel coat and will vaporize any water that has condensed in the compressed air line.
   2. Run air through the spray gun for the amount of time one would expect to be spraying the tooling gel coat.
   3. If liquid water sputters out the spray gun exhaust, the water trap is passing vapor that is condensing in the hose or spray gun.

   Water in the gel coat film will cause problems and should be removed with a compressed air cooler. Compressed air coolers are commercially available. A simple, homemade cooler can be fashioned from a 50-foot coil of ½" copper tubing that is spiraled to fit inside a plastic tub or drum filled with tap water. Gallon jugs of ice can provide additional cooling when placed in the water within the tubing spiral.

D. **Proper spray technique** is very important to prevent pinholes and porosity in the gel coat film.

   - Use slow, even strokes, keeping the gun at right angles to the surface.
   - Trigger the spray gun at the end of each stroke to prevent build-up at overlaps.
   - Begin applying gel coat near the booth exhaust in order to avoid over-spray from air-drying on the master. Air-dried overspray can cause pigment separation and form pinholes once the tooling gel coat is applied. Pigment separation appears like a watermark on the cured gel coat surface.
   - The gel coat must be well atomized and each coat applied to a wet film thickness of 18 ± 2 mils in three passes. Subsequent passes should always be at right angles to the prior pass.

- Use air atomization (pressure pot) equipment with a minimum of 60 psi dynamic (at the gun, trigger pulled wide open). Low atomizing pressure will result in poor breakup and leave entrapped air (pinholes) in the sprayed film.

Refer to the Tooling: Building a Mold section.

E. **Do not use internal air atomization or catalyst injection spray equipment with standard tooling gel coat.** These types of equipment often result in thick films and porosity.

Refer to the Tooling: Building a Mold section.

F. Airless air-assist spray equipment can be used to apply Polycor® 945 and 965 series tooling gel coats.

Refer to the Tooling: Building a Mold section.

G. **Best results when spraying tooling gel coat are obtained by using a pressure pot.** This prevents catalyzation problems due to surging in resin or catalyst pumps, lack of calibration, and poor mixing. Avoid material delivery rates in excess of 2.5 pounds per minute because more than this is difficult to atomize.

Refer to the Tooling: Building a Mold section.

H. **Never add acetone or other solvents to tooling gel coat.** A compatible patching thinner or PATCHAID® can be used for repair activities. PATCHAID® contains a surfacing agent that prevents air from inhibiting the cure. This surfacing agent can prevent a second layer from adhering. For multiple cured coats, the patching thinner (without the surfacing agent) is recommended.

Refer to the Tooling: Mold Repair section.

I. **Molds can develop stress cracks due to thermal shock.** If molds are stored at cold temperatures and then suddenly brought into a warm building, the rapid heat up can cause stresses that lead to fracture in the gel coat.

Refer to the Tooling: Mold Storage section.

J. **Manufacturers of conventional paste wax claim indefinite shelf life as long as the solvents do not evaporate.** Keep containers closed except to remove the wax.

- Do not apply paste wax using the ‘sock method.’ This involves tying the wax up into a ball with sheeting. The sock allows solvent and oil to pass through, but the waxes remain in the sock.

Refer to the Tooling: Mold Break-In Procedures section.

K. **Semi-permanent mold releases have a shelf life and must be kept closed when not in use.** These materials are polymers that require humidity for proper cure. Low humidity conditions will extend the time required for them to cure. Always follow the storage and usage recommendations from the semi-permanent release system manufacturer.

Refer to the Tooling: Mold Break-In Procedures section.

L. **Both conventional paste wax and semi-permanent mold release systems must bond to the mold surface.** A good bond requires a clean mold surface. The residue from rubbing or polishing compounds must be removed using a mild detergent solution such as dish soap and water. If these residues are not removed prior to mold release application, the first pull may remove the release agent and the second part can stick.

Refer to the Tooling: Mold Break-In Procedures section.

M. **Do not be afraid of silicones.** Most mold waxes contain silicone, and non-silicone types are the exception rather than the rule. Excess silicone can and will cause problems, such as fish eye and pre-release. The important thing is to make sure all excess wax is polished from the tooling gel coat surface. Fish eye and pre-release will be more of a problem on fresh wax than on ensuing parts.

Refer to the Tooling: Mold Break-In Procedures section.

N. **Do not use high-speed buffers (more than 3,000 RPM).** High-speed buffers cause excessive heat and can lead to burning.

Refer to the Tooling: Mold Repair section.

13. ThermaCLEAN® Products

Overview

- **Introduction**
- **Technology**
- **Application**
- **Waste Disposal**

13.1. Introduction

Traditional cleaning solvents for equipment and tools in the composites and casting industries have been acetone, methyl ethyl ketone, ethyl acetate, methylene chloride, and toluene. These conventional solvents have been used for every aspect of tool and equipment cleaning as well as personnel skin contact cleaning. These solvents are volatile and flammable to varying degrees. Methylene chloride, while not flammable, is a known cancer causing agent. In the past several years, the toxicological and environmental risk aspects of these cleaning products have caused fabricators to seek alternative cleaners. Desirable features for such alternative cleaners are:

- Effective polymer solubility or loosening
- Carrying ability of the cleaner
- Low volatility
- Low or no flammability
- Reasonable cost
- Ease of disposal
- Reduced risk to employees, facility, or environment

Benefits derived through reduced fire insurance rates have been further encouragement for alternatives. Polynt manufactures ThermaCLEAN®, a line of replacement cleaners which meet the above listed objectives and which provide Polynt customers with a product support system that addresses technology, application, and waste disposal.

ThermaCLEAN® products are effective industrial cleaners with lower environmental impact when used as replacements to conventional, highly volatile solvents. These products are used in a variety of cleaning applications within the composites, industrial, cultured marble/cast polymers, and other industries.

13.2. Technology

The ThermaCLEAN® product line consists of two basic technologies:

- Water-based products, including resin emulsifiers and wipe-down cleaners.
- High flash point, no HAP, low VOC emission, solvent-based products, including a variety of specialized gun flushes.

These products are cost effective when compared to low flash point solvents because ThermaCLEAN® products have very slow evaporation loss rates. Further, the water-based products can be diluted with up to 10 parts of water.

These products also significantly improve personnel and plant safety, since high flash point solvents greatly reduce fire hazards, while low toxicity minimizes employee health risks. ThermaCLEAN® products are non-hazardous for flammability and toxicity by EPA and DOT definitions.

13.3. Application

To assist customers with the use of ThermaCLEAN® products, Polynt provides application support including specialized equipment which improves productivity, such as Polynt's MARBLECLEAN machine, redi-SCRUB machine, and its AQUACLEAN machine. For specialized application tips and product use, consult contact Polynt's ThermaCLEAN® support group.

13.4. Waste Disposal

Water-based products can be reused if the resin/filler precipitate is separated from the cleaner. Once spent, these products may be sewerable (with prior POTW approval) or disposed of through an appropriate waste disposal company. Solvent-based ThermaCLEAN® products should only be disposed of through an appropriate waste disposal company.

Polynt customers who choose ThermaCLEAN® products not only use the best environmental cleaners available, but gain access to Polynt's support and resources as well.

ThermaCLEAN® products are well-demonstrated as they have been specifically developed in Polynt's research laboratories to clean a variety of gel coats and resins, including epoxy, urethanes, unsaturated polyesters, and vinyl esters.

Product data sheets describing the entire ThermaCLEAN® line are available upon request from Polynt Customer Service and will soon be available on our website and mobile app.

14. IMEDGE® Products

Overview

- **Introduction**
- **IMEDGE® PCT100 and PCT110**
- **IMEDGE® ECT120**
- **IMEDGE® HPC610**
- **IMEDGE® HPB210**
- **Conclusions**

14.1. Introduction

Polynt's IMEDGE® products are high performance in-mold cutting edge polymer technologies that offer unique and revolutionary alternatives to conventional FRP materials. The IMEDGE® technologies were developed to promote and drive innovation in the FRP industry. The IMEDGE® product line represents Polynt's commitment to be a leader in the industry through technology, sales, and technical and customer support. IMEDGE® is a technology platform from which new and innovative products will be launched on a regular basis.

The product offerings in the IMEDGE® product line are:

- IMEDGE® PCT100 - Polymer Coating Technology
- IMEDGE® PCT110 - Polymer Coating Technology
- IMEDGE® ECT120 - Epoxy Compatible Technology
- IMEDGE® HPC610 - High Performance Coating
- IMEDGE® HPB210 - High Performance Barrier Coat

The benefits of each product are described below.

14.2. IMEDGE® PCT100 and PCT110

IMEDGE® PCT100 and PCT110 are MACT-compliant coatings that provide a visibly glossier, darker and more richly colored surface than traditional gel coat. IMEDGE® PCT100 and PCT110 are offered in a wide variety of colors (non-white).

These cosmetic benefits are most evident in dark colors. IMEDGE® PCT100 and PCT110 colors have measured more than two color units darker than conventional MACT-compliant products when both systems are pigmented similarly. Fiberglass parts fabricators and their dealers have recognized the "new look" of parts built using the IMEDGE® PCT100 and PCT110 technology and have called the appearance difference "remarkable."

The deep, rich color and high gloss of the IMEDGE® PCT100 and PCT110 coating system can easily be restored to its initial gloss and color when sanded and buffed for repair and finishing operations. Conventional MACT-compliant dark color gel coats get lighter in color when sanded and buffed. The IMEDGE® PCT100 and PCT110 show less than one unit total color change after sanding and buff back or more than 75% less color change than currently available MACT-compliant gel coat products. The gloss of the IMEDGE® PCT100 and PCT110 is also restored with sanding and buffing without the use of any additional finish materials.

Another benefit of IMEDGE® PCT100 and PCT110 is blush resistance or resistance to color change with water exposure. Figure 14-1 includes pictures of two panels after exposure to boiling water for 100 hours.

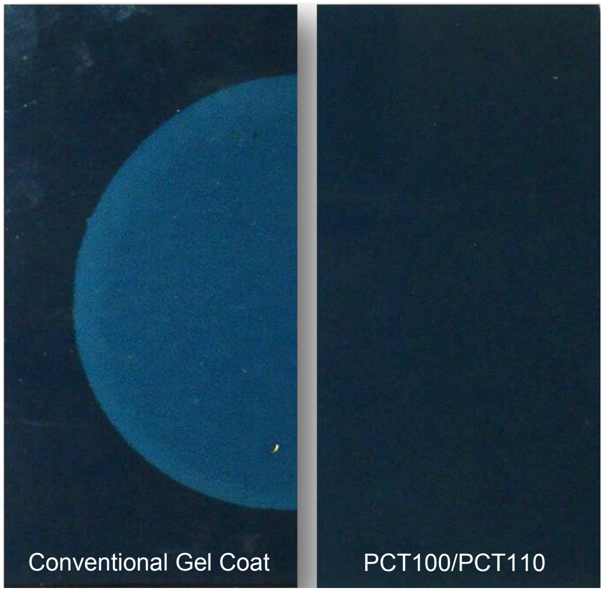


Figure 14-1. Blush resistance of conventional gel coat versus IMEDGE® PCT100/PCT110.

The panel on the left was fabricated with a conventional gel coat and shows significant color change in the exposure area. The panel on the right was fabricated with IMEDGE® PCT100. This panel retained its original color.

IMEDGE® PCT100 and PCT110 can now be considered for applications needing color retention with water exposure. Opportunities for a new, remarkable look include marine applications under the water line, sanitary and swimming pool applications.

IMEDGE® PCT100 and PCT110 also have excellent resistance to the effects of weathering. The weathering resistance of IMEDGE® PCT100 is similar to top of the line marine gel coats. IMEDGE® PCT110 exceeds that performance. Figure 14-2 shows a comparison of IMEDGE® PCT110 to a conventional marine gel coat technology noted for its superior weathering performance. Both coatings were pigmented to a jet black color. Figures 14-2 and 14-3 show gloss and total color change results for panels weathered in South Florida.

The superior weathering grade gel coat performed as expected with good gloss and color retention over a significant portion of the exposure. However, this gel coat reached gloss failure (gloss <50) and chalked between 18 and 21 months. IMEDGE® PCT110 did not reach gloss failure even after 27 months of exposure. The IMEDGE® PCT110 did not chalk, showing almost no color change during the entire weathering exposure.

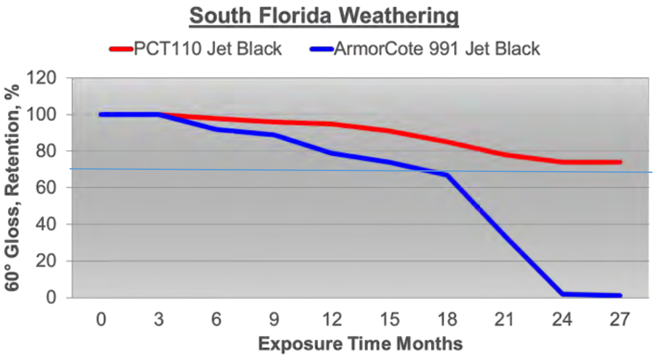


Figure 14-2. Gloss retention of IMEDGE® PCT110 versus conventional gel coat.

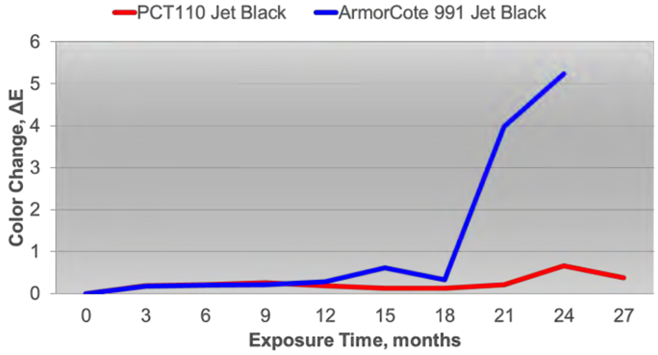


Figure 14-3. Color change of IMEDGE® PCT 110 versus conventional gel coat

IMEDGE® PCT100 and PCT110 are also resistant to cracking as demonstrated by a benchmarking study conducted by Independent Boat Builders Inc. (IBBI). In this study, IBBI evaluated the flexure to first audible crack toughness of 16 competitive blue gel coat products. Flexure to first audible crack is a modified version of ASTM D790 Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. A schematic of the test is shown in Figure 14-4. The coating side of the sample is in tension. Loading of the specimen is stopped at the first audible crack. Results are generally expressed as toughness or the ability of the material to absorb mechanical energy until fracture.

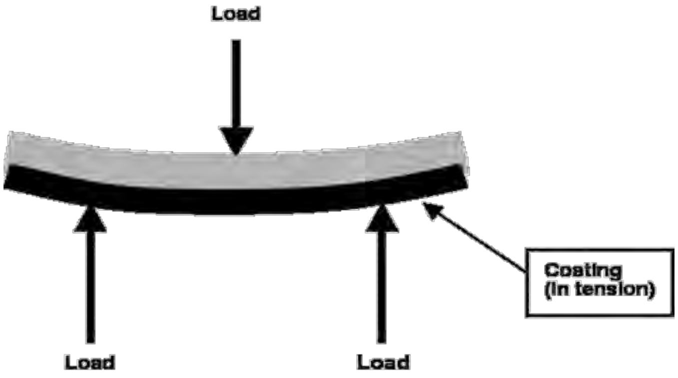


Figure 14-4. Flexure to first crack test schematic.

The IBBI results are shown in Figure 14-5. IMEDGE® PCT100 and PCT110 absorbed much more energy prior to cracking than the competitive gel coats. The crack resistance of IMEDGE® PCT100 and PCT110 can be further increased by backing these coatings with IMEDGE® HPB high performance barrier coats.

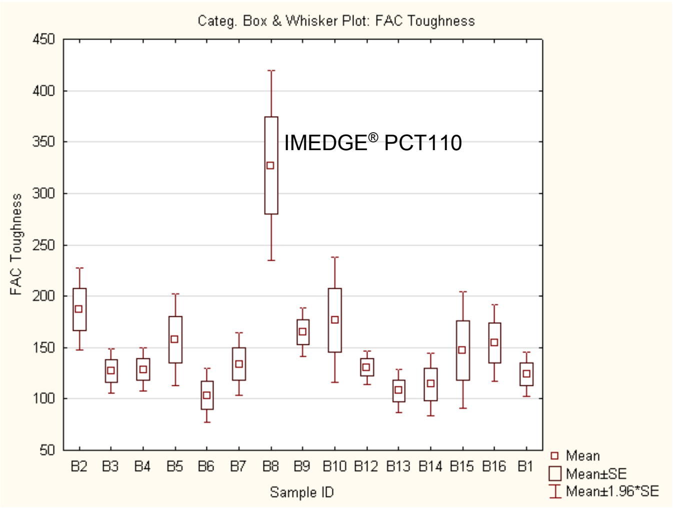


Figure 14-5. IBBI results for flexure to first crack testing.

In addition to the benefits described above, IMEDGE® PCT100 and PCT110 are also resistant to porosity during application, have excellent scratch and wear resistance, and low weight per gallon.

IMEDGE® PCT100 and PCT110 are applied using the same equipment and techniques as conventional gel coat.

IMEDGE® PCT100 and PCT110 meet the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) for boat manufacturing and reinforced composites production.

14.3. IMEDGE® ECT120

Figure 14-6. Product that uses IMEDGE® ECT120.

IMEDGE® ECT120 is an in-mold coating that has excellent adhesion to epoxy matrix resins, as shown in Table 14-1 below. Prior to the development of IMEDGE® ECT120, fabricators of epoxy resin matrix laminates had to either use a tie coat between the gel coat and laminate or post paint their parts. Use of IMEDGE® ECT120 eliminates the need for the tie coat, saving process steps and reducing the weight of the parts. It also allows fabricators to use an in-mold coating rather than post painting, resulting in significant labor savings.

Table 14-1. Adhesion to epoxy laminate.

Adhesive Strength (psi) (1)	ECT120 Black Gel Coat	Standard Polyester Gel Coat
No post-cure	490.2	182.9
Post-cured at 150°F (66°C) for 2 hours	402.4	112.2

(1) Epoxy laminate made with four plies of 1.5 oz. (450 g/m^2) chopped strand mat at about 35% glass content.

In addition to adhering to epoxy resins, IMEDGE® ECT120 MACT-compliant coatings offer the same performance benefits as IMEDGE® PCT100 and PCT110. These include deep, rich colors, excellent buff back and repair properties, blush resistance, weathering resistance and crack resistance. It is resistant to porosity during application, has excellent scratch and wear resistance, and low weight per gallon.

IMEDGE® ECT120 is offered in whites, clears, and colors.

IMEDGE® ECT120 is applied using the same equipment and techniques as conventional gel coats.

IMEDGE® ECT120 meets the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) for boat manufacturing and reinforced composites production.

Gougeon Brothers has approved IMEDGE® ECT120 for use with their PRO-SET epoxy resins.

14.4. IMEDGE® HPC610

IMEDGE® HPC610 is a MACT-compliant coating that provides a visibly glossier, darker and more richly colored surface than traditional gel coat. IMEDGE® HPC610 is offered in colors and white.

The advantages of IMEDGE® HPC610 are:

- Applied in mold with conventional equipment for ease of application.
- Excellent sag resistance and cure profile that provides a clean, sharp tape line.
- Provides paint-like depth and richness to enhance the appeal of dark colors.
- Outstanding gloss retention for that new-look shine.
- Excellent elongation and toughness to prevent fractures and scuff marks.
- Blush resistance for better protection from water and sun exposure.
- Low HAP to meet environmental standards.
- Back-side cures tack-free.

The deep, rich color and high gloss of the IMEDGE® HPC610 coating system can easily be restored to its initial gloss and color when sanded and buffed for repair and finishing operations. Conventional MACT-compliant dark color gel coats get lighter in color when sanded and buffed. The gloss of the IMEDGE® HPC610 is also restored with sanding and buffing without the use of any additional finish materials.

Another benefit of IMEDGE® HPC610 is water resistance. Figure 14-7 shows that IMEDGE® HPC610 has better water resistance than IMEDGE® PCT110. Water resistance (boil) testing measures the size and number of blisters, change in surface profile (fiber prominence), cracks, loss of visible gloss, and color change. This test is described in the Open Molding-Field Service: Blisters and Boil Tests section under Boil Tests (ANSI Water Resistance Test).

When IMEDGE® HPC610 coatings are used in conjunction with an IMEDGE® HPB210 high performance barrier coat, ARMORGUARD® vinyl ester barrier coat, or ARMORSTAR® vinyl ester skin coat resin, a durable osmotic blister resistant composite can be made that is suitable for applications with extended water exposure.

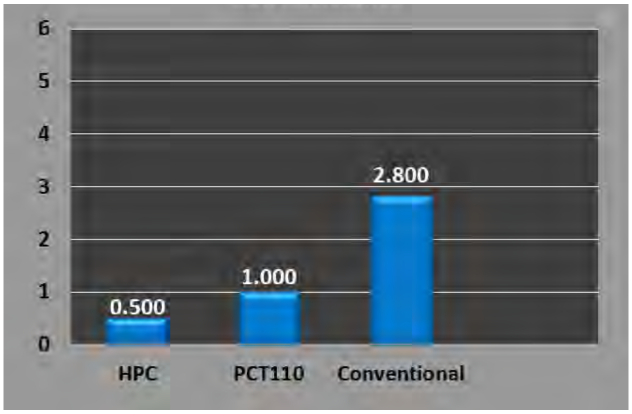


Figure 14-7. Water resistance of IMEDGE® HPC610.

IMEDGE® HPC610 has excellent resistance to the effects of weathering, similar to IMEDGE® PCT110.

IMEDGE® HPC610 is resistant to cracking as shown in Figure 14-8. The flexure to first audible crack test is described in the paragraphs on IMEDGE® PCT100 and PCT110. A schematic of the test is shown in Figure 14-4. The crack resistance of IMEDGE® HPC610 can be further increased by backing this coating with IMEDGE® HPB210 high performance barrier coat.

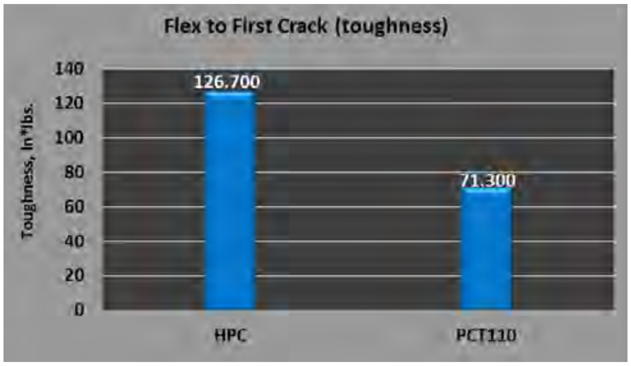


Figure 14-8. Crack resistance of IMEDGE® HPC610.

IMEDGE® HPC610 has excellent scratch and wear resistance. Figure 14-9 summarizes the results of Taber® Abrasion testing. IMEDGE® HPC610 performs better than IMEDGE® PCT110, which performs better than conventional gel coat.

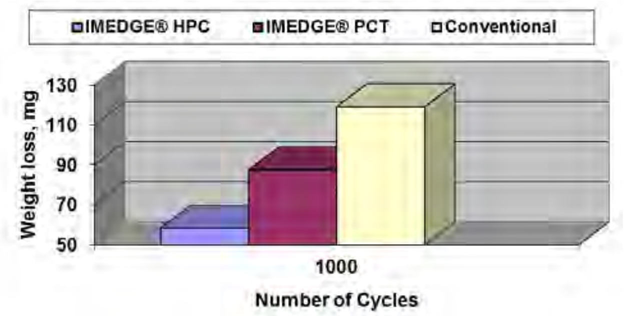


Figure 14-9. Wear resistance of IMEDGE® HPC610.

For Taber® abrasion testing, a sample is placed on a turntable. As the turntable rotates a designated number of turns, abrading wheels rotate opposite directions to simulate accelerated wear. Figures 14-10 to 14-12 show the Taber® Abraser, turning action, and a sample after testing. The results measure weight lost.

Figure 14-10. Taber® Abraser.

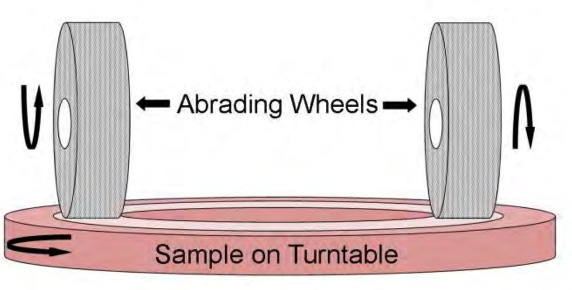


Figure 14-11. Sample/turntable and abrasing wheels motion during Taber® abrasion testing.

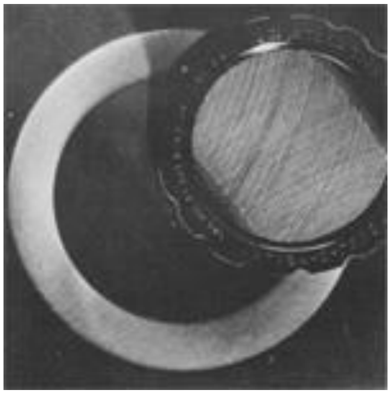


Figure 14-12. Sample after testing, as seen with magnification.

In addition to the benefits described above, IMEDGE® HPC610 also resists porosity during application and has low weight per gallon.

IMEDGE® HPC610 is applied using the same equipment and techniques as conventional gel coat. IMEDGE® HPC610 cures to a tack-free back-side surface.

IMEDGE® HPC610 meets the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) for boat manufacturing and reinforced composites production.

14.5. IMEDGE® HBP210

IMEDGE® HPB210 is a toughened polymer barrier technology that is resistant to cracking and blistering (with water exposure). It also improves surface quality by reducing fiber print and distortion.

Exterior coating cracks lead to significant internal rework and warranty expense for FRP manufacturers. The crack resistance of IMEDGE® HPB210 can be demonstrated by numerous tests, including flexure to first crack and thermal cycling.

Flexure to first audible crack test is described in the paragraphs on IMEDGE® PCT100 and PCT110. A schematic of the test is shown in Figure 14-4.

Flexure to first crack toughness for IMEDGE® HPB210 is shown in Figure 14-13. Results for laminates fabricated with IMEDGE® HPB210 are compared to results for laminates fabricated with a VE barrier. The use of a VE barrier coat increases crack resistance compared to gel coat only. The use of IMEDGE® HPB210 increases crack resistance by 50% in comparison to the VE barrier coat.

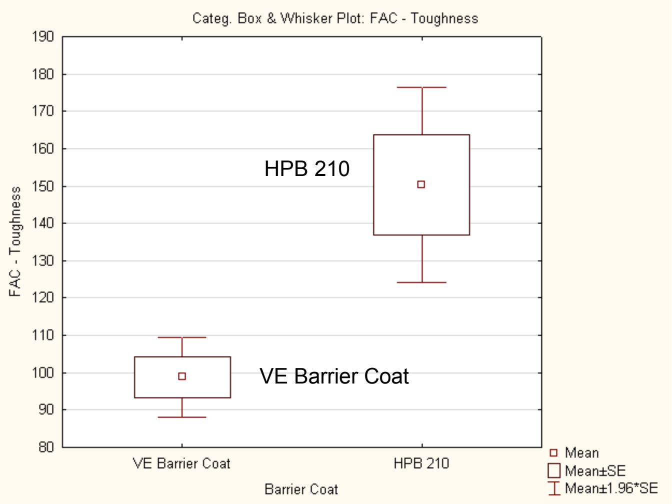


Figure 14-13. Flexure to first crack toughness of IMEDGE® HPB210 versus VE barrier coat.

Polynt also uses thermal cycling testing to demonstrate the crack resistance of coatings and resins. The test involves fabrication of laminates specially designed to promote cracking. These laminates are then mounted in a rigid fixture to limit flexing and stress relief during cycling. The laminates and fixtures are then loaded into the test chamber of a thermal shock or cycling unit (Figure 14-14). The test chamber alternates between cold and warm air on a programmed cycle (Figure 14-15).

Figure 14-14. Thermal cycling testing fixture and unit.

The panels are visually examined at regular intervals during the cycling for cracking. Panels are usually subjected to 150 cycles, but can be cycled longer if no cracks develop. Thermal cycling results for IMEDGE® HPB210 are shown in Figure 14-16.

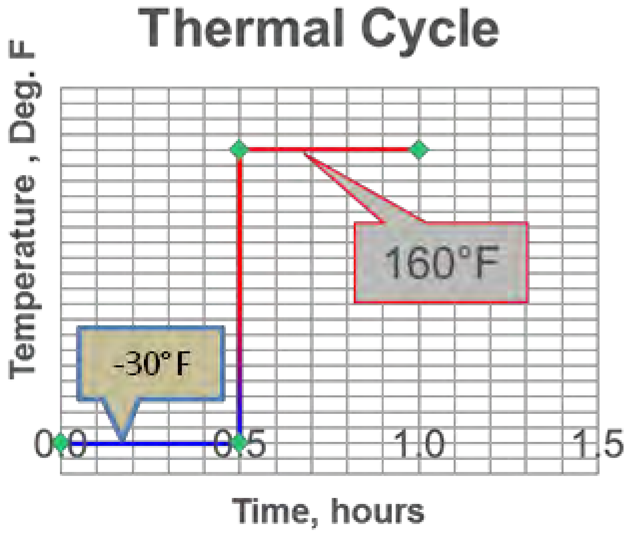


Figure 14-15. Thermal cycle.

Panels fabricated with conventional white gel coats (no barrier coat) typically crack within the first 30 cycles and develop 60-70 cracks during the course of 150 cycles. Panels made with Polynt's Armorflex® 99F backed by IMEDGE® HPB 210 withstood 298 thermal cycles before cracking and had only 2 cracks after 300 cycles. Panels fabricated with IMEDGE® PCT100 backed by IMEDGE® HPB210 withstood 300 cycles without cracking. These are shown in Figure 14-16.

In addition to its toughness and crack resistance, IMEDGE® HPB210 provides excellent water resistance and blister protection. This can be seen in Figure 14-1. The panels shown in this photograph were constructed using IMEDGE® HPB210 behind both the conventional gel coat and IMEDGE® PCT100 coating. The entire water-exposed area of the panel is free of blisters and other effects of water with the exception of the blushing of the conventional gel coat.

IMEDGE® HPB210 also provides an excellent barrier against print and distortion. In some nonstructural applications, IMEDGE® HPB210 can also reduce the need for detailed rolling typically done in the skin laminate. IMEDGE® HPB 210 provides a tough barrier between air in the laminate and the part surface.

IMEDGE® HPB210 is applied using the same equipment and techniques as conventional gel coats and barrier coats. A spray application of 25-40 mils wet is recommended for IMEDGE® HPB210.

IMEDGE® HPB210 meets the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) for boat manufacturing and reinforced composites production.

Figure 14-16. Cracks resulting from thermal cycling testing.

14.6. Conclusions

IMEDGE® PCT100, PCT110, ECT120, HPC610 and HPB210 are innovative products developed to meet specific needs of the FRP industry. Polynt customers who choose IMEDGE® products choose to be on the leading edge of FRP technology and position themselves for further innovations launched from the IMEDGE® technology platform.

Appendix A: Quality Control Lab and Test Methods

Overview

- **Introduction**
- **Basic Needs and Equipment**
- **Basic Testing Methods and Equipment**
- **Advanced Testing**
- **Sources of Equipment**

A.1. Introduction

The fiberglass industry is constantly changing. Parts are made at faster rates, with a demand for higher quality and better durability. There is less latitude for errors that can cause unsatisfactory products and costly downtime. Everything must work properly and be compatible.

Many companies in the fiberglass industry are setting up their own internal quality control (QC) labs to monitor materials, to do in-house process monitoring, and to assure performance of final parts. Qualification for ISO certification requires monitoring of materials and processes.

A QC lab (or any laboratory) has one basic function: it collects and reports factual information that should be used to make reasonable decisions. A QC lab can answer the following questions:

- Is the material to be used really what the supplier says it is?
- Does it meet in-house requirements for processing?
- Is consistent material (necessary for optimum production schedules and requirements) being supplied?
- Does a new vendor's different material match the presently used product?
- Can production use the product?
- Is production consistent?
- What amount of material is actually used on each part? Are parts consistent, not only in weight, but in quality?
- Is the process used in making the part cost efficient?
- Does a specific change in production actually bring about a cost or quality benefit?
- Are the products and parts compatible with each other to produce the desired quality?

A QC lab can also perform several other functions:

- Evaluate new products, equipment, or processes.
- Run safety testing.
- Coordinate samples to be sent out for testing—product testing, environmental testing, or analysis work.
- Assume responsibility for regulatory activities (Sara III Reports).

A QC lab can also provide:

- Design testing.
- Cost information on parts.
- Cost estimates on new parts.

Before setting up a quality control lab, it is important for each company to review its expectations and determine the scope of its needs.

A single company's needs will vary greatly (e.g., critical aerospace applications versus non-critical parts), and one company's needs will vary greatly from another. It is not possible for Polynt to provide a complete layout or list of equipment for each possible situation. Listed in this chapter, however, are basic equipment and general costs. Final choices are up to each fiberglass manufacturer.

A.2. Basic Needs and Equipment

The most rudimentary quality control lab needs a room that is temperature-controlled and equipped with good lighting. Other requirements are a sink with hot and cold water, electrical outlets for test apparatus, shelves, and a desk.

One of the primary functions of a QC lab is record keeping. Data must be collected, recorded, and put in a form that is usable and accessible for decision-making.

The economical way of doing this is with pencil and paper. The use of a computer with a spread sheet program, database, or statistical quality control program is a better way to organize and review data.

A QC lab should have available a list of all raw materials, with approved suppliers, used in the company's plants. It should have the phone numbers of not only the sales people but the technical staff of suppliers. A list of industry organizations such as the ACMA and SPI-CI, with phone numbers, may also be helpful. Files of Safety Data Sheets (SDS) from suppliers and certificates of analysis should be maintained. All of the test methods that the lab is to use must be readily available.

The QC lab should have a system for reporting information. Simple forms can be used and should be arranged so that the characteristics and consistency of a batch can be seen at a glance.

When a material is logged into the lab, there are a number of QC steps that should be done. The details of the actual test depend on what type of part will be made from the material, and what is required from it. Start with the simplest tests and then move on to the more complicated. The first steps must be taken before the final steps. It is acceptable to pause anywhere along the process as long as steps are taken in order.

These steps will normally include:

1. **Record the following information** on a particular product or raw material when received:
   - Code number
   - Batch number
   - Batch date
   - Date received
   - A part number if available
   - Specifications (if set up for a particular raw material) should be listed with their tolerances.
   - If a specification sheet comes with the material, it should be compared to standard specifications and the typical results of previous batches.
2. **Visual Inspection**—The simplest inspection is visual and oftentimes overlooked. This should consist of:
   - Examining containers as they are received. Are any damaged? Is there any swelling or buckling? Are there any leaks?
   - Opening the container and examining the material. Does it appear like the previous batch? Is it roughly the same color, cloudy, clear, etc.? Are there any visible signs of contamination, water, etc.?

     NOTE: The color of resins may vary from batch to batch. If there seems to be a significant variation, check with the supplier. Results of these visual inspections should be written down.
   - Mixing the container's contents and visually comparing it to the inspection report's reference to the unmixed appearance.

     NOTE: Some settling may be normal. It is important to be aware that materials need to be mixed before use.
   - Pulling a sample, putting it in a proper container and marking it with the code number, batch, batch date and date received. Save this for testing or future reference for 90 days.

     NOTE: Polyesters should be stored in opaque containers at 73°F or below.

   The following are also required for the preceding procedures:
   - Clipboard
   - Paper
   - Paper cups
   - Containers
   - Marker

Before initiating a testing program, it is important to obtain a list of all the normal tests and procedures used by the supplier to control the quality of the product.

Review the literature for test methods and decide which test procedure to use. The selected procedure should be written up and filed in a notebook. A copy of the proposed procedure should be sent to the supplier with a request for comments.

Any time a test is run, results should be recorded and compared to the standard and to previous batches.

The following general methods and equipment used in testing catalysts may be used to test a variety of materials.

While a very small component, catalyst is a very important one. There are only two basic tests that can be run with catalysts (unless the laboratory is highly sophisticated). These tests are:

- **Visual**—Check the clarity of the product. Look for any seeds, crystals or cloudiness in the material. If found, contact the supplier at once.
- **Reactivity**—Tests must be run to compare a new lot of catalyst to an old lot of catalyst in the same resin

or gel coat. For QC work to be effective, tight controls are required for accuracy. Run gel, cure, and peak.

Equipment needed for catalyst testing includes:

- A water bath, accurate to within 1°F. An example of this type of bath is Blue M Magni-Whirl Model MW110A1.
- A gel meter. Polynt uses Sunshine gel meters.
- A balance accurate to 0.1 gram.
- A thermometer accurate to within 0.2°F.
- For a more permanent record of temperature changes or time versus temperature, a strip chart recorder is required.

The equipment mentioned here is provided as an example. Other brands may be suitable.

A.3. Basic Testing Methods and Equipment

A.3.1. Barcol Hardness (Similar to ASTM D2583)

This test is used to determine the hardness of a material as it cures. It also can be used to compare the hardness of different resins and the development of cure. A Barcol impressor measures the resistance to penetration of a needlelike point on a scale of zero to 100. It requires a mass of material to obtain an accurate reading.

Two different Barcol meters are used in the FRP industry:

- Model 935 (softer materials): normally used for initial readings.
- Model 934 (hard materials): normally used for ultimate cure or when Model 935 gives readings of 75 or above.

Figure A-1. Barcol meter.

Barber-Colman, manufacturer of the Barcol impressor, is specific regarding instructions (and limitations) for the proper use of the Barcol impressor. Barber Coleman advises the following:

- For accurate readings, material should be at least 1/32" (31 mils) thick.
- The testing area should be smooth and free from mechanical damage.
- As a general rule, the number of readings taken increases with the softness of the materials being tested.

Barber-Colman recommends the numbers of readings for the Model 934.

Table A-1. Recommended number of readings for Barber-Colman Model 934.

Hardness Scale (934)	Reading Variance	Number of Readings
30	0.77	29
40	0.78	22
50	0.75	16

The recommended number of readings for the 934 can serve as a starting point when using the 935 meter.

Barcol readings taken on rough surfaces will vary more than readings taken on smooth surfaces.

Barcol hardness can be measured on production parts as well as used in the QC lab on lab samples. In production, the test is not applicable for gel coats. The gel coat film is too thin. The barcol meter penetrates through the film and reads the hardness of the material behind. Measurement of Barcol hardness for laminate cure can be an effective way to judge cure development in production as the fabricator progresses through the laminate build or for determining demold times.

Barcol hardness testing in the QC lab is described below. This test method is not recommended for production gel coats, but is appropriate for resins and tooling gel coats.

Procedure

Many times, this test is run at the same time as the gel time test. The sample size is increased to either 150 or 200 grams and brought to 77°F and catalyzed.

1. Calibrate Barcol impressor with test discs supplied.
2. Note the time of catalyzation.
3. Weigh a specific weight of catalyzed resin into an aluminum weighing dish and place on a non-heated, insulated surface in an area free from drafts. The remainder of the sample is used for gel time test.
4. After the sample has gelled, test sample every five minutes with a pencil. If the pencil dents the resin, do not use the Barcol impressor. Note that time starts from the moment of catalyzation, and test normally runs one hour, or until a reading of 70 or 80 is reached on a 935 Barcol.
5. If a pencil will not dent the resin, take a reading with the 935 Barcol impressor by pressing the needle assembly into the resin, noting the average of at least three readings. Make sure the needle assembly is perpendicular to the resin surface.
6. Continue this procedure until the 935 Barcol reaches 60- 70. When this occurs, the 934 may also be used.
7. Report time and readings. The needle may fade toward zero. Make note if this occurs.
8. If any resin sticks to the needle, wash the needle to prevent blockage. See the following example in Table A-2:

Table A-2. Example of Barcol hardness test.

	Time (min.)	935	934
Catalyzed	0	-	-
Gelled	15	-	-
	20-25	-	-
	30	5	-
	35	15	-
	40	50-60	0
	45	70	0-5
	50	80	15
	55	80	20-30
	60	80	40

A.3.2. Color

Polyester resins possess a color that ranges from water-clear to dark amber. This color varies with resin type and formulation. Resin color is normally only important when the resin is used to make water-clear castings and translucent sheeting.

NOTE: Additives like cobalt will affect the color. There are two color tests.

A. **Gardner Color ASTM D1544-74**—This is the normal test. A test tube of resin is compared to known standards and is ranged from 1 (lightest) to 18 (darkest).

B. **APHA Color (Hazen)—**This test is used to rank resin when the Gardner color is registered at 1 or less. Again, a tube of resin is compared to known standards.

Spectrophotometer Measurements

A color standard must be established in order to run a color test. Normally, a color standard should be a gel-coated panel. The standard may be developed by matching some other item such as vinyl, paint, etc. Once the match is selected, three matched panels should be made up. Each panel should be permanently marked on the back as ‘Standard, Part Number ___, Color ___, Date ____.’ Each panel should be at 3" x 5" in size and placed in envelopes. One should go to the supplier and one is a working standard that is used day-to-day. The third panel is retained as a master, stored in a cool, dark place, and only used when the working standard is in question. This is the final reference for color.

If accurate color consistency is required, the master standard and working standard must be kept in the freezer when not in use. Color standards will change upon aging. That change can be minimized by storing between 0-32°F. In this case, a freezer is necessary.

NOTE: This freezer should not be used to store peroxides or food.

The equipment for running color tests is:

- Fiberglass or glass mold. (Used to prepare cured sprayouts for batch color comparisons.)
- Spray gun, one quart pressure pot, stem cut off so a small bottle (eight ounce jar) can be inserted. (Used to prepare cured sprayouts for batch color comparisons.)
- Light source—one of the following, in order of effectiveness:
  - North light
  - Fluorescent light (cool daylight bulbs)
  - A light booth
  - Color instrument

  - A consistent observer with no color blindness for visual color comparison.

See the Conventional Gel Coat: Color section for further details.

A.3.3. Gel Time at Room Temperature

Equipment Required

- Timer—An inexpensive stopwatch may be picked up at a discount store. An example of a high end alternative would be a Sunshine gel meter. An alternate gel meter is the Shyodu. The mechanics between the two differ somewhat. A Sunshine meter should be used if close comparisons to Polynt results are required.
- A thermometer is required. A glass thermometer, a good pocket thermometer, or an electronic thermometer can be used.
- Eight-ounce paper cups, wide mouth glass jars, or high-density plastic beakers are required.
- Some type of scale is required to measure both gel coat and catalyst, which must be measured consistently from test to test.

  There are a number of choices available, depending on the degree of accuracy desired. Some options include:

  - Graduated paper or plastic cups marked in cc's or ml's
  - A syringe or 10 ml graduated cylinder. These can be picked up at any store that handles medical supplies, (e.g., food, drug, or discount stores)
  - Small school balance
  - Balance scale
  - Spatula and stirring stick
  - Water bath options include:
    - Fish tank, plus heater (only heated models are available, so other means of cooling would be necessary)
    - Blue M Bath.

Polynt has found the following can occur:

- Variation between gel meters (of the same type) can be up to 1/2 minute.
- Variation in mass size (container and volume) can be up to 12 minutes.
- Variation of temperature at 76°F versus 78°F can be more than a minute.
- Variation in repeatability (same meter, same mass, same temperature) can be up to 1/2 minute.

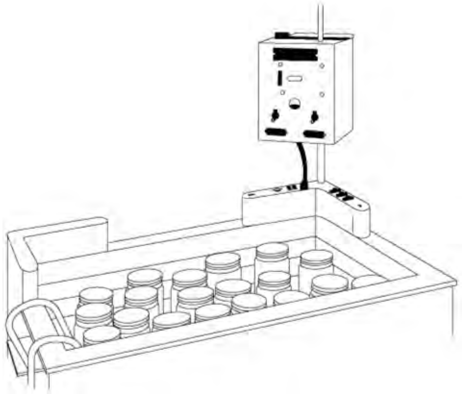


Figure A-2. Water bath.

Measurement of Gel Time

Measured as the amount of time from when the catalyst is mixed in until it is no longer liquid. This test is normally run at 77°F. Temperature greatly affects this test.

A. Procedure

1. Adjust sample to 77°F (25ºC) (± 1°F).
2. Check gel meter for proper operation.
3. Set gel meter timer to zero.
4. Accurately weigh in the required amount of catalyst (normally 1.2% methyl ethyl ketone peroxide) to 100 grams of sample unless otherwise specified.
5. Simultaneously start the power and stir catalyst into sample. Stir in catalyst for one minute. Scrape the side of the jar while stirring.
6. Place cup beneath gel meter. Attach glass rod to magnetic contact assembly. Center the rod in sample. Adjust the meter and rod for vertical alignment.
7. Turn on test switch.
8. When the buzzer sounds, the timer will stop. Turn the power and test switches off. Record results.
9. Clean all equipment and set timer back to zero.

10. When measuring cure time, the gel timer can be used to determine the time until peak exotherm. See Measurement of Cure Time information below for details.

B. Report

1. Record gel time to nearest 0.1 minute.
2. Report any deviations from standard temperature and conditions.

Measurement of Cure Time

Measured as the amount of time from when the catalyst is mixed in until the exothermic reaction has reached the maximum temperature for the 100 gram sample.

The gel-to-peak time is the time difference between the cure time and gel time.

Additional equipment is required to measure the peak exotherm. A strip chart recorder illustrated in Figure A-3 or a thermocouple with 1°F graduations can be used.

1. The thermocouple is positioned into the sample while liquid or as a soft gel. The point of peak exotherm is centered both vertically and horizontally.

   The sample should be insulated from the bench top and protected from other conditions affecting temperature.
2. Record the peak temperature and the time elapsed using a stop watch or gel meter timer.
3. Remove the thermocouple and clean the equipment.

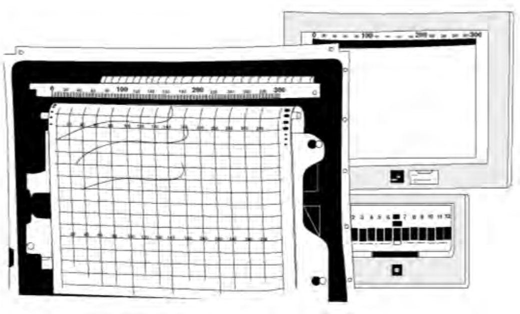


Figure A-3. SPI gel time recorder.

Elevated Temperature (SPI)

This test is used when a resin will be processed by catalyst plus heat rather than a promoter. It provides a procedure for determining the relative reactivity between different batches.

A. SPI Procedure for Running Exotherm Curves

1. Allow sample of uncatalyzed polyester resin to reach room temperature, preferably 75-79°F (24-26ºC).
2. Weigh 100 grams of resin into an 8 ounce jar.
3. Weigh 2 grams of catalyst (50% BPO paste) into the resin in 8 ounce jar.
4. Stir catalyst into the resin; stir well for one minute, being careful to avoid air entrapment.
5. Pour the catalyzed resin into a 19x150 mm test tube to a depth of 8 cm (approximately 20 grams of resin).
6. Allow the resin mixture to set at room temperature approximately 15 minutes (plus or minus 5 minutes) away from strong light.
7. Submerge test tube into constant temperature 180°F (82ºC) water bath.
8. Insert thermocouple (iron-constantan) into center of resin mixture.
9. Record time required for resin mixture to go from 150°F to 190°F (66 to 88ºC) as the gel time; the time from 150°F (66ºC) to peak exotherm as cure time; and the peak exotherm.

A.3.4. Grind

This test may or may not be run on gel coats. It normally is run on the pigment concentrates used to make the gel coat.

1. A small amount of material is placed on a grind gauge and leveled with a special draw-down knife.

   A grind gauge (a Hegman is normally used) is a stainless steel slab in which a variable depth trough is milled. The scale runs from zero (4 mils deep) to eight (0 mils deep).
2. The material is visually inspected to see at what thickness particles appear on the scale.

3.

Figure A-4. Hegman grind gauge.

A.3.5. Hide

This test determines at what thickness a gel coat will prevent a standard colored pattern from being visible. The thickness at which a gel coat will hide is normally set below its minimum application thickness.

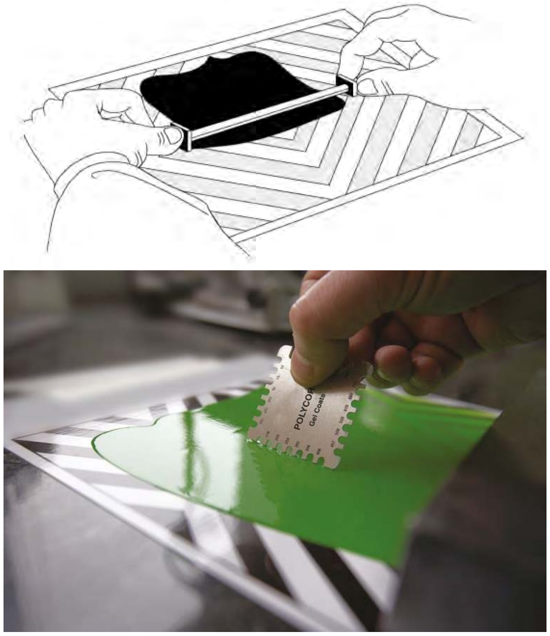


Figure A-5. Hide check.

1. A standard hiding paper is secured flat and a small quantity of gel coat is placed on it.
2. A draw-down bar is then used to spread the gel coat out evenly.
3. The thickness is then measured with a mil gauge.

   NOTE: The gap on a draw-down bar will not deposit the same thickness of gel coat due to friction and fluid dynamics, (e.g., 10 mil gap may give only 6-8 mils film thickness).

4. The paper is then observed to see at what thickness of gel coat the pattern is no longer visible.

A.4. Advanced Testing

Note that in all physical tests, the test sample is preconditioned to assure full cure. If the part is not properly cured, the full physical properties cannot be obtained and failure or low readings may result, which may not be due to the material. Also, it is essential that the test samples for comparisons be constructed in an identical manner, since variances in thickness, type of substrate, and amounts of resin and reinforcement can change the results.

A.4.1. Tensile Strength, ASTM D638

Specimen

Specimens can be molded or machined from castings, laminates, or compression molded plaques. They are given standard conditioning. Typically ⅛" thick, their size can vary; their shape is like a dog bone, (e.g., ⅛" thick, 8½" long, ¾" wide at the ends and ½" wide in the middle).

Procedure

1. Both ends of the specimen are firmly clamped in the jaws of a testing machine.
2. The jaws may move apart at the rate of 0.2, 0.5, 2.0 or 20 inches per minute, pulling the samples from both ends. The stress is automatically plotted against strain.

Significance

Tensile properties are usually the most important single indication of strength in a material. The force necessary to pull the specimen apart is determined; also, how much the material stretches before breaking can be determined.

A.4.2. Flexural Properties, ASTM D790

Flexural Strength

A. **Specimen** ⅛" x 1" x 4". Sheet or plaques as thin as 1/16" may be used. The span and width depend upon thickness. Specimens are conditioned.

B. **Procedure**

   1. The specimen is placed on two supports spaced 2" apart.
   2. A load is applied in the center at a specified rate.

3. The loading at failure is used to calculate the flexural strength (psi).

C. **Significance**—In bending, a beam is subject to both tensile and compressive stresses.

Flexural Modulus

Flexural Modulus is calculated from the data generated during the flexural strength tests. Flexural modulus is the material's ability to hold its shape under flexural loading, or its stiffness.

A.4.3. IZOD Impact, ASTM D256

Specimen

Specimen is usually ⅛" x ½" x 2½". Specimens of other thicknesses can be used (up to ½") but ⅛" is frequently used for molding materials because of its representative average part thickness.

Procedure

1. A sample is clamped in the base of a pendulum testing machine so that it is cantilevered upward.
2. The pendulum is released.
3. The force consumed in breaking the samples is calculated from the height the pendulum reaches on the follow-through.

Significance

The IZOD value is useful in comparing various types or grades of plastics and constructions. In comparing one plastic with another, however, the IZOD impact test should not be considered a reliable indicator of overall toughness or impact strength. Some materials are notch-sensitive and derive greater concentrations of stress from the notching operation. The IZOD impact test may indicate the need for avoiding sharp corners in parts made of such materials.

A.4.4. Compressive Strength, ASTM D695

Specimen

Specimens are prisms ½" x ½" x 1" or cylinders 1/2" diameter x 1".

Procedure

1. The specimen is mounted in a compression tool between testing machine heads which exert a constant rate of movement. An indicator registers loading. Specimens are usually conditioned.
2. The compressive strength of a material is calculated as the psi required to rupture the specimen or deform the specimen at a given percentage of its height. It can be expressed as psi either at rupture or at a given percentage of deformation.

Significance

The compressive strength of plastics is of limited design value, since plastic products (except foams) seldom fail from compressive loading alone. The compressive strength figures, however, may be useful in specifications for distinguishing between different grades of a material, and also for assessing, along with other property data, the overall strength of different kinds of materials.

A.4.5. Heat Distortion Temperature, ASTM D648

Specimen

Specimens measure 5" x ½" by any thickness from to ½", conditioned (oven post-cured).

Procedure

1. The specimen is placed on supports 4" apart.
2. A load of 66 or 264 psi is placed on its center.
3. The temperature in the chamber is raised at the rate of 2°C + 0.2°C per minute.
4. The temperature at which the bar has deflected 0.010" is reported as 'deflection temperature at 66 (or 264) psi fiber stress.'

Significance

This test shows the temperature at which an arbitrary amount of deflection occurs under established loads. It is not intended to be a direct guide to high temperature limits for specific applications. It may be useful in comparing the relative behavior of various materials in these test conditions, but it is primarily useful for control and development purposes.

A.4.6. Glass Content

Procedure for Laminates with No Fillers

1. A small piece is accurately weighed and placed in a tared crucible.
2. The sample is then burned in a furnace to remove all the resin.
3. Sample residue is then weighed and percent glass is calculated

Procedure for Laminates with Fillers

Many fillers break down under heating (e.g., calcium carbonate and hydrated alumina) and leave a partial residue. To determine the percent glass in a filled laminate, digestion and separation methods must be used. It is not easy to do.

A.4.7. Water Absorption, ASTM D570

Specimen

A. For molding materials, specimens are discs 2 inches in diameter and ⅛" thick.

For sheet materials, specimens are bars 3" x 1" by thickness of the material.

B. Specimens are dried 24 hours in an oven at 122°F (50ºC), cooled in a dessicator and immediately weighed.

Procedure

1. Water absorption data may be obtained by immersion for 24 hours in water.
2. Upon removal, the specimens are dried with a cloth and immediately weighed.
3. The increase in weight is the water absorbed. It is reported as a percent of the original weight.

Significance

Various plastics absorb varying amounts of water and the presence of absorbed water may affect plastics in different ways.

- Electrical properties change most noticeably with water absorption.
- Materials which absorb relatively larger amounts of water tend to change dimension in the process. When dimensional stability is required in products made of such materials, grades with fewer tendencies to absorb water are chosen.

A.4.8. Viscosity/Thixotropic Index (TI)/Sag

Viscosity is a material's resistance to flow. Tests include:

A. **Gardner-Holdt ASTM D154 and D1545**—The rate of rise of an air bubble in a sample centered in an inverted corked glass tube is matched against known lettered standards at the same (77°F) temperature. The method has an accuracy of ± 5%.

B. **Brookfield Viscosity**—Equipment for this test includes Brookfield Model LV and RV viscometers and spindles (see Figure A-6). The procedure is as follows:

1. Fill an 8-ounce wide mouth jar to within 1" of the jar neck.
2. Adjust the temperature to 77°F (25ºC) ± 0.5°F (-17ºC), being careful to avoid inclusion of foreign material. Adjust the temperature by placing a lid on the jar and placing it in a 77°F (25ºC) constant temperature water bath until 77°F (25ºC) temperature is reached.
3. **Thixotropic materials require a different method** of measuring viscosity than that used with non-thixotropic materials:
   - **Laminating resins** are thixotropic, (i.e., are shear thinning). This makes it essential that the model of Brookfield, spindle, speed, and time of reading are noted. These must be in the same order to compare viscosities with other tests or resins. Normally, the RVF model, with the number 2 spindle at 50 RPM, is used and run the same way as an unaccelerated resin, except the sample is shaken for 20 seconds before testing, and readings are taken after 2 minutes..

     The **thixotropic index (TI)** is the ratio of the viscosities at low shear (5 RPM) divided by higher shear (50 RPM).
   - **Gel coat** is a thixotropic material. The sample should be shaken prior to testing to determine the rate of recovery. A common procedure would measure the viscosity with the RVF model, with the number 4 spindle at 2, 4, and 20 RPM.

     The **Thixotropic Index** is the ratio of the viscosities of low shear (2 or 2.5 RPM) divided by higher shear (20 RPM).
   - **Non-thixotropic materials** can be measured at a single speed. A common procedure would measure the viscosity with the LVF model, with the number 3 spindle at 30 RPM.
4. Choose the spindle to be used. Remove the lid from the container and place the spindle into the sample, being careful to avoid entrapment of air bubbles beneath the spindle.

5. Attach the spindle to the viscometer and lower the spindle to the level mark indicated on spindle.
6. Start the viscometer and set it to the specified speed for testing. Allow the viscometer to run for 2 minutes. Stop and take a reading.
7. Determine the viscosity from the Brookfield conversion table.

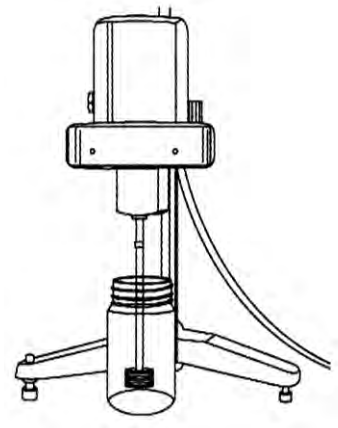


Figure A-6. Brookfield Viscometer.

C. **Gel Coat Sag**—This is normally checked in one of two ways:

- Method 1
    1. Spray the gel coat 18-20 mils thick onto a glass panel.
    2. A sag gauge is then drawn across, leaving gaps.
    3. The panel is placed at a 90° angle and checked later to see if the gel coat has sagged and filled the gaps.
- Method 2
    1. A piece of 1" tape is placed on a glass panel and 18-20 mils of gel coat are sprayed over the whole panel.
    2. The tape is pulled immediately after spraying and the panel is placed at a 90° angle.
    3. Later, the amount of sag into the 1" area is noted.

D. **Weight per Gallon**—Tests are run after gel coat or resin samples have been in a constant temperature bath at 77°F (25ºC) for at least 30 minutes.

1. Weigh gallon cup and lid.
2. Fill cup with resin.
3. Place lid on cup so that resin comes out small hole in top. Wipe off excess.
4. Weigh cup and resin. Subtract empty weight from filled weight.

The weight per gallon (see Figure A-7) equals the weight of the sample in grams divided by 10. For example:

Weight in grams	83.4 grams
Weight per gallon	8.34 pounds per gallon

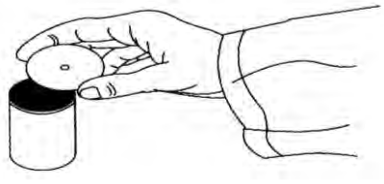


Figure A-7. Weight per gallon cup.

A.4.9. Acid Number (Similar to ASTM D465-59)

The acid number is the number of milligrams of potassium hydroxide (KOH) necessary to neutralize the free acid end groups in one gram of sample. This test is used on resins to determine how far the reaction has proceeded during cooking. It is also used for batch-to-batch consistency. The acid number will vary from resin to resin. It may be as high as 60 or as low as 3.

NOTE: Acid number can be calculated in either of two ways: On resin solids only (monomer factored out), or on total solution (monomer not factored out). Polynt acid numbers are based on resin solution.

Procedure

1. Weigh 5.6 grams of resin into a 150 ml Erlenmeyer flask (or other similar sized container).
2. Add about 20 ml of the following solvent mix:

Toluene	33 grams
Xylene	33 grams
Ethanol (denatured)	34 grams
Phenolphthalein	2 grams

3. Swirl and warm on a hot plate, if necessary, to dissolve the resin.
4. Titrate, using 0.1 normal KOH solution until the resin solution, holds a faint pink color for 30 seconds; the color will tend to fade away.
5. The acid value (AV) = ml of KOH solution used.

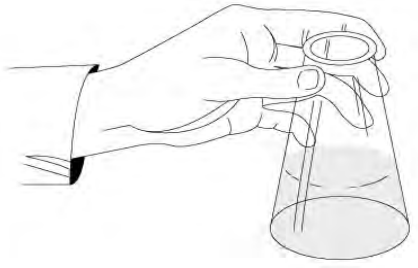


Figure A-8. Titration for acid value.

A.4.10. ANSI (American National Standard) for Plastic Bathtub Units

The purpose of this standard is to establish generally acceptable quality for plastic bathtub units. It serves as a guide for producers, distributors, architects, engineers, contractors, home builders, code authorities, and users:

- To promote understanding regarding materials, manufacture, and installation.
- To form a basis for fair competition.
- To provide a basis for identifying bathtub units that conform to this standard.

This standard and test procedures deal with the acceptability of a plastic bathtub unit as a plumbing fixture. Building codes may have additional requirements.

This standard has a number of tests within it. All will not be covered in detail (see the actual standard). Basically, the tests which must be run by an independent lab are:

- **Workmanship and Finish**—This test spells out how many defects and blemishes are allowed after visual inspections, inking, and sanding.
- **Structural Integrity**—This series states what types of loading and impact the drain fittings, sidewalls, and floor must withstand.
- **Water Resistance**—This is the 100 hour boil test (212°F [100ºC]). The 100 hour boil test requires a panel to be exposed to boiling water, normally for 100 hours. The panel is then visually inspected for color change, blisters, change in surface profile, cracks, and loss of visible gloss. Each item is rated on a scale of 0-5, with zero being no change and five being extreme change approaching maximum possible. The ratings are somewhat subjective and a certain degree of change in each category (e.g., color, change, blisters, cracks, etc.) is allowed. Failure occurs when any one area is rated above 4 or when the total of all five areas is above 9.

  NOTE: The applicability of this test is to compare product to product. Field suitability has not been established. It has been used to rank materials under one set of conditions, but passing or failure does not automatically imply that material is or is not suitable for other types of applications. Suitability is determined by the user.

  NOTE: Type Four bathtub units (thermoplastics) are tested at 180°F (82ºC); not in boiling water.

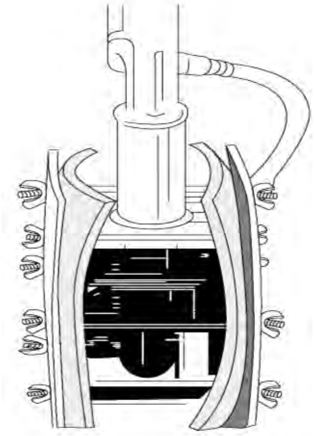


Figure A-9. Boil tester.

- **Color Fastness**—This is a 200 hour weatherometer test.
- **Stain Resistance**—The stain resistance to a number of chemicals is tested.
- **Wear and Cleanability**.
- **Ignition Test**.
- **Cigarette Test**—This test checks if the unit can be ignited or irreversibly damaged by a cigarette burn.

NOTE: Type Four units (thermoplastic faced) have a series of other test requirements; see the standard for details.

A.4.11. Dielectric Strength, ASTM D149

Specimen

Specimens are thin sheets or plates having parallel plane surfaces and of a size sufficient to prevent flashing over. Dielectric strength varies with thickness and, therefore, specimen thickness must be reported.

Since temperature and humidity affect results, it is necessary to condition each type of material as directed in the specification for that material. The test for dielectric strength must be run in the conditioning chamber or immediately after removal of the specimen from the chamber.

Procedure

1. The specimen is placed between heavy cylindrical brass electrodes which increase in voltage during the test.
2. There are two ways of running this test for dielectric strength:
    - **Short-Time Test**: The voltage is increased from zero to breakdown at a uniform rate of 0.5 to 1.0 kV.sec. The precise rate of voltage rise is specified in governing material specifications.
    - **Step-by-Step Test**: The initial voltage applied is 50 percent of breakdown voltage shown by the short-time test. It is increased at rates specified for each type of material and the breakdown level noted.

The term ‘breakdown’ used with these tests means passage of sudden current flow through the specimen and can be verified by instruments and visible damage to the specimen.

Significance

This test is an indication of the electrical strength of a material as an insulator. The dielectric strength of an insulating material is the voltage gradient at which electric failure or breakdown occurs as a continuous arc (the electrical property analogous to tensile strength in mechanical properties). The dielectric strength of materials varies greatly with several conditions, such as humidity and geometry, and it is not possible to directly apply the standard test values to field use unless all conditions, including specimen dimensions, are the same. Because of this, the dielectric strength test results are of relative rather than absolute value as a specification guide.

A.4.12. Fire Tests

The use, applicability, and statements regarding fire test results must be handled with great care, as this whole area is in a great state of flux due to federal regulations. Different regulatory bodies have different requirements for a material’s fire resistance. The major question to answer is: Does the fire resistance test predict what happens in an actual fire? The documented tests at this time are full-scale tests which absolutely predict what will happen under actual fire conditions. Other currently available tests tell only how materials burn under a single set of conditions.

Listed here are common tests which have been used to rate the burning properties of polyesters, but may or may not be Polynt recommendations. These tests are:

A. **ASTM D635**—This test was designed to compare the flammability characteristics of different materials, in controlling manufacturing processes, or as a measure of deterioration or change in flammability rating prior to or during use. In this test:

    1. At least ten specimens 5" in length by 0.5" in width and thickness of the sample normally supplied (usually ⅛") are marked 1" from each end.
    2. The specimens are held in position with the longitudinal axis horizontal and the transverse axis at 45° to the horizontal.
    3. The specimens are ignited for 30 seconds with a Bunsen burner with the flame adjusted to a prescribed height.
    4. The rate of burning is calculated (inch per minute).

    This is not a very severe test and does not distinguish relative flammability characteristics between specimens which have good flame retardant properties. At best, it can only be utilized for rough screening work.

B. **HTL-15 Intermittent Flame Test**—The apparatus needed for conducting this test is quite simple. The test is much more severe than the test previously described because the specimen is suspended in a vertical position and heat from the burner will be carried upward by convection along the length of the specimen. In addition, the specimen is ignited five times using increasingly longer ignition periods. The sequence of ignition times and flame with withdrawals is shown in Table A-3.

Table A-3. Sequence of ignition times and flame with withdrawals.

Applications	Ignition Time (Seconds)	Burner Withdrawn (Seconds)
1	5	10
2	7	14
3	10	20
4	15	30
5	25	50

In rating a sample, five specimens 8" x ½" x ⅛" are burned. If the flame is extinguished within the period that the burner flame is withdrawn, the specimen has passed the ignition test. Each of the five test ignitions successfully passed is worth 20 toward the rating for that specimen. For example, if a specimen successfully passes the five ignitions and flame-off periods, it is rated at 100, four ignitions rate at 80, and so on. An average is taken of the ratings for the five specimens.

C. **ASTM E162**—In this method, a radiant heat energy source is used to supply heat to the surface of a specimen being tested. It is believed that in using a radiant energy source rather than supplying heat by a propagating flame, more accurate observations of the progress of the flame-front can be made. The heat source consists of a vertical 12 by 18 inch panel in front of which is placed an inclined six by 18 inch specimen. The specimen is oriented in such a manner that ignition occurs at the upper edge and the flame-front moves downward.

A factor derived from the rate of progress of the flame front and another relating to the rate of heat liberation by the material under test is combined to provide a flame spread index. The amount of smoke evolved during the test can also be measured. It is pointed out in the ASTM method that the method, although suitable for research and development for measuring surface flammability of materials, is not intended for rating materials for building code purposes.

D. **ASTM E84**—This is a large scale test which requires a considerable amount of material and is quite expensive to set up and run. Only a few test 'tunnels' used for this test are in actual use in the United States. The purpose is to determine the comparative burning characteristics of the material being tested by evaluating the flame spread over its surface, fuel contributed by its combustion, and the density of smoke developed when exposed to a test furnace.

Briefly, the specimen for combustion (after prior conditioning) is fastened to the roof of the tunnel and ignited by means of a gas flame impinging on the surface of the specimen. The gas flow is carefully regulated. During the test, air is drawn through the tunnel at a constant rate. Smoke density is measured by means of a light source and a photoelectric cell in the furnace vent; fuel contributed is measured by means of thermocouples placed near the vent end of the furnace.

The furnace is calibrated using red oak flooring and asbestos board as standards. Conditions are adjusted so the red oak spreads a flame the length of the furnace in five and 1/2 minutes ± 15 seconds (19.5 feet from the end of the gas flame to the end of the tunnel). This is considered (arbitrarily) as a classification of 100 while the flame spread of asbestos is 0. In testing a material, classification is made relative to these two ratings. Also, fuel contributed and smoke density is classified in respect to values obtained for red oak and asbestos.

E. **ASTM D2863—Flammability of Plastics Using the Oxygen Index Method**

Scope

This method describes a procedure for determining the relative flammability of plastics by measuring the minimum concentration of oxygen in a slowly rising mixture of oxygen and nitrogen that will just support combustion. This method is presently limited to the use of physically self-supporting plastic test specimens.

Significance

This method provides a means for comparing the relative flammability of physically self-supporting plastics.

Principle of Method

The minimum concentration of oxygen in a slowly rising mixture of oxygen and nitrogen that will just support combustion is measured under equilibrium conditions of candle-like burning. The balance between the heat from the combustion of the specimen and the heat lost to the surroundings establishes the equilibrium. This point is approached from both sides of the critical oxygen concentration in order to establish the oxygen index.

Calculations

Calculate the oxygen index, n, of the material as follows:

n, percent = (100 x O2)/ (O2 + N2)

O2 = volumetric flow of oxygen, CM1/S at the limiting concentration determined

N2 = corresponding volumetric flow rate of nitrogen, CM1/S.

There are a number of other tests which are, at times, used in the fiberglass industry. Only the most common generally accepted tests have been described here. Other tests can be found in textbooks and/or industry literature. All manufacturers of any product should have an in-house testing program, but tests should not be run just to be running tests. Rather, tests should be run to determine how material will perform in the manufacturing process, to determine its quality, and to determine how the final product will perform for its intended end use.

A.4.13. Nonvolatile (NV or Resin Solids or Vehicle Solids)

This test is run only on the resin and monomer or solvent portion of any system. All pigments or fillers, if present, are separated out before the tests. This test is used to determine the ratio of base polyester resin to monomer (usually styrene). This is done by boiling off monomers or solvents which boil above 105°F (41ºC). This ratio of base resin to styrene can affect the cured physical properties of the resin. It will vary according to type of material and application method. It can be as low as 40% resin and range as high as 80% resin. (Refer to the data sheet of the material for its proper range.)

Two methods are used in the industry. These are:

A. Foil Solids (based on ASTM D1259)

1. A folded rectangle of smooth 6" x 12" heavy duty aluminum foil is weighed to the nearest 0.0001 gram.
2. An eyedropper full of resin (approximately 1 gram) is placed inside the center of the folded foil and quickly weighed to the nearest 0.0001 gram.
3. The foil, with the resin inside, is placed between two glass plates and pressed to produce a 3"-4" circle of resin.
4. The foil is opened and placed in a clean 105°F (41ºC) oven for 10 minutes.
5. After the foil is removed and cooled, it is re-weighed to the nearest 0.0001 gram.
6. The percent NVM is calculated:

   Percent NVM =

   100 x (weight e - weight a)(weight b - weight a)
7. Percent monomer = 100 minus percent NVM.

This test is always done in duplicate; the results should be within 0.4% of each other.

B. Determination of Nonvolatile in Polyester Resins

1. Weigh a 60 mm aluminum dish (containing a bent paper clip to use as a stirrer) to 4 decimal point accuracy on an analytical balance.
2. Fill a plastic eyedropper with the resin and wipe off the resin from the outside of the eyedropper.
3. Weigh the eyedropper to 4 point decimal accuracy. Transfer about 0.5 gram of resin to the aluminum weighing dish; reweigh the eyedropper to determine the exact weight of resin transferred to the dish.
4. Add 2 ml of toluene or toluene/acetone mix to the dish and mix into the resin using the bent paperclip.
5. Dry the sample for 30 minutes in a 200°F (93ºC) oven and reweigh to 4 point decimal accuracy. The percent nonvolatile of the resin is:

   100 x (weight e - weight a)(weight c)
6. Run three samples and average the results to get a final value for percent nonvolatile.

Pigment Solids— This test, in which a weighed gel coat is centrifuged, is not normally run except as a double-check for a particular reason.

1. The separated pigment is mixed with solvent and centrifuged.
2. The process repeated several times until the pigment is free of resin.
3. The washed pigment is dried and weighed.

Pigment solids are determined by:

> 100 x weight of dried pigment weight of gel coat
>
> NOTE: Be sure to subtract the weight of the container.

A.5 Sources of Equipment

Normally, lab supplies and equipment are purchased from a company that specializes in laboratory equipment. Such companies are good sources, but if a lab is being set up on a conditional basis, there are other sources of supply that are good to know. For example, many items can be purchased at a local drug store or discount store. Milliliters of catalyst can be measured in syringes that are calibrated in milliliters and which can be purchased in many states. A source that sells medical supplies for infant children can be a source to purchase cylinders or eyedroppers that are graduated in milliliters.

For many supplies, the best reference source is the Yellow Pages. Look under laboratory supplies—or, if seeking specific items, such as paper cups, look under paper cups first.

If a full laboratory is to be installed, obtain the catalogs of from laboratory supply companies.

For local supply sources, check the business telephone directory under Laboratory Supplies.

Major Laboratory Supply Companies

Fisher Scientific
300 Industry Drive
Pittsburgh, PA 15275
Phone: 800-766-7000
Fax: 800-926-1166
www.fishersci.com

Thomas Scientific
1654 High Hill Road
PO Box 99
Swedesboro, NJ 08085-6099
Phone: 800-345-2100
www.thomassci.com

VWR Scientific Products
Radnor Corporate Center
Building One
Suite 200
PO Box 6660
100 Matsonford Road
Radnor, PA 19087-8660
Phone: 800-932-5000
847-229-0180
www.vwr.com

Specialized Equipment

(Not normally found in scientific laboratory houses)
Paul N. Gardner
316 N.E. First St.
Pompano Beach, FL 33060
Phone: 800-762-2478
www.gardco.com

(This company offers a wide selection of hard-to-find items that are used by the plastics and paint industries, including Barcol impressors.)

Manufacturers of Specialized Equipment

Brookfield Engineering Laboratories, Inc. (Viscometers)
11 Commerce Boulevard
Middleboro, MA 02346
Phone: 800-628-8139
Fax: 508-946-6262
www.brookfieldengineering.com

Delval Glass (Boil Test Apparatus; Corrosion Tester)
1135 E. 7th Street
Wilmington, DE 19801
Phone: 800-628-3641
Phone: 302-656-6606

Instron Corporation (Physical Testing Equipment)
825 University Ave.
Norwood, MA 02062-2643
Phone: 800-564-8378
www.instron.com

Davis Inotek (Sunshine Gel Meters)
1810 Grant Ave.625 East Bunker Ct.
Vernon Hills, IL 60061-1844
Phone: 800-358-5525
Fax: 1-800-433-9971
www.davis.com or www.inotek.com

National and International Standards

American National Standards Institute (ANSI) Headquarters
1899 L Street NW
11th Floor
Washington, DC 20036
Phone: 202-293-8020
Fax: 202-293-9287
www.ansi.org

American Society for Quality (ASQC)
600 N. Plankinton Avenue
Milwaukee, WI 53203
Phone: 800-248-1946
Fax: 414-272-1734
www.asq.org

Test Procedures

ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959
Phone: 877-909-2786
www.astm.org

NOTE: Many major libraries have ASTM Standards.

Appendix B: Polyester Resin Bulk Storage

Overview

- **Introduction**
- **Tote Tanks**
- **Storage Tanks**
- **Construction**
- **Size**
- **Inert Gas Atmosphere**
- **Level Indicators**
- **Storage Tank Cleaning**
- **Pumps and Agitation**
- **Valves, Pipes, and Fittings**
- **Location**
- **Loss Prevention Guidelines**
- **Reference Material**

B.1. Introduction

This section covers general information for those who are considering the installation of storage tanks for unsaturated polyester resins. More detailed information should be acquired from equipment suppliers and tank fabricators.

Polyester resins can be safely and economically stored and handled in bulk with properly designed equipment.

Resin temperature control is especially important because polyesters are temperature sensitive and exposure to elevated temperature conditions drastically shortens their life. Polyester resins stored at low temperatures become very thick. This makes them very difficult or impractical to handle, as well as slowing down gel and cure times.

Ideally, the storage temperature is 72-78°F (22-25°C) and should not exceed 85°F (29°C). The expected storage life at ideal temperatures is about three months but will vary depending upon the resin. The usage life is cut in half for every 20°F (-7°C) over 73°F (23°C).

Storage tanks should be inspected frequently, particularly in warm summer weather, because styrene can polymerize on the tops and sides of the tanks, forming stalactites that sometimes break off and contaminate the resin. The vent line should be inspected before every bulk delivery to insure it is clear. A cleaning of the tank once per year is considered normal.

Agitation, or a recirculation system, is necessary for bulk storage of polyesters, particularly thixotropic polyesters, due to the settling or flotation of certain components.

B.2. Tote Tanks

In a review of packaging alternatives, shipping/handling, and recycling and waste disposal, there are options that exhibit both advantages and disadvantages. While tote tanks, both stainless steel and disposable (cage exterior with polyethylene bladder), offer certain conveniences in material handling and in addressing concerns regarding container disposal, they do not allow practical agitation.

In the case of the plastic bladder disposable tote, the head opening does not accommodate the normal drum agitator assembly. Also, the use of plastic totes is not permitted by NFPA, whose standards are incorporated by reference by OSHA.

Modified mixers such as butterfly blades or chains are inadequate to agitate the entire content of the tote. Regular drum agitators are also inadequate to mix the entire content of the tote tank. In order to perform any useful mixing, the agitator must be operated at an adequate speed and the blade must extend sufficiently across the container.

As a polyester ages, some stratification may develop. This separation must be reincorporated to enable proper performance of the material and to prevent application difficulties. Following the recommended procedure of 5-10 minutes mixing before each shift will accomplish reincorporation of any stratified components.

It is important to keep in mind potential mixing difficulties with tote tanks, and, as much as possible, to guard against problems generated by containers not favorable to content mixing.

It is also important to thoroughly inspect tote tank contents prior to use in order to avoid problems associated with such containers and with stratification.

Under normal aging, storage, and transporting conditions—except long, vibration-intense hauls—stratification will not occur before two weeks of age. This is not an endorsement of the use of product that is less than two weeks old without agitation; rather, it is intended to encourage the use of product before age creates the condition.

B.3. Storage Tanks

The storage tank may be either vertical or horizontal. If vertical, less surface area of the resin will be exposed to the atmosphere; therefore, there is less opportunity for evaporation and styrene buildup. In addition, less floor area is required and agitation cost is minimized. The bottom of vertical tanks should be dished or coned. Horizontal tanks should be sloped to allow complete drainage of the vessel. A vertical tank requires a higher enclosure if installed inside a heated structure. A clean-out port should be provided in the top as well as near the bottom of either type of tank.

Storage tanks may be located outside any building enclosure. If located outside, heating and/or cooling coils and insulation will be required for the tank. Transfer lines should be maintained at a constant temperature (72-74°F (22-23°C) by means of jacketed or self-limiting heat-traced pipe.

Underground storage of polyester resins is not recommended because the resin must be maintained at 70°F (21°) minimum temperature, which is higher than year-round ground temperature. Resin viscosity increases rapidly with a decrease in temperature. In addition, underground tank inspection and cleaning is more difficult, and monitoring the tank for leakage is also more difficult.

B.4. Construction

As a general rule, 304 grade stainless steel and phenolic-lined or epoxy-lined carbon steel tanks are recommended for promoted resins. Some coatings used for tank lining contain TBC inhibitor to prevent formation of polystyrene gel particles. For information concerning coatings and techniques used for lining tanks, refer to the coating's manufacturer.

Some users report that DCPD-based resins have poorer quality life in stainless steel than in lined carbon steel. Stainless steel or lined carbon steel is suitable for orthophthalic- and isophthalic-based polyesters.

In a tank's service life, cleaning will be required. Usually, when hot, caustic cleaning solutions or intense mechanical abrasion must be used; all lining must be replaced as well.

Do not use copper or brass fittings because these metals or alloys react with polyester resin and create compounds that may affect the cure, color or shelf life characteristics of a polyester. Cast iron or stainless steel fittings are satisfactory if designed to withstand normal pumping pressure.

It is desirable to have the tank vent attached to an air dryer or desiccator to remove all moisture from the air that goes into the tank. Excessive moisture may affect the resin and cause rusting in the system.

A flame arrestor must be used on all vents. Check local codes for installation approval. Caution should be taken to prevent the flame arrestor from becoming blocked by polystyrene buildup. The flame arrestor should be inspected before each bulk delivery to ensure that it is free of build-up.

A thermometer should be installed so that the temperature of the resin can be observed at all times. The resin should not be allowed to rise above 85°F (29°) for an extended period of time. Experience has shown that in most locations— except in some areas of the southern United States—the temperature of a storage tank of resin, enclosed in a well-ventilated shelter will not rise above 85°F (29°C). It is important that the shelter be provided with good ventilation 24 hours a day during the hot summer months, and that the roof, in particular, is well-insulated, or that suitable air conditioning is provided. Cooling jackets or coils could be needed for exterior tanks.

In some cases, it may be advisable to install a water sprinkler over the storage tank, especially if the tank is exposed to direct sunlight or where necessary to meet insurance or building code regulations.

B.5. Size

The storage tank should be approximately 1½ times the maximum size of the shipment to be stored. A normal tank wagon shipment weighs from 40,000-45,000 pounds. Depending on the weight per gallon, a minimum tank size would be approximately 6,000 gallons.

B.6 Inert Gas Atmosphere

If an inert gas atmosphere is used, make sure the inert gas does not bubble through the resin since this will reduce the stability of the resin.

B.7. Level Indicators

Arrangements should be made for monitoring the level of liquid in the tank. Usually a daily visual check or stick measurement is adequate. Other methods such as radar gauges or differential pressure (DP) cells may be used, but must be considered in the tank construction.

B.8. Storage Tank Cleaning

To clean a polyester resin storage tank, a detergent wash, followed by a water rinse, followed by a solvent wash, is recommended. A cleaning compound supplier should be contacted for recommendations and suggestions for a cleaning compound and a cleaning spray head.

NOTE: Always use appropriate respirators while servicing the tanks. Specific OSHA requirements should be adhered to when entering a confined space.

NOTE: All material, including cleaning liquids, must be disposed of in accordance with local and federal regulations.

B.9. Pumps and Agitation

An air diaphragm pump is recommended if resin is to be recirculated. It can be installed in such a way that it operates only when the pressure in the system is relieved. If a gear pump is used in a recirculating system, it may heat the resin, causing changes in cure and viscosity. Gear or diaphragm pumps can be used as auxiliary equipment for unloading the resin, for intermittent delivery to a factory work area, or for periodic recirculation of the resin.

A gear or sliding valve pump operated at 350-450 RPM with an external relief device may be used. The size of the pump will depend upon the specific gravity and viscosity of the resin involved, the quantity required, and the length of transfer line involved. Pumps should be all iron or suitable polymer construction. No copper bearing alloys should be used.

The tank must be equipped with some means of agitation if it is to be used for storing thixotropic resins which contain additives, such as a silica or an organic thickening agent. Silica tends to settle to the bottom because of its high specific gravity and the organic materials tend to migrate to the top.

A fully enclosed, explosion-proof, electrically driven agitator mounted at the top of the storage tank is an ideal arrangement.

B.10. Valves, Pipes, and Fittings

- When an epoxy- or phenolic-lined carbon steel storage tank is required, all pipe fittings and valves should be stainless steel. When a carbon steel tank is acceptable, iron valves and carbon steel pipe and fittings are satisfactory.
- Transfer lines to and from the storage tank should be sloped for drainage and vented to prevent siphoning.
- Drain valves should be installed wherever drain problems may be encountered.
- Stems of valves should point up, wherever possible, to prevent locking up due to possible resin gelation.
- Outlets and pipes should measure at least 2" in diameter (preferably 3" Certain resins that are low in viscosity (200-500 cps), such as those used in the boat manufacturing industry, can be circulated or pumped through smaller diameter pipe. However, Polynt recommends that no less than 1½" in diameter be used. Temperature must be considered if using ceiling mount pipe.
- The hookup from a plant work area to the storage tank will vary with the material being used and the product being manufactured. When a spray gun is used, a recirculating system may be desirable. Do not use a configuration that creates a dead end, where resin remains static and cannot be returned to the storage tank. Resin that is not recirculated or used may eventually gel and plug the lines.

B.11. Location

The location of storage tanks with respect to work area depends on several factors. The most important factors will be local fire hazard codes and insurance recommendations. In general, it is recommended that tanks be located outside or enclosed within a suitable fire wall. In some cases, tanks can be installed in a separate building, if the building is located an acceptable distance from the manufacturing area.

B.12. Loss Prevention Guidelines

Some loss prevention items that should be considered when planning bulk storage facilities are:

- Compliance with all federal, state, and local codes. Contact local fire marshal and insurance company for specific information.
- The tank should be equipped with a pressure and vacuum relief valve to allow for normal tank breathing while the tank is being filled and emptied.
- A flame arrestor must be installed with the tank pressure-vacuum relief valve.

- Copper bearing alloys should not come into contact with resin. Exposure to these materials will inhibit resin cure.
- All motors and electrical equipment, including instrumentation and lighting, should be suitable for flammable liquid storage installation. Most polyester resins have a flash point of about 88°F.
- Sufficient grounding should be provided for the tank wagon or tank car, storage tank, pump, motor, etc., to prevent static electricity build-up and a potential explosion hazard.
- No smoking or open flame should be permitted in the area of the resin storage facility.
- The storage tank should be contained as required by regulations.
- Storage tanks should be equipped with overflow alarms.

B.13. Reference Material

Excellent information on storage may be obtained from the National Fire Protection Association (NFPA).

Specific references include:

- NFPA #30—Standards of the NFPA for Storage, Handling, and Use of Flammable Liquids, as recommended by the National Fire Protection Association.
- NFPA #70—National Electrical Code.
- NFPA #77—Static Electricity as adapted by the National Fire Protection Association.

Appendix C: Definitions and Trademarks

Overview

- **Definitions**
- **References**
- **Polynt Trademarks**

C.1. Definitions

— A —

ACCELERATOR—Additive that reduces gel and cure time of thermosetting plastics such as polyester gel coat and resin. Also called promoter or activator.

ACETONE—In the context of FRP, primarily useful as a cleaning solvent for removal of uncured resin from applicator equipment and clothing. Very flammable liquid.

ACI—Air Catalyst Integrator (ACI) valve, which is mounted on Binks spray guns. Functions as a point where catalyst and air are introduced, internally mixed, and atomized in preparation for external mixing with the resin or gel coat in a spray pattern.

ADHEREND—Any object or substance that is bonded to another with adhesive material.

ADHESIVE—Material that unites two surfaces.

ADHESIVE FAILURE—Failure in an adhesive joint that occurs between the adhesive material and the adherend; contrast with Cohesive Failure.

ADDITIVE—Substance added to resin mix to impart special performance qualities, such as ultraviolet absorbers, and flame retarding materials (waxes, accelerators, etc.).

AIR DRY—To cure at room temperature with addition of catalyst but without assistance of heat and pressure.

AIR-INHIBITED RESIN—Resin which cures with a tacky surface; air inhibits its surface cure.

ALLIGATORING—Wrinkling of gel coat film resembling alligator hide; caused by poor cure at time of contact with styrene from a subsequent or preceding coat.

ANTIMONY TRIOXIDE—Additive used to provide special flammability characteristics to a polyester.

ARCING—Spray method, which should normally be avoided since it consists of directing spray passes by gun rotation at the wrist (arcing), as opposed to conventional stroke from shoulder, keeping the fan pattern perpendicular to the mold.

AREAL WEIGHT—Weight of a fiber reinforcement per unit area (width times length) of tape or fabric.

ATOMS—Smallest possible unit of an element; may combine with another atom or atoms to form a compound.

AUTOCLAVE MOLDING—Molding technique in which an entire composite assembly is placed in an autoclave (or closed vessel with pressure/heat capability) at 50-100 psi pressure to consolidate the laminate by removing entrapped air and volatiles.

AUTO-IGNITION TEMPERATURE—Lowest temperature required to initiate or cause self-sustained combustion in the absence of a spark or a flame.

AUTOMATIC MOLD—Mold (for injection or compression molding) that cycles repeatedly through injection phase without human assistance.

— B —

BAG MOLDING—Technique in which composite material is placed in a rigid mold and covered with a flexible bag. Pressure is applied by vacuum, autoclave, press, or by inflating the bag.

BALANCED—Laminate design term used with aligned-fiber composites to indicate that each ply oriented at plus theta degrees is matched by a ply at minus theta degrees. When plus theta is 0°, minus theta is 90°. See related Symmetric. Laminate can be balanced and not be symmetric.

BARCOL HARDNESS—Degree of material's hardness obtained by measuring resistance to penetration by a sharp, steel point. This hardness corresponds roughly to the degree of cure in a gel coat or laminate.

BARCOL IMPRESSOR—Instrument invented by Walter Colman during World War II to measure hardness of soft metals; manufactured by Barber-Colman Company. Two types are commonly used in the FRP industry. Model 934 is used to check ultimate cure; Model 935 is used for initial readings prior to ultimate cure.

BATCH (OR LOT)—Identity for all material produced during one operation possessing identical characteristics throughout.

BENZOYL PEROXIDE (BPO)—Catalyst used in conjunction with aniline accelerators or where heat is used as an accelerator.

BI-DIRECTIONAL—Arrangement of reinforcing fiber strands in which half the strands are laid at right angles to the other half; a directional pattern that provides maximum product strength to those two directions.

BINDER—Bonding resin applied to glass fibers to hold them in position in a broad goods textile structure. During lamination, this resin is dissolved by the styrene in polyester resin, and, if unsaturated, can become part of the final polymer network.

BINDERLESS CHOPPED STRAND MAT—Textile material consisting of short glass fibers held together with polymer fiber cross-stitches; resembles chopped strand mat without the binder. Also called Stitched Chopped Strand Mat.

BLEEDER CLOTH—Layer of woven or non-woven material (not part of the composite) that allows excess gas and resin to escape during the molding process.

BLEEDING—Result of softening of backside of gel coat, typically by laminating resin or post applied gel coat, which causes pigments (color) to reflow.

BLEED OUT—Excess liquid resin appearing at the surface, primarily occurring during filament winding or from an RTM mold tube.

BOND STRENGTH—Stress required (as measured by load/bond area) to separate a layer of material from another material to which it is bonded. Also, amount of adhesion between bonded surfaces.

BRACE—Integral structural element used to stiffen or strengthen mold skin.

BREAKOUT—Separation or breakage of fibers when the edges of a composite part are drilled or cut.

BRIDGING—Condition that occurs when textile or sheet material does not conform to the inside edge or radius on a mold or laminate surface.

BUCKLING—Failure mode usually characterized by fiber deflection rather than breaking.

BULK MOLDING COMPOUND (BMC)—Pre-mixed blend of thermosetting resin, reinforcements, catalysts and fillers for use in closed molding process. Similar to sheet molding compound (SMC), but mechanical qualities are not as good and it is less expensive.

— C —

CARBON (OR GRAPHITE) FIBER—Reinforcing fiber known for its light weight, high strength, and high stiffness.

CARBOXYL—Chemical group characteristic of organic acids, which are incorporated into the polyester reaction process.

CAST POLYMER—Non-reinforced composite (resin used without reinforcing fibers). Combines polymers, fillers and additives as composites to meet specific applications' requirements.

CATALYST—In the scientific sense, a substance that promotes or controls curing of compound without being consumed in the reaction (initiator). Within the composites industry, free radical initiators such as MEKP are often referred to as 'catalysts.' Such usage is scientifically inaccurate since an initiator is consumed during usage.

CATALYST INJECTION—Used with spray equipment to catalyze polyester at the spray gun, therefore eliminating the need to clean the system within the gel time of polyester. Internal mix guns require a solvent flush for cleaning the gun head.

CATALYST (PEROXIDE)—In FRP terms, substance added to resin or gel coat in controlled quantities to make it gel and cure. Catalyst is reduced by accelerator, creating free radicals, which in turn initiate polymerization.

CAVITY—Space between matched molds (pressure molds) in which laminate is formed. Also a term for a female mold.

CENTIPOISE (CPS)—Unit of measure used to designate a fluid's viscosity. At 70°F, water is 1 cps; peanut butter is 250,000 cps.

CHALKING—Dry, powder-like appearance or deposit on exposed gel coat surface.

CHARGE PATTERN—Ply schedule used in parts made from sheet molding (SMC); pre-weighed number of SMC plies cut from SMC sheet and oriented to fill a mold cavity when placed in a mold and compressed.

CHOPPED STRAND—Uniform lengths of fibers formed by cutting continuous strand yarn or roving, usually from 1/32"-2" long. Lengths up to ⅛" are called milled fibers.

CHOPPED STRAND MAT (CSM)—Uniform lengths of fibers held together by binder and added to increase composite part glass skin thickness. Relatively inexpensive, generally used with other glass mats.

CLOSED MOLDING—Fabrication process in which a composite part is produced in a mold cavity formed by the joining of two or more tool pieces.

CLOTH—Fine weave of woven fiberglass.

COBALT—Used as accelerator for methyl ethyl ketone peroxide catalyzed polyesters.

COEFFICIENT OF THERMAL EXPANSION (CTE)—Material's fractional change in dimension for a given unit change of temperature.

COHESION—Tendency of a single substance to adhere to itself. Also, force holding a single substance together.

COHESIVE FAILURE—Failure of an adhesive joint that occurs either within the adhesive material or within one or both adherents.

COMPOSITE—Material that combines fiber and binding matrix to maximize specific performance properties. Neither element merges completely with the other.

COMPRESSION MOLD—Mold that is open when material is introduced and that shapes material by heat and by the pressure of closing.

COMPRESSION MOLDING—See Chapter 10—Compression Molding.

COMPRESSIVE STRENGTH—Resistance to crushing or buckling force; the maximum compressive load a specimen sustains divided by its original cross-sectional area.

CONDENSATION POLYMERIZATION—Polymerization reaction in which simple by-products (e.g., water) are formed.

CONSOLIDATION—Processing step that compresses fiber and matrix to remove excess resin, reduce voids and achieve a particular density.

CONTACT MOLDING—Open-mold process that includes spraying gel coat, followed by hand layup or sprayup with glass and resin. Also called open molding.

CONTAMINANT—Impurity or foreign substance that affects one or more properties of a composite material.

CONTINUOUS FILAMENT MAT (CFM)— Textile material made of continuous fibers, typically glass, that are swirled randomly in a construction with more loft than chopped strand mat for the same areal weight.

CONTINUOUS FILAMENT STRAND—Individual fiber with small diameter, flexibility and indefinite length.

CONTINUOUS LAMINATING—Process for forming panels and sheeting in which fabric or mat is passed through resin dip, brought together between cellophane covering sheets, and passed through a heating zone for cure. Squeeze rollers control the thickness and resin content as various plies are brought together.

CONTINUOUS ROVING—Parallel filaments coated with sizing, gathered together into single or multiple strands and wound into a cylindrical package. May be used to provide continuous reinforcement in woven roving, filament winding, pultrusion, pre-pregs, or high-strength molding compounds. Also see Chopped Strand.

COPOLYMER—Large chemical chain composed of two or more dissimilar groups.

CORD, REINFORCING—Loosely twisted cord made up from rovings and designed for incorporation in moldings where edge reinforcement and high strength ribs are necessary.

CORE—(1) Central component of a sandwich construction to which inner and outer skins are attached; common core materials include foam, honeycomb, paper and wood. (2) Channel in mold for circulation of heat-transfer media. (3) Part of a complex mold tool that molds undercut parts, also called core pin.

CORE CRUSH—Compression damage to core.

CORE ORIENTATION—On honeycomb core, used to line up ribbon direction, thickness of cell depth, cell size, and transverse direction.

CORNER—Geometric feature characterized as a point where three edges come together, as in a box corner. Can be either an inside or outside corner.

COSMETIC STABILITY—Capability of substance or part to maintain appearance with respect to surface smoothness, color, gloss or other visual appearance characteristics.

CRAZING—Cracking of the resin due to internal stress.

CREEL—Device used to hold the required number of roving spools or other supply packages of reinforcement in a desired position for unwinding.

CREEP—Over time, dimensional change in material under physical load (beyond initial elastic deformation).

CROSS-LAMINATED—Laminated so some layers are oriented at right angles to the remaining layers with respect to grain or strongest direction in tension.

CROSS-LINKING—Process of bridging two polymer chains, which converts liquid to a thermoset solid.

CRYSTALLINITY—Quality of the molecular structure in which atoms are arranged in orderly, three-dimensional pattern.

CURE—Polymerization or irreversible transformation from a liquid to solid state with the maximum physical properties, including hardness.

CURE TEMPERATURE—Temperature at which material attains final cure.

CURE TIME—Time required for liquid resin to reach a majority of the polymerized state after catalyst has been added.

CURING AGENT—Catalytic or reactive agent that initiates polymerization when added to resin; also called Hardener.

— D —

DAMAGE TOLERANCE—Measure of ability of structures to retain load-carrying ability after experiencing damage (e.g., ballistic impact).

DELAMINATE—Separation of layers due to failure of adhesion or cohesion of one component to others. Also includes separation of layers of fabric from core structure. May be associated with bridging, drilling, and trimming.

DELAMINATION—Laminate defect that occurs due to mechanical or thermal stress and is characterized by separation between laminae.

DEMOLD—To remove a part from a tool, or a tool from an intermediate model.

DENSITY—Weight per unit of volume, usually expressed as pounds per cubic foot.

DESIGN ALLOWABLE—Limiting value for material property that can be used to design a structural or mechanical system to a specified level of success with 95 percent statistical confidence.

DIALLYL PHTHALATE (DAP)—In reinforced plastics, high-boiling monomer which will polymerize with heat and catalyst into clear, hard polymer.

DIBUTYL PHTHALATE—Lubricant for spray equipment.

DIELECTRIC—Nonconductor of electricity; ability of material to resist flow of an electrical current.

DIELECTRIC STRENGTH—Voltage required to cause an electrical arc to penetrate insulating material.

DIETHYLANILINE (DEA)—Accelerator used in conjunction with BPO catalyst, or as co-promoter for cobalt/MEKP systems.

DILUENT—Diluting (reducing or thinning) agent.

DIMENSIONAL STABILITY—Capability of substance or part to maintain its shape when subjected to varying forces, moments, degrees of temperature and moisture, or other stress.

DIMETHYLANILINE (DMA)—Accelerator used in conjunction with BPO catalyst; more effective than DEA.

DIMPLES—Small sunken dots in gel coat surface, generally caused by foreign particles, air voids, or catalyst droplets in gel coat or laminate.

DISPERSION—Homogeneous mixture of suspended solid particles in liquid medium.

DISTORTION—Wavy gel coat surface reflection often found in conjunction with print-through. Commonly caused by problem in laminating system.

DOUBLER—Extra layers of reinforcement for added stiffness or strength where fasteners or other abrupt load transfers occur.

DRAFT ANGLE—Mold or mandrel's taper or angle for ease of part removal (minimum of 3° is recommended).

DRAPE—Ability of fabric (or pre-preg) to conform to shape of contoured surface

DRAIN OUT—Leaking, sagging and puddling of laminating resin from reinforcement.

DRY SPOT—Laminate defect that occurs during molding process and is characterized by dry, unwet fibers that have never been encapsulated by matrix material.

DUPLICATION MOLD—A mold made by casting over or duplicating another article.

— E —

EDGE—Geometric feature characterized as a line formed where two panels on different planes come together. When the angle between the two panels is between 0°-180°, the edge is inside. When angle is between 180°-360°, the edge is outside.

E-GLASS—Electrical glass; refers to borosilicate glass fibers most often used in conventional polymer matrix composites.

ELASTICITY—Capacity of materials to recover their original size and shape after deformation.

ELASTIC LIMIT—Greatest stress a material is capable of sustaining without permanent strain remaining after complete release of stress.

ELASTOMER—Material that substantially recovers original shape and size at room temperature after removal of deforming force.

ELONGATION—Increase in length of section under tension when expressed as percentage difference between original length and length at moment of rupture.

ENAMEL—Gel coat or surface coat which cures tack free.

ENCAPSULATING—Enclosing article (in closed envelope of plastics) by immersion. Milled fibers or short chopped strands are often poured with catalyzed resin into open molds for casting electrical components.

END—Strand of roving consisting of a given number of filaments is considered an end before twisting.

END COUNT—Exact number of strands contained in roving.

EXOTHERMIC HEAT—Internally developed heat accompanying a chemical reaction (e.g., curing).

EXTENDERS—Low-cost materials used to dilute or extend higher-cost resins without excessive reduction in properties.

— F —

FABRIC, NON-WOVEN—Material formed from fibers or yarns without interlacing (e.g., stitched nonwoven broad goods).

FABRIC, WOVEN—Material constructed of interlaced yarns, fibers, or filaments.

FABRICATION—Process of making composite part or tool.

FATIGUE—Failure of material's mechanical properties caused by repeated stress over time.

FATIGUE STRENGTH—Maximum cyclical stress withstood for given number of cycles before material fails.

FADING—Loss of color in gel coat.

FEEDEYE—Mechanism on filament winding machine through which roving is dispensed onto mandrel.

FELT—Fibrous material made up of interlocking fibers by mechanical or chemical action, pressure or heat. Felts may be made of cotton, glass or other fibers.

FEMALE—Term used to describe the concave surface or inside edge or feature.

FIBER—Individual rod of sufficiently small diameter to be flexible, having a known or approximate limit of length.

FIBER ARCHITECTURE—Arrangement of fibers and fiber bundles in textile construction.

FIBER BLOOMING—Fiber and resin are eroded by weathering or sandpaper at different rates. Resins erode before fiber. As a result, fiber rich surface, when sanded, often has fibers protruding, known as fiber blooming.

FIBER CONTENT—Amount of fiber in composite expressed as ratio to the matrix by weight.

FIBER ORIENTATION—Direction of fiber alignment in non-woven or mat laminate. Most fibers are placed in the same direction to afford higher strength in that direction.

FIBER PRINT—Cosmetic defect, visible on exterior gel coat surface that resembles fiber bundle and reflects architecture of glass reinforcement bundle at or near part surface.

FIBER REINFORCED PLASTICS (FRP)—General term for composite material or part that consists of a plastic matrix containing reinforcing fibers such as glass or carbon, with greater strength or stiffness than plastic. FRP is most often used to denote glass fiber-reinforced plastics. 'Advanced composite' usually indicates high-performance aramid or carbon fiber-reinforced plastics.

FIBERGLASS—Fibers similar to wool or cotton fibers, but made from glass; sometimes call fibrous glass. Glass fiber forms include cloth, yarn, mat, milled fibers, chopped strands, roving, and woven roving.

FILAMENT—Single, thread-like fiber or number of these fibers drawn together. Variety of fiber characterized by extreme length, which permits its use in yarn with little or no twist and usually without a spinning operation required for fibers.

FILAMENT WINDING—Process for production of high-strength, light-weight products in which tape, roving or single strands are fed from a creel through a bath of resin (or fed dry using pre-impregnated roving) and wound on a suitably designed mandrel. Wound mandrel can be cured at room temperature or in oven.

FILLERS—Relatively inert organic or inorganic materials which are added to resins or gel coats for special flow characteristics, to extend volume, and to lower the cost of the article being produced.

FINISH—Surface treatment applied to fibers or filaments after they are fabricated into strands, yarn or woven fabrics to allow resins to flow freely around and adhere to them.

FIRE POINT—Lowest temperature at which liquid in an open container will give off enough vapors to continue to burn once ignited. Fire point generally is only slightly higher than flash point.

FISH EYES—Circular separation in gel coat film generally caused by contamination, such as silicone, oil, dust, water, freshly waxed mold, or low gel coat viscosity.

FLASH POINT—Lowest temperature at which a substance emits enough vapors to form a flammable or ignitable mixture with air near the surface of the substance being tested.

FLEXURAL MODULUS—Ratio, within the elastic limit, of applied stress in a test sample in flexure to corresponding strain in the outermost fibers of sample.

FLEXURAL STRENGTH—Strength of material (in bending) expressed as the stress of a bent test sample at the instant of failure; usually expressed in force per unit area.

FLOODING—High delivery rate from spray gun; in pigmented systems, difference in color between surface and bulk of film.

FLOW METER—Instrument designed to measure flow of liquid.

FRACTURE—Rupture of surface of laminate due to external or internal forces; may or may not result in complete separation.

FRAMING—Structure that supports mold skin and its bracing.

FREE RADICALS—Highly reactive molecular fragments capable of initiating chemical reactions, such as polymerization of polyester resins.

FRIABLE—Term used to describe material that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure.

FRP—Fiber Reinforced Polymers; with evolution of new fibrous materials, GRP (or GRFP) becomes Glass Reinforced Polymers term.

FUMED SILICA (Aerosil®, CAB-O-SIL®)—Thickening agent used in polyesters to increase flow or sag resistance qualities.

— G —

GEL—Partial cure stage in plastics resins of a viscous, jelly-like state where liquid material starts to transform into solid.

GEL COAT—Surface coat, either colored or clear, providing cosmetic enhancement and protection for the laminate.

GEL TIME—Length of time that catalyzed polyester remains workable after hardener is added.

GELATION—Transition of a liquid to soft solid.

GENERATION—Term used to describe a single step in progression from concept to master mold to production mold when molding composite parts with multiple molds from the same pattern.

GLASS TRANSITION—Reversible change in amorphous polymer between the viscous or rubbery condition and the hard, relatively brittle one.

GLASS TRANSITION TEMPERATURE (Tg)—Approximate temperature above which increased molecular mobility causes a material to become rubbery rather than brittle. The measure value of Tg can vary, depending on the test method. A widely accepted method is Differential Scanning Calorimeter (DSC).

— H —

HAND LAYUP—Laminating by ‘hand’ as opposed to using spray equipment. Usually requires mat and fabric reinforcements in sheet form.

HAP—Acronym for Hazardous Air Pollutants. Over 180 chemicals identified by Congress in the 1990 Clean Air Act, Section 112. In this law, Congress mandated that the EPA control emissions of these chemicals. The EPA has endeavored to do this through a series of MACT standards (see **MACT**).).

HARDENER—Substance that reacts with resin to promote or control curing action.

HEAT—Term used colloquially to indicate any temperature above ambient (room) temperature, to which a part or material is or will be subjected.

HEAT-CONVERTIBLE RESIN—Thermosetting resin convertible by heat to an infusible and insoluble mass.

HEAT DISTORTION TEMPERATURE (HDT)—Temperature at which the test bar deflects a certain amount under a specified load (e.g., temperature at which the material softens).

HEAT-PRESSURE LAMINATES—Laminates molded and cured at pressures not lower than 1000 psi.

HELICAL—Ply laid onto mandrel at an angle, often a 45° angle.

HERMETIC—Completely sealed, air-tight.

HONEYCOMB—Manufactured product of sheet metal or resin-impregnated sheet (paper, fibrous glass, etc.) that has been formed into hexagonal shaped cells. Used as core material for sandwich construction.

HOOP—Ply laid onto mandrel at 90° angle.

HOOP STRESS—Circumferential stress in cylindrically shaped part as a result of internal or external pressure.

HOT POT—Catalyst is mixed with gel coat or resin in a material container prior to spraying, as opposed to internal or external gun mixing.

HYBRID COMPOSITE—Composite with two or more types of reinforcing fibers. Also refers to a composite prepared from a polymer which uses more than one type of chemistry, such as XYCON® polyester/polyurethane hybrid material.

HYBRID RESIN—Resin with two or more types of chemistries combined.

HYDROPHOBIC—Moisture resistant capability, moisture repelling.

HYGROSCOPIC—Moisture absorbing capability.

— I —

IMPREGNATE—Saturation of reinforcement with a resin.

IMPREGNATED FABRIC—See Pre-preg.

INCLUSION—Physical and mechanical discontinuity occurring within a material or part.

INHIBITOR—A substance designed to slow down or prevent a chemical reaction; a chemical additive that slows or delays the cure cycle.

INITIATOR—Substance added to resins and gel coats to make them gel or cure. Also see Catalyst.

INJECTION MOLDING—Method of forming plastic to a desired shape by forcibly injecting polymer into a mold.

INTEGRAL HEATING—System in which heating elements are built into a tool, forming part of the tool and usually eliminating the need for an oven or autoclave as the heat source.

INTERFACE—Surface between two materials in glass fibers (e.g., the area at which glass and sizing meet). In laminate, the area at which reinforcement and laminating resin meet.

INTERLAMINAR—Existing or occurring between two or more adjacent laminae.

INTERLAMINAR SHEAR—Shearing force that produces displacement between two laminae along the plane of their interface.

IN SITU—In original position. In filament winding, used to indicate mandrel that remains in place after winding, as opposed to mandrel that is removed after winding.

ISOTROPIC—Arrangement of reinforcing materials in a random manner, resulting in equal strength in all directions.

— J —

JACKSTRAWING—Prominence of fiberglass pattern having turned white in the laminate because glass has separated from resin due to excessive exothermic heat; usually associated with thick, resin rich laminates. Cosmetic problem only.

— K —

KEVLAR™—Strong, lightweight aramid fiber trademarked by Dupont; used as reinforcement fiber.

— L —

LAMINA—One layer of laminate; can be a chopped fiber reinforced plastic layer, textile reinforced plastic layer, or core material, etc. Plural is laminae.

LAMINATE (noun)—Panel that consists of multiple laminae that are permanently bonded together.

LAMINATE (verb)—Action of manufacturing laminate (noun) by arranging one or more laminae. In FRP, each lamina usually consists of a fibrous reinforcement and a resinous matrix material.

LAMINATED PLASTICS—Material consisting of superimposed layers of synthetic materials that have been bonded together, usually by means of heat and pressure, to form a single piece.

LAMINATION—Laying on of layers of reinforcing materials and resin, much like the buildup of plywood. Several layers of material bonded together.

LAY-UP—Placing reinforcing material onto a mold and applying resin to it; can be done by hand or by using spray-up equipment. Lay-up is sometimes used as a term for the work piece itself.

LOW-PRESSURE LAMINATES—Laminates molded and cured in a range of pressures from 400 psi down to, and including, pressure obtained by the mere contact of plies.

LOW PROFILE—Resin compounds formulated for low, zero, or negative shrinkage during molding.

— M —

MACROSCOPIC—Large enough to be visible at magnification of 60x or less.

MACT—Acronym for Maximum Achievable Control Technology. Standards established by the EPA in response to the 1990 Clean Air Act, Section 112. These standards set forth regulations for reduced emissions of Hazardous Air Pollutants. See HAP.

MALE—Term used to describe the convex surface or outside edge or feature.

MANDREL—Elongated mold around which resin-impregnated fiber, tape or filaments are wound to form structural shapes or tubes.

MASS—Quantity of matter contained in a specific body. In reference to polyesters, mass is measured in terms of weight and/or volume.

MASTER MODEL—General term for a full-scale representation of the part design. Incorporates all geometry for one of the part surfaces. See also Pattern and Plug.

MASTER MOLD—General term for durable, robust full-scale representation of part design. Used to produce multiple copies of production mold.

MAT—Fibrous reinforcing material composed of chopped filaments (for chopped strand mat) or swirled filaments (for continuous strand mat) with binder applied to maintain form; available in blankets of various widths, weights, thicknesses and lengths.

MATCHED-METAL MOLDING / MATCHED-DIE MOLDING—Method of closed molding in which reinforced plastics are molded between two close-fitting metal molds mounted in a hydraulic press. Generally considered the most economical mass production method for manufacturing FRP parts in large volumes.

MATRIX—Material in which fiber reinforcements of composite system is imbedded. Thermoplastic and thermoset resin systems can be used, as well as metal and ceramic.

MEK PEROXIDE (MEKP)—Abbreviation for methyl ethyl ketone peroxide; free radical source commonly used as an initiator for polyesters in the FRP industry.

MEK (SOLVENT)—Abbreviation for methyl ethyl ketone; colorless flammable liquid commonly used in spray gun clean up procedures.

MICRO CRACKING—Cracks formed in composites when thermal stresses locally exceed strength of matrix.

MICROSCOPIC—Small enough to require magnification much greater than 10x to be visible.

MIL—Unit used in measuring film thickness and diameter of fiber strands, glass, wire, etc., (one mil = 0.001 inch).

MILLED FIBERS—Carbon or glass used for making fiber-filled putty or BMC strands hammer-milled into short fiber lengths of 1/32", 1/16", ⅛" and ¼".

MODULUS OF ELASTICITY—Material property that describes the relationship between tension, compression or shear forces, and deflection experienced by a material. Known as Young's Modulus for isotropic materials in tension. Modulus is independent of specimen geometry; therefore, it is a material property.

MOISTURE ABSORPTION—Pick-up of water vapor from air by a material. Relates only to vapor withdrawn from air by a material; must be distinguished from water absorption, which is a gain in weight due to take-up of water by immersion.

MOLD—(1) To shape plastics parts by heat and pressure. (2) Cavity or matrix into/onto which plastics composition is placed and from which it takes its form. Female: Made into. Male: Made onto. (3) Assembly of all parts that function collectively in molding process.

MOLD CLAMPING METHOD—RTM process feature that describes how mold pieces are held together.

MOLD COAT—Coat of resin over bare mold. Used to seal mold and make a smooth surface on which to mold parts. Essentially the same as a gel coat.

MOLD OPEN-CLOSE METHOD—RTM process feature for separating mold pieces to allow the insertion of dry glass and removal of a finished part.

MOLD RELEASE—A substance used on the mold or in the compound to prevent sticking and for ease of part release.

MOLD SKIN— Element of cure tool with a hard surface that is polished to a high gloss. This surface forms one external face of a production part during the molding process.

MOLDING—Forming of a part by various means, such as contact, pressure, matched die and continuous laminating, into given shape.

MOLECULES—Chemical units composed of one or more atoms.

MONOFILAMENT—Single filament of indefinite length; generally produced by extrusion.

MONOMER—A relatively simple compound capable of polymerization with itself or with a compatible resin. It may also is be used to dissolve or dilute polyester.

— N —

NANOMETER— Abbreviated nm; equal to one millimicron or one billionth of meter; used to measure wavelengths of light.

NET SHAPE—Part fabrication resulting in final dimensions that do not require machining or cutting.

NON-DESTRUCTIVE INSPECTION (NDI)—Determining material or part characteristics without permanently altering a test subject. Nondestructive testing (NDT) and nondestructive evaluation (NDE) are widely considered synonymous with NDI.

NPG®—Registered trademark of Eastman Chemical Company for neopentyl glycol.

NON-AIR INHIBITED RESIN—Resin, whose cure not be inhibited or stopped by the presence of air, possibly due to a surfacing agent added to exclude air from the resin surface.

NON-VOLATILE MATERIAL—Material remaining after heating to a condition short of decomposition.

— O —

ONE-OFF—Fabrication process in which a single part is fabricated.

ORANGE PEEL— Backside of a gel coated surface that takes on a rough wavy texture of an orange peel.

ORIFICE—Opening, generally referred to regarding spray tip size.

ORIGINAL EQUIPMENT MANUFACTURER (OEM)—Companies that design and build products bearing their name.

OUT-GASSING—Release of solvents, volatiles, gasses and moisture from composite parts under vacuum.

— P —

PAN (POLYACRYLONITRILE)—Base material used in the manufacture of some carbon fibers.

PARALLEL-LAMINATED—Laminated so all layers of material are oriented approximately parallel with respect to the grain or strongest direction in tension. Also called unidirectional. This pattern allows the highest loading of reinforcement, but gives maximum strength in only one direction.

PART CONSOLIDATION—Process of composites fabrication in which multiple discrete parts are designed and fabricated together into a single part, thus reducing the number of fabricated parts and need to join those parts together.

PARTING AGENT—See Mold Release.

PATTERN—General term for the master model that is usually constructed from a single material or material type. Pattern is generally not durable and is suitable for producing only one (or small number) mold. Sometimes used interchangeably with Plug.

PEEL PLY—Layer of material applied to a layup surface that is removed from the cured laminate prior to bonding operations, in order to leave a clean, resin-rich surface ready for bonding.

PEEL STRENGTH—Strength of adhesive bond obtained by stress that is applied ‘in a peeling mode.’

PEROXIDES—Category of compounds containing unstable O-O (or O-OH) Group: Oxygen to Oxygen atoms; used as initiators.

PHENOLIC RESIN—Thermosetting resin produced by condensation of aromatic alcohol with aldehyde, particularly phenol with formaldehyde.

PIGMENT—Ingredient used to impart color, as in gel coats.

PIGMENT SEPARATION—Mottled (varied color) appearance of gel coat surface.

PINHOLES—Small air bubbles in the gel coat film, few enough to count. Generally larger in size than porosity.

PLASTICS—High molecular weight thermoplastics or thermosetting polymers that can be molded, cast, extruded or laminated into objects; the major advantage of plastics is that they can deform significantly without rupturing.

PLUG—General term for a master model that is usually hand-crafted from variety of materials. Plug is generally not durable; suitable for producing only one (or small number) molds. Sometimes used interchangeably with Pattern.

PLY—Fabric/resin or fiber resin/layer bonded to adjacent layers in composite.

PLY SCHEDULE—Layup of individual plies or layers to build laminate (FRP). Plies may be arranged (scheduled) in alternating fiber orientation to produce multi-directional strength part. See Fiber Architecture.

POLYESTER (Unsaturated)—Resin formed by the reaction between dibasic acids and dihydroxy alcohols, one of which must be unsaturated (typically maleic anhydride) to permit cross-linking.

POLYMER—Large chemical chain composed of many repeating groups such as polystyrene.

POLYMERIZATION—Chemical reaction of linking molecules or chains of molecules.

POLYVINYL ALCOHOL (PVA)—Water soluble release agent.

POROSITY—Small air bubbles in a composite or gel coat film; too numerous to count. Generally smaller in size than pinholes.

POSTCURE—Exposure of cured resin to higher temperatures than during molding; necessary in certain resins to attain complete cure and ultimate mechanical properties.

POT LIFE—See Gel Time.

POTTING—Similar to encapsulating, except steps are taken to ensure complete penetration of all voids in the object before the resin polymerizes.

PREFORM—Pre-shaped fibrous reinforcement formed by distribution of chopped fibers by air, water flotation, or vacuum over the surface of a perforated screen to approximate the contour and thickness desired in a finished part. Also, a compact pill of compressed premixed materials.

PREFORM MAT—Fiber reinforced mat shaped like the mold in which it will be used. Eliminates the need for overlapping corners in molding.

PREHEATING—Heating of a compound prior to molding or casting in order to facilitate operation, reduce the molding cycle, or remove volatiles.

PREMIX—Mixture of resin, pigment, filler and catalyst for molding.

PRE-PREG—Resin-impregnated cloth, mat or filaments in flat form that can be stored for later use. Resin is often partially cured to a tack-free state called 'B-staging.' Additives can be added to obtain specific end-use properties and improve processing, storage and handling characteristics.

PRE-RELEASE—Premature release of the gel coat or laminate from the mold.

PRESSURE BAG—Tailored bag (usually rubber sheeting) placed against an open mold in a hand layup process. Air or steam pressure (up to 50 psi) is applied between the bag and pressure plate located over mold.

PRIMARY LAMINATE—'Bulk' or 'second' laminate; laminate is applied after the skin coat has cured. Generally thicker than skin coat.

PRINT-THROUGH—Transfer through the gel coat film of an image of the glass strands.

PRODUCTION MOLD—Durable, robust mold used to produce hundreds or thousands of part copies. Laminated production molds are best manufactured from laminated master molds.

PROFILE—Surface contour of a part viewed from an edge or cross section. When describing cosmetic features, profile is the roughness of the surface on a scale large enough to affect visual appearance but small enough to be insignificant with respect to dimensional functionality. Low profile corresponds to a very smooth surface; high profile corresponds to a surface with greater roughness.

PROMOTER—See Accelerator.

PROTOTYPE—Process of creating a test part not intended for commercial release that establishes design, material and fabrication parameters for new product. May require multiple iterations (repetitions) to arrive at a final/commercial part design.

PULTRUSION—Automated continuous process for manufacturing composite rods, tubes and structural shapes having a constant cross-section. Roving and other reinforcements saturated with resin and continuously pulled through a heated die, where the part is formed and cured. The cured part is then automatically cut to length.

— R —

RAMPING—Gradual programmed increase/decrease in temperature or pressure to the control cure or cooling of composite parts.

REINFORCED MOLDING COMPOUND—Reinforced compound in the form of ready-to-use materials, as distinguished from premix, as BMC or Gunk.

REINFORCEMENT—Strong, relatively inert material molded into plastics to improve strength, stiffness and impact resistance. Usually fibers of glass, carbon, boron mineral, synthetic polymer, ceramic, textile, sisal, cotton, etc., in woven or non-woven form.

RELEASE AGENT—See Mold Release.

RELEASE FILM—Impermeable film layer that does not bond to composite during cure.

RESIN—Any of class of natural or synthetic polymers, solubilized or semi-solid, generally of high molecular weight having no definite melting point. Used in reinforced products to surround and hold fibers. Most resins are polymers.

RESIN INFUSION—To draw or force resin into a dry reinforcement already in the mold cavity.

RESIN PRESSURE HEAD—RTM process feature; state of pressure across a part from injection point to vent point; driving force that causes resin to flow through and saturate fiber pack.

RESIN RICH—Localized area filled with excess resin when compared to consistent resin/fiber ratio.

RESIN STARVED—Localized area lacking sufficient resin for fiber wetout.

RESIN TEARING—Separation of vehicle from pigments/ fillers in gel coat film, usually seen as black wavy lines.

RESIN TRANSFER MOLDING (RTM)—Molding process in which catalyzed resin is pumped into a two-sided, matched mold where fibrous reinforcement has been placed. Mold and/or resin may or may not be heated.

RESIN TRANSFER SCHEME—RTM process feature that describes the pathway used to transfer resins into a fiber pack.

RIBBON DIRECTION—On honeycomb core, the direction in which honeycomb can be separated; direction of one continuous ribbon.

ROVING—Collection of bundles of continuous filaments either as untwisted strands or as twisted yarns. For filament winding, generally wound as bands or tapes with as little twist as possible.

RUBBER PLUNGER MOLDING—Variation of matched-die molding process which uses a heated metal female mold (or outer half) and rubber plunger male mold. Applicable for relatively small molds with modest undercuts where low pressures are involved.

— S —

S-GLASS—Magnesia/alumina/silicate glass reinforcement designed to provide very high tensile strength. Commonly used in high-performance parts.

SAGS/RUNS—Sag: Slumping of gel coat or resin film. Run: Running of gel coat film or laminating resin.

SANDWICH LAY-UP— Laminate composed of two outside layers of reinforced material, such as glass mat, and an inside layer or layers of honeycomb, glass cloth, or other light-weight core material.

SCRIMP— Seemann Composite Resin Infusion Molding Process. Pulls the vacuum before resin entry. See Resin Infusion.

SEALANT—Applied to a joint in paste or liquid form that hardens in place to form a seal.

SECONDARY BONDING—Joining together by adhesive bonding of two or more previously cured parts or subsequent lamination onto an earlier cured laminate surface.

SET—To convert a resin into a fixed or hardened state by chemical or physical action, such as condensation, polymerization, vulcanization or gelation.

SHEAR—Stress resulting from applied forces. Caused by two contiguous parts of a body sliding, relative to each other, in a direction parallel to their plane of contact. In cross shear, the plane of contact is composed of resin and glass fibers. In interlaminar shear (ILS), the plane of contact is composed of resin only. In liquids, the force and movement of components or layers against each other.

SHEET MOLDING COMPOUND (SMC)—Ready-to-mold, glass-fiber-reinforced, thickened polyester material primarily used in closed molding. Similar to bulk molding compound (BMC), but with improved mechanical properties.

SHELF LIFE—Length of time uncatalyzed polyester remains workable while stored in a tightly sealed container; also referenced as Storage Life.

SHOT—One complete cycle on an injection molding machine. Shot weight is a measured compound delivered to completely fill the mold in injection or transfer molding.

SISAL—White fiber produced from the leaves of the agave plant. Used as reinforcing filler, in short chopped lengths, to impart moderate impact resistance.

SIZING—Water-soluble solution of chemical additives used to coat filaments; additives protect the filaments from water absorption and abrasion. They also lubricate the filaments and reduce static electricity. See chapters on Open Molding.

SKIN LAMINATE—Thin, glass laminate applied directly against gel coat to provide durability by eliminating entrapped air and good cosmetic quality by isolating gel coat from subsequent laminate shrinkage due to exotherm heat.

SLAVE PUMP—Small, specifically sized pump driven by the master gel coat or resin pump to deliver catalyst in a ratio of 1-3%.

SOLVENT—Liquid used to dissolve and clean materials.

SPEC—Specification of properties, characteristics or requirements a particular material or part must have to be acceptable to a potential user of the material or part.

SPECIFIC GRAVITY— Ratio of the weight of any volume of a substance to the weight of an equal volume of some substance taken as a standard unit; usually water for solids and liquids, and air or hydrogen for gasses.

SPRAY-UP—Process in which glass fibers, resin and catalyst are simultaneously deposited onto a mold. Roving is fed through a chopper and ejected into the resin stream directed at the mold. Catalyst and accelerated resin may be sprayed from one or two guns. Glass resin mix is then rolled by hand before curing.

STABILIZER—Additive for polymers which aids maintenance of certain properties.

STIFFNESS—Structural property that describes the relationship between the forces and moments applied to, and stretching and bending deflections experienced by any item.

STRAIN—Deformation resulting from stress.

STRANDS—Primary bundle of continuous filaments combined into single compact unit without twist.

STRESS—Internal resistance to change in size or shape, expressed in force per unit area.

STRESS CORROSION—Preferential attack of areas under stress in a corrosive environment, where such an environment alone would not have caused corrosion.

STRESS CRACK—External or internal cracks in a composite caused by tensile stresses; cracking may be present internally, externally or in combination.

STYRENE MONOMER—Unsaturated aromatic hydrocarbon, used in plastics. In polyester, a reactive diluent.

SUBSTRATE—Material on which an adhesive-containing substance is spread for any purpose (e.g., bonding or coating).

SURFACE PROFILE—Cosmetic quality of a surface. See Profile.

SURFACING AGENT—Material (commonly paraffin wax) that allows the surface of polyesters to cure; limits adhesion of another coat of resin if first is thoroughly cured. May be removed by sanding or rubbing with steel wool.

SURFACING VEIL—Used with other reinforcing mats and fabrics to enhance the quality of a surface finish. Designed to block out fiber patterns of underlying reinforcements; also called Surfacing mat.

SYMMETRIC—Laminate design term used with composites to indicate that laminate is symmetric about the plane, midway through its thickness.

— T —

TACK—Stickiness.

TBPB—Abbreviation for tertiary-butyl perbenzoate; used as a catalyst (initiator) in high temperature molding of polyester resin systems.

TBPO—Abbreviation for tertiary-butyl peroctoate used as a catalyst in high speed, heated cures of polyester resin systems.

TENSILE STRENGTH—Maximum stress sustained by a composite specimen before it fails the tension test.

TEXTILE—Any type of sheet material made from fibers that are woven, knitted, knotted, stitched or bonded together.

THERMAL CONDUCTIVITY—Ability to transfer heat.

THERMAL SHOCK—Rapid temperature changes causing large thermal stresses.

THERMAL STRESS—Occurs when a change in temperature causes materials to expand and contract at different rates. Can form within and between layers of laminate, as well as between laminate and the steel frame.

THERMAL STRESS CRACKING—Crazing or cracking of some thermoset or thermoplastic resins from overexposure to elevated temperatures or cyclic temperature variations.

THERMOCOUPLE—Assembly used to sense and record temperature.

THERMOPLASTICS—Polymers that can be repeatedly softened when heated and hardened when cooled. Thermoplastics, such as polymers and co-polymers of acrylics, PET, polycarbonates, nylons, fluorocarbons and styrene, are fast becoming important engineering materials.

THERMOSETS—Materials that will undergo or have undergone chemical reaction, leading to relatively infusible state. Typical materials are aminos (melamine and urea), unsaturated polyesters, alkyds, epoxies and phenolics; not reformable.

THIXOTROPIC—Condition in which a material possesses resistance to flow until it is agitated (mixed, pumped, or sprayed).

THIXOTROPIC INDEX (TI)—Indication of sag resistance determined by dividing the low shear viscosity by the high shear viscosity.

TOOL—Mold, either one- or two-sided, and either open or closed, in or upon which composite material is placed to make a part. See also Mold.

TOOLING GEL COAT RESIN—Special polyesters designed for mold making.

TOUGHNESS—Measure of the ability of a material to absorb energy.

— U —

UNDERCUT—Negative or reverse draft on the mold. Split molds are necessary to shape pieces that are undercut.

UNIDIRECTIONAL—Refers to fibers oriented in the same direction, such as unidirectional fabric, tape or laminate; often called UD.

UPPER MOLD TYPE—RTM process feature that describes materials and construction used for mating the mold.

— V —

VACUUM BAG MOLDING—Molding process for minimizing emissions voids and maximizing reinforcement content, forcing out entrapped air and excess resin from layups, by drawing vacuum into flexible film draped over part. Also considered Resin Infusion. Vacuum may be drawn after resin entry.

VACUUM-ASSISTED RESIN TRANSFER MOLDING (VARTM)—Infusion process where a vacuum draws resin into one-sided mold; a cover, either rigid or flexible, is placed over the top to form a vacuum-tight seal.

VAPOR BARRIER—Material through which water vapor will not pass readily or at all.

VEIL—Tissue of fibers which drapes and wets easily; of particular value to provide a resin-rich barrier to corrosion or glass print, as in surfacing veil.

VISCOSITY—Fluid's resistance to flow.

VOIDS— Laminate defect that occurs during the molding process; characterized by a lack of resin material (entrapped air, un-wetted fibers).

VOLATILE MATERIAL—Material vaporizing under specific conditions short of decomposition; non-volatile material remains.

VOLATILE ORGANIC COMPOUNDS (VOC)—Carbon-containing chemical compounds (e.g., solvents or liquids) that evaporate readily at ambient or process temperatures. Environmental, safety and health regulations often limit exposure to these compounds, so a low VOC content is preferable.

— W —

WARP—Yarns running lengthwise and perpendicular to the narrow edge of woven fabric.

WARPAGE—Dimensional distortion in a composite part.

WATER JET—High-pressure water stream used for cutting polymer composite parts.

WAX—Mold release agent or surfacing agent.

WEAVE—Pattern by which fabric is formed from interlacing yarns. In plain weave, warp and fill fibers alternate to make both fabric faces identical. In satin weave, the pattern produces a satin appearance with warp roving crossing over several fill rovings and under the next one (e.g., eight-harness satin would have the warp roving over seven fill rovings and under the eighth).

WEAVE PRINT—Extreme form of fiber print resembling the architecture of a woven or stitched glass ply just below or near the gel coat surface.

WEFT—Yarns running perpendicular to the warp in woven fabric.

WET LAY-UP—Application of liquid resin to dry reinforcement in the mold.

WET WINDING—Filament winding where fiber strands are impregnated with resin immediately before they contact the mandrel.

WETOUT—Process in which reinforcing material can be completely saturated with resin. Rate is usually determined visually and measured in elapsed time.

WETTING AGENT—Surface-active agent that promotes wetting by decreasing cohesion within a liquid.

WHISKER—Short single crystal fiber or filament used as reinforcement in matrix.

WIND ANGLE—Measure in degrees between direction parallel to filaments and an established reference.

WINDING PATTERN—Regularly recurring pattern of the filament path in the filament winding after a certain number of mandrel revolutions.

WIRE MESH—Fine wire screen used to increase electrical conductivity. Typically used to dissipate electrical charge from lightning or an electromagnetic interference.

WITNESS MARK—Defect in the gel coat surface profile that corresponds to some feature, either in the underlying laminate or on/in the molding surface; sometimes called mark-off.

WOVEN ROVING FABRIC—Heavy fabrics woven from continuous filaments in roving form. They drape well, are quickly impregnated, are intermediate in price between mats and yarn cloths, and contribute to higher glass content.

WOVEN TAPE—Tape of various thicknesses woven from continuous filament yarns.

WRINKLE— Imperfection in the surface of a laminate that appears to be creased in one of the outer layers; occurs in vacuum-bag molding when a bag is improperly placed.

— X —

X-AXIS—Axis in the plane of laminate used as the zero reference.

— Y —

Y-AXIS—Axis in the plane of the laminate perpendicular to the x-axis.

YARN—Twisted strand of roving.

YOUNG'S MODULUS—Ratio of the normal stress to the corresponding strain for tensile or compressive stresses less than the proportional limit of the material.

— Z —

Z-AXIS—Reference axis normal to laminate the plane in composite laminates.

ZERO MOLD—General term for the intermediate piece of tooling that resembles a production model but belongs to an earlier generation. Molded from the part-image master model (pattern or plug); subsequently used to produce the master model.

C.2. References

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- Whittington's Dictionary of Plastics, 3rd Ed. (1993), James Carley, Ed., Technomics, Lancaster, PA

C.3. Polynt Trademarks

Listed below are trademarked Polynt products designed specifically for the composites market. The Polynt logo and trademarked product name assure optimum quality backed by a tradition of commitment to research.

ACPOL™—acrylic modified polymers.

AQUACLEAN—machine designed for cleaning tools used in composite parts manufacturing.

AQUAWASH®—water-based resin emulsifier cleaner.

ArmorCast®—casting resins designed for a wide variety of casting applications.

ArmorClear®—lower emission gel coat with improved flexibility and good weathering resistance.

ARMORCOTE®—in-mold coating with durability that far exceeds basic gel coat.

ArmorFlex®—gel coat with improved flexibility over standard gel coats.

ArmorGuard®—vinyl ester barrier coat designed for reducing osmotic blistering.

ArmorHP®—MACT compliant gel coat with superior weathering resistance and excellent processing characteristics.

ArmorPlus®—MACT compliant gel coat with improved flexibility and excellent processing characteristics.

ArmorPro®—MACT compliant gel coat with marine quality weathering, low tack and excellent processing characteristics.

ArmorStar®—epoxy-modified skin and bulk-laminating resins designed for the marine industry.

BathCote®—MACT compliant gel coat for the sanitary industry.

BathCote® HF—MACT complaint gel coat for the sanitary industry with improved flexibility.

BUFFBACK®—gel coat with excellent gloss recovery in the repair process.

EnviroGUARD®—polyester resin formulated for building reinforced plastic parts using closed molding processes such as RTM, light RTM, or infusion.

EPOVIA®—vinyl ester resins.

FIREBLOCK™—produces flame retardant resins and gel coats for industries including transportation, building, architecture and construction.

Gun Flush—cleaner for cleaning tools and equipment.

HiGloss THP™—MACT compliant, high performance gel coats for the transportation industry.

HiGloss TR™—MACT compliant, high performance gel coats for the reinforced plastics industry.

IMEDGE®—Polymer Coating Technology (PCT) and Polymer Barrier Technology (PBT) high performance products.

Kayak™—vinyl ester resin containing styrene monomer used for building reinforced plastic parts using molding processes, infusion processes, hand lay-up, spray-up, and filament winding applications.

MARBLECLEAN—cleaning machine for cultured marble and solid surface.

MARBLEWASH®—nonhazardous solvent-based cleaner for use in a MARBLECLEAN™ machine.

Norsodyne™—flame retardant resin.

NUPOL®—thermosetting acrylic resin.

NuTack®—aerosol tackifier for RTM, vacuum bagging, and infusion applications.

OPTIMOLD®—mold construction system that includes a filled tooling resin mix for rapid mold production.

OptiPLUS®—mold construction system for non-filled shrink controlled tooling resin.

PATCHAID®—additive designed for gel coat and in-mold coating to improve patching results.

POLYCOR®—products of UPR, gel coats, and polymer systems.

QUICKMIX®—gel coat base and pigment pack system for easy inventory and on-site mixing.

RediSCRUB—machine designed for cleaning tools and used with Replacetone™ and ThermaCLEAN® products.

Replacetone™—water-based resin emulsifier.

ReplacetoneX™—"ready to use" water-based resin emulsifier.

Shimmer®—gel coat formulated for the swimming pool industry.

Spraycure™—overspray to reduce patch cure time and used to thin gel coat for spray through aerosol bottles.

STYPOL®—products of UPR, gel coats, and polymer systems.

THERMACLEAN®—non-hazardous cleaning products.

UNISOLVE™—universal solvent.

UNIWIPE™—low NVR surface cleaner.

Wipe-Bright®—surface cleaner.

XYCON®—family of hybrid polymers based on polyester (or other unsaturated polymers) and urethane chemistries; also considered an inter-penetrating polymers network.

Appendix D: Additional Information

Overview

- **Useful Conversion Factors**
- **Drums (Stick Measurement)**
- **Conversion Tables and Material Coverage Charts**
- **Comparison of Sizes**
- **Temperature Conversion**
- **Record of Current Products**
- **Gel Coat Spray Test Sheet**
- **Mixing**
- **Catalyst Levels**
- **Application Helpful Hints**
- **Wet-to-Cured**
- **Service Kit Items**
- **Equipment Maintenance and Cleanup Procedures**
- **Catalyst Precautions**

D.1. Useful Conversion Factors

Table D-1. Peroxide/cobalt/polyester resin.

MEK Peroxide	
1 fluid oz. * 1 gm wt. 1 cc 1 gm wt.	= 33.1 gms = 0.0302 fluid oz. = 1.12 gms = 0.89 cc
Cobalt	
1 fluid oz. ** 1 gm wt. 1 cc 1 gm wt.	= 30.15 gm. wt. = 0.033 fluid oz. = 1.02 gms = 0.99 cc
Polyester Resin, Unpigmented	
1 gal. 1 lb. 1 lb.	= 9.2 lbs. = 13.89 fluid oz. = 411 cc
*9% active oxygen	** 6% solution

Table D-2. Weight conversions.

Weight	
1 gm (gram)	= 0.0022 lbs. = 0.0353 oz. = 0.001 Kg
1 lb. (pound)	= 16 oz. = 453.6 gms = 0.454 Kg
1 oz. (ounce) (avoirdupois)	= 0.0625 lbs. = 28.35 gms = 0.0284 Kg
1 Kg (Kilogram)	= 1000 gms = 2.205 lbs. (av.) = 35.27 oz. (av.)

Table D-3. Volume conversions.

Volume	
1 cc (cubic centimeter)	= 1 ml (milliliter) = 0.000264 gallons = 0.0338 fluid oz.
1 U.S. gallon	= 3785 cc = 128 fluid oz. = 231 cubic inches
1 fluid oz.	= 29.57 cc (or ml) = 0.00781 gallons

Table D-4. Weight/volumetric additive chart.

	0.01% by Weight			0.10% by Weight			1.0% by Weight		
Approx. Volume[2]	**gm**	**cc[1]**	**oz.[1]**	**gm**	**cc[1]**	**oz.[1]**	**gm**	**cc[1]**	**oz.[1]**
1 quart	0.11	0.11	0.004	1.11	1.11	0.037	11.12	11.12	0.375
1 gallon	0.44	0.44	0.015	4.45	4.45	0.150	44.50	44.50	1.500
5 gallons	2.22	2.22	0.075	22.25	22.25	0.750	222.50	222.50	7.500
1 drum	23.58	23.58	0.795	235.80	235.80	7.950	2358.50	2358.50	79.5000

	1.2% by Weight			1.8% by Weight			2.0% by Weight		
Approx. Volume[2]	**gm**	**cc[1]**	**oz.[1]**	**gm**	**cc[1]**	**oz.[1]**	**gm**	**cc[1]**	**oz.[1]**
1 quart	13.35	13.35	0.450	20	20	0.675	22.25	22.25	0.750
1 gallon	53.40	53.40	1.800	80	80	2.700	89.00	89.00	3.000
5 gallons	267.00	267.00	9.00	400	400	13.50	445.00	445.00	15.00
1 drum	2830.20	2830.20	95.00	4240	4240	143.100	4717.00	4717.00	159.00

Specific Gravity Factor/Additives

[1] Based on the weight/gallon of 8.33 pounds for approximate measurements; for more accurate additions, divide the number of cc's or oz. shown in the Table D-3 by the proper factor supplied below:

970-C-981 Ethylene Glycol	1.11
970-C-903 Cobalt	1.02
970-C-960 Styrene	0.91
970-C-951 Inhibitor Solution	0.98
970-C-940 Wax Solution	0.91
970-C-943 Fisheye Solution	0.97

Specific gravity (factor) is the 'ratio of the weight of any substance to that of an equal volume of water.' The weight gallon of water is 8.33 pounds; therefore divide the weight/gallon of a given substance by 8.33. When using water as the standard, 1 cc or ml (volume) is equal to 1 gram (weight). The specific gravity is a very useful conversion factor for converting volume to weight or weight to volume.

Example A

If percent by weight is desired and the addition is to be by volume, divide weight desired by the specific gravity.

30 grams of catalyst desired
cc graduate going to be used
30/1.12 = 27 cc's to equal 30 grams

Density Compensation Factor/Products

[2] Based on an average weight/gallon of 9.8 pounds. For more accurate additions, divide the number of cc's or oz. shown in the Table D-3 by the proper factor supplied below:

944-W-016	1.10
Other gel coats	0.97
040-4812	0.91

[3] Cured weight/gallon:

Polyester resins (9.0 lbs. liquid)	9.90
Fiberglass (roving)	21.15

Example B

If volume is known and gram weight is desired, multiply volume by specific gravity.

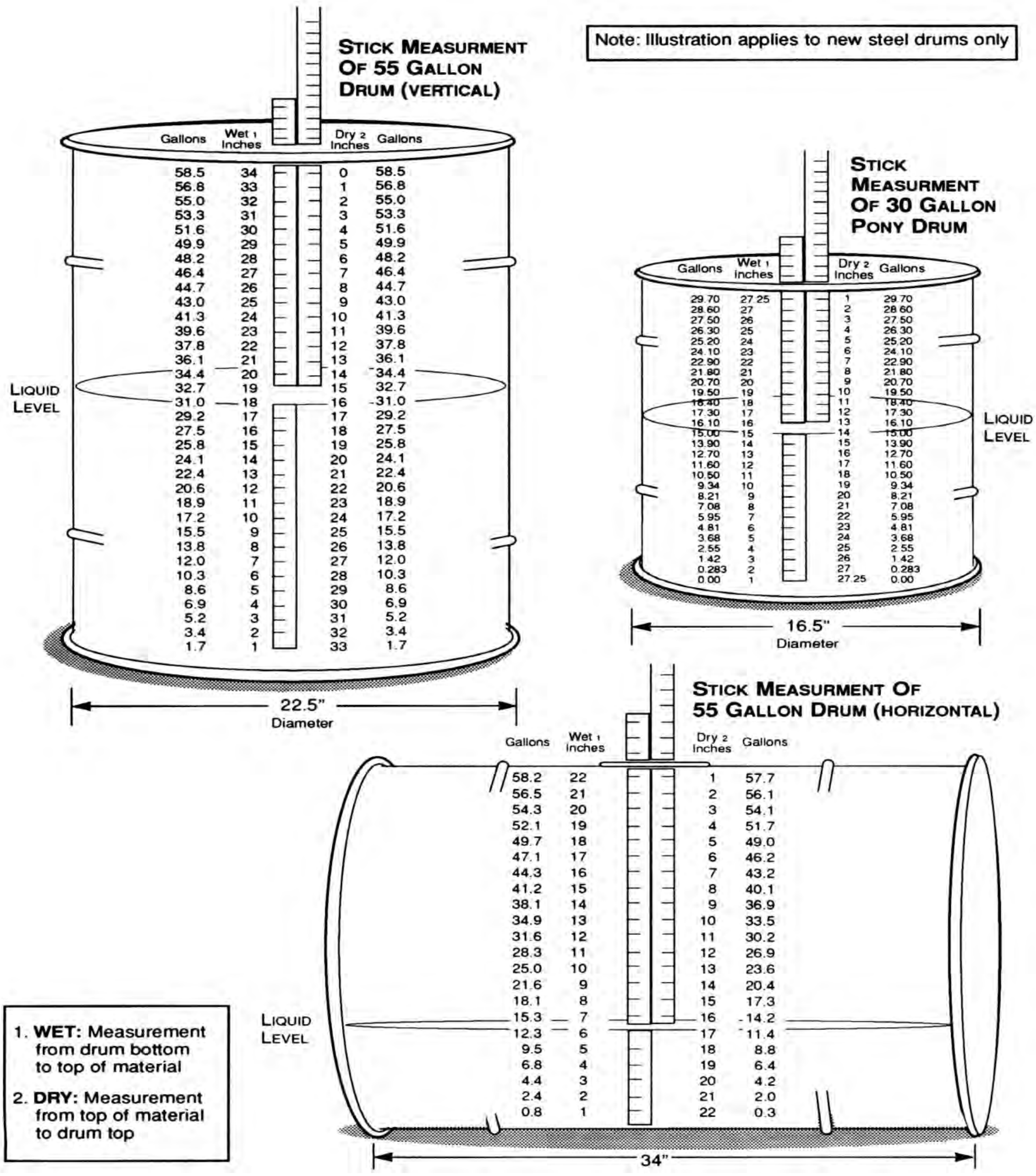
2000 cc's of white gel coat
Weight ÷ gallon of white gel coat is 10.9
10.9 ÷ 8.33 = 1.31 specific gravity
2000 x 1.31 = 2620 grams of white gel coat

Remember:

- Grams to cc's, divide by specific gravity
- Cc's to grams, multiply by specific gravity

See Drum Measurement Chart in this section to determine how much material is in a drum.

D.2. Drums (Stick Measurement)



Note: Illustration applies to new steel drums only

STICK MEASURMENT OF 55 GALLON DRUM (VERTICAL)

Gallons	Wet[1] Inches	Dry[2] Inches	Gallons
58.5	34	0	58.5
56.8	33	1	56.8
55.0	32	2	55.0
53.3	31	3	53.3
51.6	30	4	51.6
49.9	29	5	49.9
48.2	28	6	48.2
46.4	27	7	46.4
44.7	26	8	44.7
43.0	25	9	43.0
41.3	24	10	41.3
39.6	23	11	39.6
37.8	22	12	37.8
36.1	21	13	36.1
34.4	20	14	34.4
32.7	19	15	32.7
31.0	18	16	31.0
29.2	17	17	29.2
27.5	16	18	27.5
25.8	15	19	25.8
24.1	14	20	24.1
22.4	13	21	22.4
20.6	12	22	20.6
18.9	11	23	18.9
17.2	10	24	17.2
15.5	9	25	15.5
13.8	8	26	13.8
12.0	7	27	12.0
10.3	6	28	10.3
8.6	5	29	8.6
6.9	4	30	6.9
5.2	3	31	5.2
3.4	2	32	3.4
1.7	1	33	1.7

STICK MEASURMENT OF 30 GALLON PONY DRUM

Gallons	Wet[1] Inches	Dry[2] Inches	Gallons
29.70	27.25	1	29.70
28.60	27	2	28.60
27.50	26	3	27.50
26.30	25	4	26.30
25.20	24	5	25.20
24.10	23	6	24.10
22.90	22	7	22.90
21.80	21	8	21.80
20.70	20	9	20.70
19.50	19	10	19.50
18.40	18	11	18.40
17.30	17	12	17.30
16.10	16	13	16.10
15.00	15	14	15.00
13.90	14	15	13.90
12.70	13	16	12.70
11.60	12	17	11.60
10.50	11	18	10.50
9.34	10	19	9.34
8.21	9	20	8.21
7.08	8	21	7.08
5.95	7	22	5.95
4.81	6	23	4.81
3.68	5	24	3.68
2.55	4	25	2.55
1.42	3	26	1.42
0.283	2	27	0.283
0.00	1	27.25	0.00

STICK MEASURMENT OF 55 GALLON DRUM (HORIZONTAL)

Gallons	Wet[1] Inches	Dry[2] Inches	Gallons
58.2	22	1	57.7
56.5	21	2	56.1
54.3	20	3	54.1
52.1	19	4	51.7
49.7	18	5	49.0
47.1	17	6	46.2
44.3	16	7	43.2
41.2	15	8	40.1
38.1	14	9	36.9
34.9	13	10	33.5
31.6	12	11	30.2
28.3	11	12	26.9
25.0	10	13	23.6
21.6	9	14	20.4
18.1	8	15	17.3
15.3	7	16	14.2
12.3	6	17	11.4
9.5	5	18	8.8
6.8	4	19	6.4
4.4	3	20	4.2
2.4	2	21	2.0
0.8	1	22	0.3

1. **WET:** Measurement from drum bottom to top of material
2. **DRY:** Measurement from top of material to drum top

Figure D-1. Drum measurement chart.

D.3. Conversion Tables and Material Coverage Charts

Table D-5. Millimeter/Inch conversion.

MM	Inches
0.25400	0.01000
0.30480	0.01200
0.35560	0.01400
0.40640	0.01600
0.45720	0.01800
0.50800	0.02000
0.60960	0.02400
0.71120	0.02800
0.81280	0.03200
0.91440	0.03600
1	0.03937
2	0.07874
3	0.11811
4	0.15748
5	0.19685
6	0.23622
7	0.27559
8	0.31496
9	0.35433
10	0.39370
11	0.43307
12	0.47244
13	0.51181
14	0.55118
15	0.59055
16	0.62992
17	0.66929
18	0.70866
19	0.74803
20	0.78740

Table D-6. Units of area.

Unit	Sq. Inches	Square Feet	Square Yards	Square Centimeter	Square Meters
Sq. inch	1	0.006944	0.000772	6.45162	0.000645
Sq. foot	144	1	0.11111	929.034	0.092903
Sq. yard	1296	9	1	8361.31	0.836131
Sq. cm.	0.155	0.001076	0.00012	1	0.0001
Sq. meter	1550	10.7639	1.19598	10000	1

Table D-7. Units of length.

Unit	Inches	Feet	Yards	Centimeter	Meters
Inch	1	0.08333	0.02777	2.54	0.0254
Foot	12	1	0.3333	30.48	0.3048
Yard	36	3	1	91.44	0.9144
Mile	63360	5280	1760	160934	1609.34
Cm.	0.3937	0.03281	0.01094	1	0.01
Meter	39.37	3.3808	1.09361	100	1

Table D-8. Units of volume.

Unit	Cubic Inches	Cubic Feet	Cubic Yards	Cubic Centimeters
Cubic inch	1	---	---	16.3872
Cubic foot	1728	1	0.03704	28317
Cubic yard	46656	27	1	764.559
Cubic cm.	0.06102	---	---	1
Cubic meter	61203	35.314	1.3079	1000000

Table D-9. Gel coat wet-to-cured correlation.

Mils Wet (Approx.)	Mils Cured
10	7
12	8
14	10
16	11
18	13
20	14
24	16
28	19
32	24
36	29

Table D-10. Resin to use to achieve 'x' percent of glass when glass weight is known. Determine what percentage of glass is desired; multiply glass weight by resin factor.

Desired % of Glass	Factor for Resin
30	2.33
31	2.22
32	2.12
33	2.03
33.33	2.00
34	1.94
35	1.86
36	1.78
37	1.70
38	1.63
39	1.56
40	1.50

Table D-11. Miscellaneous conversions.

Miscellaneous

- 10 cc (ml) per catalyst cap
- 1 jigger = 1.5 fl. ounces
- 100 gms. = approx. 3 fl. ounces gel coat
  = 1½" x 2½" (in 8 oz. jar)
- 1 fluid ounce = 2 tablespoons (T.)
  = 6 teaspoons (t.)
  = 29.6 cubic centimeters (cc)
- 1 cup = 8 fl. oz. = 16 T. = 48 t.
- 128 fl. ounces = 1 gallon
- approx. 36 eye drops/gram of 970-C-951 (inhibitor solution)
- approx. 30 eye drops/gram of 970-C-981 (viscosity thickener)
- approx. 36 eye drops/gram of catalyst
- Density glass = approx. 1.6 gms./cc
  = 162.5 lbs./ft.^{3}
  = 21.6 lbs./gallon

Table D-12. Materials coverage (theoretical – assuming no loss).

Wet Film Thickness	Sq. Ft./Gal.	Gal./1000 Sq. Ft.
0.001" (1 mil)	1600.0	0.63
0.003" (3 mils)	534.0	1.90
0.005" (5 mils)	320.0	3.10
0.010" (10 mils)	160.0	6.30
0.015" (15 mils)	107.0	9.40
0.018" (18 mils)	89.0	11.20
0.020" (20 mils)	80.0	12.50
0.025" (25 mils)	64.0	15.60
0.030" (30 mils)	53.0	19.00
0.031" (31 mils)	51.0	19.50
0.060" (60 mils)	27.0	38.00
0.062" (62 mils)	26.0	38.00

Table D-13. Catalyzation.

The importance of proper catalyzation when using polyesters cannot be emphasized enough. Over catalyzation, as well as under catalyzation, can cause a variety of problems. Using the 9.0% active oxygen catalyst, recommended catalyzation levels are:

	Recommended @ 77%	Min.	Max.
Gel Coats[1]	1.8%	1.2%	3.0%
Laminating Resins[1]	1.2%	.9%	2.4%
Marble Resins[1]	1.2%	.5%	2.4%

[1] Ideal catalyst level for gel coat is 1.8%; 1.2% for laminating and marble resins at 77°F. Add .07 catalyst to the ideal % for each °F below 77°F to no lower than 60°F and a maximum total of 3.0% gel coat and 2.4% for laminating and marble resins.

Example: When testing gel coat, ambient plant temperatures are found to be 70°F (or 7°F below 77°F):

7°F x .07 = 0.49

1.8% + 0.49 = 2.3% for that plant temperature

NOTE: Check liquid temperature of catalyst, resin and gel coat to be tested.

D.4. Comparison of Sizes

Table D-14. Accepted depth-of-fineness gauge readings from 0 to 1 inch.

Fineness Gauge Readings						Sieves	
Prod. Club	**Mils**	**Hegman**	**Inches**	**Millimeters**	**Microns**	**U.S. Std. Eq. No.**	**Tyler Mesh**
10	0.00	8	0.00000	0.0000	0		
	0.25	7½	0.00025	0.0064	6.4		
9	0.40		0.00040	0.0102	10.2		
	0.50	7	0.00050	0.0127	12.7		
	0.75	6½	0.00075	0.0191	19.1		
8	0.80		0.00080	0.0203	20.3		
	1.00	6	0.00100	0.0254	25.4		
7	1.20		0.00120	0.0305	30.5		
	1.25	5½	0.00125	0.0318	31.8		
	1.50	5	0 00150	0.0381	38.1	400	400
6	1.60		0.00160	0.0406	40.6		
	1.75	4½	0.00175	0.0445	44.5	325	325
5	2.00	4	0.00200	0.0508	50.8		
	2.10		0.00210	0.0533	53.3	270	270
	2.25	3½	0.00225	0.0572	57.2		
4	2.40		0.00240	0.0610	61.0	230	250
	2.50	3	0.00250	0.0635	63.5		
	2.75	2½	0.00275	0.0699	69.9		
3	2.80		0.00280	0.0711	71.1		
	2.90		0.00290	0.0737	73.7	200	200
	3.00	2	0.00300	0.0762	76.2		
2	3.20		0.00320	0.0813	81.3		
	3.25	1½	0.00325	0.0826	82.6		
	3.50	1	0.00350	0.0889	88.9	170	170
1	3.60		0.00360	0.0914	91.4		
	3.75	½	0.00375	0.0953	95.3		
0	4.00	0	0.00400	0.1016	101.6		
			0.00410	0.1041	104.1	140	150
			0.00490	0.1250	125.0	120	115
			0.00590	0.1490	149.0	100	100
			0.00700	0.1770	177.0	80	80
			0.00830	0.2100	210.0	70	65
			0.00980	0.2500	250.0	60	60
			0.01170	0.2970	297.0	50	48
			0.01380	0.3500	350.0	45	42

Table D-14. Accepted depth-of-fineness gauge readings from 0 to 1 inch. (cont.)

Fineness Gauge Readings						Sieves	
Prod. Club	Mils	Hegman	Inches	Millimeters	Microns	U.S. Std. Eq. No.	Tyler Mesh
			0.01650	0.4200	420.0	40	35
			0.01970	0.5000	500.0	35	32
			0.02320	0.5900	590.0	30	28
			0.02800	0.7100	710.0	25	24
			0.03310	0.8400	840.0	20	20
			0.03940	1.0000	1000.0	18	16
			0.04690	1.1900	1190.0	16	14
			0.05550	1.4100	1410.0	14	12
			0.06250 (1/16")	1.5875	1588.0		
			0.06610	1.6800	1680.0	12	10
			0.07870	2.0000	2000.0	10	9
			0.09370	2.3800	2380.0	8	8
			0.11100	2.8300	2830.0	7	7
			0.12500 (⅛")	3.1750	3175.0		
			0.13200	3.3600	3360.0	6	6
			0.15700	4.0000	4000.0	5	5
			0.18750 (3/16")	4.7600	4760.0	4	4
			0.22300	5.6600	5660.0	3½	3½
			0.25000 (¼")	6.3500	6350.0		
			0.31250 (5/16")	7.9300	7930.0		
			0.37500 (⅜")	9.5200	9520.0		
			0.43750 (7/16")	11.1000	11100.0		
			0.50000 (½")	12.7000	12700.0		
			0.62500 (⅝")	15.9000	15900.0		
			0.75000 (¾")	19.1000	19100.0		
			0.87500 (⅞")	22.2000	22200.0		
			1.00000 (1")	25.4000	25400.0		

D.5. Temperature Conversion

Formula

°C to °F = °C (1.8) + 32

°F to °C = (°F-32) ÷1.8

Table D-15. Interpolation factors.

0.56	1	1.8
1.11	2	3.6
1.67	3	5.4
2.22	4	7.2
2.78	5	9
3.33	6	10.8
3.89	7	12.6
4.44	8	14.4
5	9	16.2
5.56	10	18

Instructions for Table D-16

To convert from Celsius to Fahrenheit

1. Find Celsius degrees in center column.
2. Read equivalent Fahrenheit degree in right hand column.

To convert from Fahrenheit to Celsius

1. Find Fahrenheit degree in center column.
2. Read equivalent Celsius degree in left hand column.

Table D-16. Temperature conversion.

-100 to 0		
°C		°F
-73.3	-100	-148.0
-72.8	-99	-146.2
-72.2	-98	-144.4
-71.7	-97	-142.6
-71.1	-96	-140.8
-70.6	-95	-139.0
-70.0	-94	-137.2
-69.4	-93	-135.4
-68.9	-92	-133.6
-68.3	-91	-131.8
-67.8	-90	-130.0
-67.2	-89	-128.2
-66.7	-88	-126.4
-66.1	-87	-124.6
-65.6	-86	-122.8
-65.0	-85	-121.0
-64.4	-84	-119.2
-63.9	-83	-117.4
-63.3	-82	-115.6
-62.8	-81	-113.8
-62.2	-80	-112.0
-61.7	-79	-110.2
-61.1	-78	-108.4
-60.6	-77	-106.6
-60.0	-76	-104.8
-59.4	-75	-103.0
-58.9	-74	-101.2
-58.3	-73	-99.4
-57.8	-72	-97.6
-57.2	-71	-95.8
-56.7	-70	-94.0
-56.1	-69	-92.2
-55.6	-68	-90.4
-55.0	-67	-88.6
-54.4	-66	-86.8
-53.9	-65	-85.0
-53.3	-64	-83.2
-52.8	-63	-81.4
-52.2	-62	-79.6
-51.7	-61	-77.8
-51.1	-60	-76.0
-50.6	-59	-74.2
-50.0	-58	-72.4
-49.4	-57	-70.6
-48.9	-56	-68.8
-48.3	-55	-67.0
-47.8	-54	-65.2
-47.2	-53	-63.4
-46.7	-52	-61.6
-46.1	-51	-59.8
-45.6	-50	-58.0
-45.0	-49	-56.2
-44.4	-48	-54.4
-43.9	-47	-52.6
-43.3	-46	-50.8
-42.8	-45	-49.0
-42.2	-44	-47.2
-41.7	-43	-45.4
-41.1	-42	-43.6
-40.6	-41	-41.8
-40.0	-40	-40.0
-39.4	-39	-38.2
-38.9	-38	-36.4
-38.3	-37	-34.6
-37.8	-36	-32.8
-37.2	-35	-31.0
-36.7	-34	-29.2
-36.1	-33	-27.4
-35.6	-32	-25.6
-35.0	-31	-23.8
-34.4	-30	-22.0

Table D-16. Temperature conversion. (cont.)

-100 to 0		
°C		°F
-33.9	-29	-20.2
-33.3	-28	-18.4
-32.8	-27	-16.6
-32.2	-26	-14.8
-31.7	-25	-13.0
-31.1	-24	-11.2
-30.6	-23	-9.4
-30.0	-22	-7.6
-29.4	-21	-5.8
-28.9	-20	-40
-28.8	-19	-2.2
-27.8	-18	-0.4
-27.2	-17	1.4
-26.7	-16	3.2
-26.1	-15	5.0
-25.6	-14	6.8
-25.0	-13	8.6
-24.4	-12	10.4
-23.9	-11	12.2
-23.3	-10	14.0
-22.8	-9	15.8
-22.2	-8	17.6
-21.7	-7	19.4
-21.1	-6	21.2
-20.6	-5	23.0
-20.0	-4	24.8
-19.4	-3	26.6
-18.7	-2	28.4
-18.3	-1	30.2
-17.8	0	32.0
0 to 100		
-17.8	0	32
-17.2	1	33.8
-16.7	2	35.6
-16.1	3	37.4
-15.6	4	39.2
-15.0	5	41
-14.4	6	42.8
-13.9	7	44.6
-13.3	8	46.4

0 to 100		
°C		°F
-12.8	9	48.2
-12.2	10	50.0
-11.7	11	51.8
-11.1	12	53.6
-10.6	13	55.4
-10.0	14	57.2
-9.44	15	59.0
-8.89	16	60.8
-8.33	17	62.6
-7.78	18	64.4
-7.22	19	66.2
-6.67	20	68.0
6.11	21	69.8
-5.56	22	71.6
-5.00	23	73.4
-4.44	24	75.2
-3.89	25	77.0
-3.33	26	78.8
-2.78	27	80.6
-2.22	28	82.4
-1.67	29	84.2
-1.11	30	86.0
-0.56	31	87.8
0.00	32	89.6
0.56	33	91.4
1.11	34	93.2
1.67	35	95.0
2.22	36	96.8
2.78	37	98.6
3.33	38	100.4
3.89	39	102.2
4.44	40	104.0
5.00	41	105.8
5.56	42	107.6
6.11	43	109.4
6.67	44	111.2
7.22	45	113.0
7.78	46	114.8
8.33	47	116.6
8.89	48	118.4
9.44	49	120.2
10.0	50	122.0
10.6	51	123.8

0 to 100		
°C		°F
11.1	52	125.6
11.7	53	127.4
12.2	54	129.2
12.8	55	131.0
13.3	56	132.8
13.9	57	134.6
14.4	58	136.4
15.0	59	138.2
15.6	60	140.0
16.1	61	141.8
16.7	62	143.6
17.2	63	145.4
17.8	64	147.2
18.3	65	149.0
18.9	66	150.8
19.4	67	152.6
20.0	68	154.4
20.6	69	156.2
21.1	70	158.0
21.7	71	159.8
22.2	72	161.6
22.8	73	163.4
23.3	74	165.2
23.9	75	167.0
24.4	76	168.8
25.0	77	170.6
25.6	78	172.4
26.1	79	174.2
26.7	80	176.0
27.2	81	177.8
27.8	82	179.6
28.3	83	181.4
28.9	84	183.2
29.4	85	185.0
30.0	86	186.8
30.6	87	188.6
31.1	88	190.4
31.7	89	192.2
32.2	90	194.0
32.8	91	195.8
33.3	92	197.6
33.9	93	199.4
34.4	94	201.2

Table D-16. Temperature conversion.
(cont.)

0 to 100		
°C		°F
35.0	95	203.0
35.6	96	204.8
36.1	97	206.6
36.7	98	208.4
37.2	99	210.2
37.8	100	212.0
100 to 1000		
38	100	212
43	110	230
49	120	248
54	130	266
60	140	284
66	150	302
71	160	320
77	170	338
82	180	356
88	190	374
93	200	392
99	210	410
100	212	413
104	220	428
110	230	446
116	240	464
121	250	482
127	260	500
132	270	518
138	280	536
143	290	554
149	300	572
154	310	590
160	320	608
166	330	626
171	340	644
177	350	662
182	360	680
188	370	698
193	380	716
199	390	734
204	400	752
210	410	770

100 to 1000		
°C		°F
216	420	788
221	430	806
227	440	824
232	450	842
238	460	860
243	470	878
249	480	896
254	490	914
260	500	932
266	510	950
271	520	968
277	530	986
282	540	1004
288	550	1022
293	560	1040
299	570	1058
304	580	1076
310	590	1094
316	600	1112
321	610	1130
327	620	1148
332	630	1166
338	640	1184
343	650	1202
349	660	1220
354	670	1238
360	680	1256
366	690	1274
371	700	1292
377	710	1310
382	720	1328
388	730	1346
393	740	1364
399	750	1382
404	760	1400
410	770	1418
416	780	1436
421	790	1454
427	800	1472
432	810	1490
438	820	1508
443	830	1526
449	840	1544

100 to 1000		
°C		°F
454	850	1562
460	860	1580
466	870	1598
471	880	1616
477	890	1634
482	900	1652
488	910	1670
493	920	1688
499	930	1706
504	940	1724
510	950	1742
516	960	1760
521	970	1778
527	980	1796
532	990	1814
538	1000	1832
1000 to 3000		
538	1000	1832
593	1100	2012
649	1200	2192
704	1300	2372
760	1400	2552
816	1500	2732
871	1600	2912
927	1700	3092
982	1800	3272
1038	1900	3452
1093	2000	3632
1149	2100	3812
1204	2200	3992
1260	2300	4172
1316	2400	4352
1371	2500	4532
1427	2600	4712
1482	2700	4892
1538	2800	5072
1593	2900	5252
1649	3000	5432

D.6. Record of Current Products

This page is provided as a suggested format for recording Polynt products currently used.

	Product Code	Gel Time	Catalyst	Viscosity
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
16.				
17.				
18.				
19.				

D.6. Record of Current Products

This page is provided as a suggested format for recording Polynt products currently used.

	Product Code	Gel Time	Catalyst	Viscosity
20.				
21.				
22.				
23.				
24.				
25.				

D.7. Gel Coat Spray Test Sheet

Purpose

- To determine proper amount of delivery.
- To determine proper amount of catalyst.
- To determine proper spray application.

For: ______________________________

Date: ______________________________

Number: ______________________________

General	Comments/Recommendations			
1. Spray area location				1.
2. Spray person				2.
3. Type parts				3.
4. Molds (condition, type wax, etc.)				4.
5. Method of spraying (molds tilted, scaffolding, etc.)				5.
6. Staging conditions				6.
7. Mixing procedures				7.
8. Moisture/oil				8.
9. Other				9.
Calibration				
10. Material	Batch #		Batch Date	10.
11. Temperature				11.
12. Gun				12.
13. Fluid orifice				13.
14. Needle				14.
15. Air cap				15.
16. Atomizing pressure				16.
17. Hose (atomizing)				17.
18. Supply (model /size/ratio)				18.
19. Pump air pressure				19.
20. Hose (fluid)				20.
21. GPM/PPM (454 g's is 1 pound)				21.
22. Other				22.
23. Catalyst (brand/type/lot)				23.
24. Supply				24.
25. Orifice size				25.
26. Dilution ratio				26.
27. Percent catalyst desired				27.

Calibration (Cont.)	Comments/Recommendations	
28. Gram s/cc’s desired (line 21 x 27)		28.
29. Catalyst pressure		29.
30. Hose		30.
31. Catalyst atomizing pressure		31.
32. Hose		32.
33. Ball(s) setting		33.
34. Catalyst delivery		34.
35. Percent catalyst (line 34÷21)		35.
36. Control gel time		36.
37. Gun gel time		37.
38. Film gel time		38.
39. Layup time		39.
40. Other		40.
Application		
41. Identification (mold #/part #)		41.
42. Start/finish/total time		42.
43. Spray distance		43.
44. Number of passes		44.
45. Mils per pass		45.
46. Total mils		46.
47. Other		47.

D.8. Mixing

- Do not overmix. Overmixing can reduce viscosity.
- Gel coat should be mixed for 10 minutes prior to shift startup.
- The gel coat should be mixed to the sides of the container.
- Use the least amount of turbulence possible.

D.9. Catalyst Levels

- Ideal Catalyst Level for Gel Coat is 1.8% at 77°F.
- The following catalysts are recommended for use with Polynt Gel Coats:
  - Luperox® DDM-9
  - Luperox® DHD-9
  - Chemtura Hi-Point 90
  - Norox® MEKP-925
  - Norox® MEKP-9
- Minimum Application Temperature is 60°F.
- Maximum Catalyst Level is 3.0%
- Minimum Catalyst Level is 1.2%
- Adjust catalyst level 0.07 for each degree from 77°F.
  - If cooler than 77°F, add 0.07 up to a catalyst level of 3.0%.
    - Example #1: Temperature of gel coat is 70°F.
      7 X 0.07 = 0.49 + 1.8% = 2.3%
  - If warmer than 77°F, subtract 0.07 down to a minimum catalyst level of 1.2%.
    - Example #2: Temperature of gel coat is 85°F.
      8 X (-0.07) = (-0.56) + 1.8% = 1.24%

D.10. Application Helpful Hints

1. Mix gel coat per recommendations.
2. Check calibration on a regular basis.
3. The first pass should be a thin, wet, continuous film.
4. Maintain a wet line.
5. Spray 3 passes for a total of 18 mils (± 2 mils) wet.

D.11. Wet-to-Cured

D.11.1. Gel Coat Wet-To-Cured Thickness Correlation – Low VOC (HAP) Gel Coat vs. Standard Gel Coat

Table D-17. Standard Gel Coat Thickness.

Mils Wet	Mils Cured
10	7
12	8
14	10
16	11
18	13
20	14
24	16
28	19
32	24
36	29

Mils Cured with Low VOC (HAP) Gel Coat = 5-7% Improvement

NOTE: Dependent on the actual VOC (HAP) of the gel coat and on application and environmental conditions.

D.12. Service Kit Items

Listed in this section are tools and equipment necessary for checking out field problems with polyester. The list can also be used as a basic reference for items a customer should have in order to run troubleshooting and calibration tests.

Table D-18. Service kit items.

Item		Source
Scales—Ohaus	0-250 gms 0-2000 gms	1 1
Single pan balance	0-2610 gms	2 1
Applicator sticks		1
Tongue depressors		2
Graduated cylinders	10 mil 100 mil 1000 mil	2 2 2
Paper tubs		2
Graduated measuring cups	3 oz/85 Ml	2
Measurematic Catalyst Dispenser		2
Small plastic bottles and eye droppers		7
Disposable gloves		2
Disposable particle mask		2
Disposable coveralls	Size M Size L	2
Disposable shoe covers	One size	2
Paint strainer		2
Magnifier flashlight	10X	3
Respirator		1
Pocket magnifier (for dry film thickness)		1
Mil gauges		3
Drum mixer	5-21-0065	8
Putty knife		5

Table D-18. Service kit items. (cont.)

Item		Source
Can opener		5
Atomizing air gauge and regulator	#73-125	8
Pocket thermometer	-30°F to +120°F	1
Adjustable wrench		5
Pliers		5
Screwdrivers		5
Masking tape		1
Barcol impressor	#934	6
Safety glasses		1
Tes Tape glucose enzymatic test strip (catalyst detector)		7
Draw-down bars and paper		3
Weight/gallon cup		3

Sources

1. Chemical/Scientific supplier
   (check Yellow Pages under 'lab supplies').
2. United Industrial Sales Co.
   4410 Glenbrook Road
   Willoughby, OH 44094
   or other fiberglass supplier
3. Paul N. Gardner Company
   316 NE First Street
   Pompano Beach, FL 33060
   Ph: 800-762-2478
4. BYK-Gardner
   Rivers Park II
   9104 Guilford Road
   Columbia, MD 21046
   Ph: 800-343-7721
5. Hardware store or similar establishment
6. Barber Colman
   1354 Clifford Ave
   Love's Park, IL 61132-2940
   Ph: 815-637-3222
7. Drug store
8. ITW Poly-Craft
   4100 McEwen, Suite 125
   Dallas, TX 75244
   Ph: 972-233-2500
   Customer Service: 800-423-3694
   Fax: 972-702-9502

D.13. Equipment Maintenance and Cleanup Procedures

D.13.1. Equipment Maintenance

Spray guns and support equipment represent a considerable investment. A planned program of maintenance should be put in place to protect that investment. Also, refer to equipment manuals for specific instruction.

A maintenance program should include the following review and checklist:

A. Maintain spare parts for all spray guns, pumps, hoses, catalyst injectors or catalyst slave pumps:
   - ☐ Air cap, nozzle and needle.
   - ☐ Packings and gaskets.
   - ☐ Extra hoses and fittings.
   - ☐ Extra gauges.

B. Continuously monitor the following:
   - ☐ Catalyst flow.
   - ☐ Condition of all hoses (no kinks or frayed hoses).
   - ☐ Spray pattern and technique.
   - ☐ Contamination—if present, remove.
   - ☐ Use of proper protective equipment.

C. Daily checklist:
   - ☐ Drain water traps every three hours— more often if needed.
   - ☐ Mix gel coat adequately but not excessively.

     NOTE: Do not overmix gel coats. Overmixing can break down a gel coat's viscosity, thereby increasing sag tendencies. Overmixing also causes styrene loss, which could contribute to porosity. Gel coats should be mixed once a day, for 10 minutes. The gel coat should be mixed to the sides of the container with the least amount of turbulence possible. Air bubbling should not be used for mixing. It is not effective and only serves as a potential for water or oil contamination.
   - ☐ Inventory catalyst for day's use. Check catalyst level. If using a slave arm pump, check for air bubbles.
   - ☐ Start pumps with regulator backed all the way out. Open valve and charge air slowly, checking for leaks. Do not let the pump cycle (both strokes) more than 1 per second.

   To shut down:
   - ☐ Turn off all air pressures and back regulator out.
   - ☐ Bleed lines.
   - ☐ Store pump shaft down to keep wet.
   - ☐ Check for material and catalyst leaks.
   - ☐ Remove spray tips and clean thoroughly. Lightly grease all threads. Protect tips from damage.
   - ☐ Secure the area. Remove all solvents and check for hot spots. Remove and properly dispose of any collections of catalyzed material, catalyst/material combinations, trimming, and FRP dust.

D. Weekly (or more often, if needed) checklist:
   - ☐ Calibrate each spray gun for material flow.
   - ☐ Calibrate each catalyzer or catalyst slave pump for catalyst flow.
   - ☐ Check gel time of gel coat through the gun versus gel time of known control.
   - ☐ Clean filter screens.

D.13.2. Spray Equipment Cleanup Procedures

These instructions are not all-inclusive. For specific instructions, consult equipment manuals.

1. Relieve all pressure from the pump and lines.
2. Place the pump in a container of solvent.
3. Wipe down the outside of the pump.
4. Remove and clean the spray tips.
5. Turn up the pressure slowly until the pump barely pumps with the trigger pulled.
6. Run 2-3 gallons of solvent through the pump and lines, spray into a bucket for proper disposal, then the relieve pressure. Do not let the pump cycle (both strokes) more than one per second.
7. Carefully open the bypass at the filter.
8. Remove and clean the filter—replace if necessary.
9. Immerse the pump in clean solvent.
10. Repeat steps 6 and 7.
11. Wipe the hoses and gun own.
12. Grease or lubricate appropriate parts as necessary.
13. Inspect for worn parts and order replacements.
14. Make sure the pump is stopped in the down position to prolong packing life.
15. Relieve all pressure and back regulators off to the 0 setting.

D.14. Catalyst Precautions

D.14.1. Storage

Methyl ethyl ketone peroxide (MEKP) formulations should be stored as follows:

- **Store in original container in a cool place.** For maximum shelf life, the storage temperature should be below 85°F (29°C). If the peroxide freezes, thaw at room temperature. Do not apply heat. Large quantities (> 500 lbs.) should be stored in a separate free-standing structure in accordance with all laws, regulations, and insurance carriers.
- **Store separately.** Prevent contact with foreign materials, contaminants, promoters, red or white label items, iron, brass, copper and other oxidizables or other flammable items. MEKP must be stored away from the manufacturing area and separated from other combustibles or materials that could induce decomposition. Failure to observe these precautions could result in fire or explosion.
- **Never store in a refrigerator that contains food or that is used for food storage!**
- **Post signs** around storage area reading:
  - DANGER!—NO SMOKING!—KEEP AWAY!
  - FLAMMABLE STORAGE!
  - AUTHORIZED PERSONNEL ONLY!

D.14.2. Safety and Handling

MEKP catalyst formulations are oxidizing materials and should be handled with care. MEKP catalyst can be hazardous to personnel and equipment if not handled in a safe manner.

- **First Aid**—Avoid contact and inhalation!
- **Eyes**—Immediately wash eyes with large volumes of water for 15 minutes and get medical aid.
- **Skin**—Immediately remove contaminated clothing and rewash before wearing. Wash well with soap and water.
- **Swallowing**—Administer milk or water and call a physician immediately. Do not induce vomiting. Have a physician contact the appropriate state Poison Control Center which will be listed under the Emergency Numbers on the first page of the local phone directory.
- **Inhalation**—Remove to fresh air and get immediate medical aid. Prolonged inhalation should be avoided.
- **Personnel should wear proper protective clothing** when handling MEKP catalyst, such as safety glasses, gloves, aprons, air masks, barrier creams, etc.
- **Drain containers** thoroughly and flush empty containers with water-detergent mixture before discarding. The work area should be well ventilated.

All work surfaces, containers, etc. in contact with MEKP should be scrupulously cleaned and all contamination avoided. The work area should be equipped with sprinklers.

- **Never bring** more MEKP catalyst than can be used immediately into manufacturing area. Rotate stocks systematically according to date received or lot number, in order to use the oldest materials first.
- **Do not mix or store with accelerators,** such as dimethyl or diethylaniline or cobalt naphthenate, thiols, or other promoters, accelerators or reducing agents. Special care must be taken to avoid contamination with combustible materials, strong oxidizing or reducing agents or accelerators for polymerization reactions, etc.
- **Equipment and containers for handling MEKP** catalyst should be made of 304 or 316 stainless steel (vented), glass (vented), Teflon®, polypropylene, polyethylene, Tygon®, silicone rubber, or high purity aluminum.
- **Dilution is not recommended.** If the user elects to dilute material, use only pure suitable diluents. **Never use acetone!**
- **If spillage occurs**, use a non-combustible material like vermiculite or perlite absorbent to soak up spilled material. Using a non-sparking shovel and/or dust pan, collect the saturated absorbent and deposit in double polyethylene bags and wet thoroughly with water. Remove the polyethylene bags of absorbent to a remote protected outside area that is safe from the spread of fire should the material self-ignite. Do not place the bags in direct sunlight. For proper disposal, contact a hazardous waste disposal company, local authorities, or state EPA. Any usage, paper towels, etc., should be disposed of in this same manner. Be sure to remove any isolated or hidden pockets of MEKP.

D.14.3. Fire

MEKP catalyst does not ignite easily but will burn very vigorously after ignition. This peroxide must be kept away from all sources of heat and ignition, such as radiators, steam pipes, direct rays of the sun, open flames, and sparks.

- **Small Fires**—Use Class B fire extinguishers (dry chemicals, foam or carbon dioxide) or water fog. Halon is also recommended.
- **Large Fires—Notify Fire Department Immediately!** Evacuate all non-essential personnel. Fight fire from a safe upwind distance with water, preferably a fog, spray or foam.
- **Avoid Inhalation of Fumes**—Use air masks if available.
- **Keep endangered containers cool with water spray to prevent overheating. Flush damaged area well with water; avoid washing MEKP down sewers. Fire may result! Do not attempt clean-up until the damaged area is at room temperature and all signs of danger are gone.**

COMPOSITES SAFETY INFORMATION
(May 2015)

All sales of products manufactured by Polynt Composites USA Inc. and described herein, are made solely on condition that Polynt Composites USA customers comply with applicable health and safety laws, regulations and orders relating to the handling of our products in the workplace. Before using, read the following information, and both the product label, and Safety Data Sheet pertaining to each product.

Most products contain styrene. Styrene can cause eye, skin and respiratory tract irritation. Avoid contact with eyes, skin and clothing. Impermeable gloves, safety eyewear and protective clothing should be worn during use to avoid skin and eye contact. Wash thoroughly after use. Styrene is a solvent and may be harmful if inhaled. Reports have associated repeated and prolonged occupational overexposure to solvents with permanent brain and nervous system damage. Extended exposure to styrene at concentrations above the recommended exposure limits may cause central nervous system depression causing dizziness, headaches or nausea and, if overexposure is continued indefinitely, loss of consciousness, liver and kidney damage.

Do not ingest or breathe vapor, spray mists or dusts caused by applying, sanding, grinding and sawing products. Wear an appropriate NIOSH/MSHA approved and properly fitted respirator during application and use of these products until vapors, mists and dusts are exhausted, unless air monitoring demonstrates vapors, mists and dusts are below applicable exposure limits. Follow respirator manufacturer's directions for respirator use.

The 12th Report on Carcinogens issued by the National Toxicology Program lists styrene as a “reasonably anticipated” carcinogen, but the Report cautions that the NTP listing does not mean that styrene presents a risk to persons in their daily lives. The Styrene Information and Research Center does not agree with the classification as it did not include a review of all available data. SIRC states: “HHS included styrene in the 12th RoC despite the fact that European Union regulators have determined styrene does not represent a human cancer concern. E.U. scientists reviewed the full styrene database, weighing all of the available data in reaching their conclusion.”

The International Agency for Research on Cancer (IARC) reclassified styrene as Group 2B, "possibly carcinogenic to humans." This revised classification was not based on new health data relating to either humans or animals, but on a change in the IARC classification system. The Styrene Information and Research Center does not agree with the reclassification and published the following statement: Recently published studies tracing 50,000 workers exposed to high occupational levels of styrene over a period of 45 years showed no association between styrene and cancer, no increase in cancer among styrene workers (as opposed to the average among all workers), and no increase in mortality related to styrene. Styrene is classified by OSHA and the Department of Transportation as a flammable liquid. Flammable products should be kept away from heat, sparks, and flame.

Lighting and other electrical systems in the work place should be vapor-proof and protected from breakage. Vapors from styrene may cause flash fire. Styrene vapors are heavier than air and may concentrate in the lower levels of molds and the work area. General clean air dilution or local exhaust ventilation should be provided in volume and pattern to keep vapors well below the lower explosion limit and all air contaminants (vapor, mists and dusts) below the current permissible exposure limits in the mixing, application, curing and repair areas.

Some products may contain additional hazardous ingredients. To determine the hazardous ingredients present, their applicable exposure limits and other safety information, read the Safety Data Sheet for each product (identified by product number) before using. If unavailable, these can be obtained, free of charge, from your Polynt Composites USA representative or from: Polynt Composites USA Inc., 99 East Cottage Ave., Carpentersville, IL 60110, 800-322-8103.

FIRST AID: In case of eye contact, flush immediately with plenty of water for at least 15 minutes and get medical attention; for skin, wash thoroughly with soap and water. If affected by inhalation of vapors or spray mist, remove to fresh air. If swallowed, get medical attention. Those products have at least two components that must be mixed before use. Any mixture of components will have hazards of all components. Before opening the packages read all warning labels. Observe all precautions.

Keep containers closed when not in use. In case of spillage, absorb with inert material and dispose of in accordance with applicable regulations. Emptied containers may retain hazardous residue. Do not cut, puncture or weld on or near these containers. Follow container label warnings until containers are thoroughly cleaned or destroyed.

FOR INDUSTRIAL USE AND PROFESSIONAL APPLICATION ONLY. KEEP OUT OF REACH OF CHILDREN.

LIMITED WARRANTY AND LIMITATION OF LIABILITY

LIMITED WARRANTY.

Seller warrants that: (i) Buyer shall obtain good title to the product sold hereunder, (ii) at shipment such product shall conform to Seller's specifications for the product; and (iii) the sale or use of such product will not infringe the claims of any U.S. patent covering the product itself, but Seller does not warrant against infringement which might arise by the use of said product in any combination with other products or arising in the operation of any process. **SELLER MAKES NO OTHER WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE, EVEN IF THAT PURPOSE IS KNOWN TO SELLER. ANY ADDITIONAL REPRESENTATIONS OR SUGGESTIONS REGARDING THE PRODUCT OR ITS POSSIBLE USES ARE BASED UPON SELLER'S GOOD FAITH OPINION AND BELIEF, BUT ARE NOT TO BE CONSTRUED AS AFFIRMATIONS OF FACT, PROMISES, OR DESCRIPTIONS, AND SHALL IN NO WAY BE DEEMED PART OF THE SALE OF PRODUCT.** In particular, and without limiting the foregoing, because of environmental and use conditions beyond Seller's control, Seller offers no warranty and makes no promise concerning the results that may be obtained by the Buyer (or the Buyer's customer) with the product or the performance of the product. Each user should satisfy itself, by adequate testing, of the suitability of the product for its particular application.

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(a) Seller's total liability for any claim arising out of or in connection with this contract, including for breach of contract, warranty, statutory duty, or for other tort, including seller's negligence, shall not exceed the purchase price of such product as to which such liability arises. Seller shall not be liable for any injury, loss or damage, resulting from the handling or use of the product shipped hereunder whether in the manufacturing process or otherwise. **IN NO EVENT SHALL SELLER BE LIABLE FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, INCLUDING WITHOUT LIMITATION LOSS OF PROFITS, CAPITAL OR BUSINESS OPPORTUNITY, DOWNTIME COSTS, OR CLAIMS OF CUSTOMERS OR EMPLOYEES OF BUYER, WHETHER IN AN ACTION UNDER CONTRACT, NEGLIGENCE OR ANY OTHER THEORY, ARISING OUT OF OR IN CONNECTION WITH THIS CONTRACT, OR THE USE, INABILITY TO USE, OR PERFORMANCE OF THE PRODUCT.**

(b) If Seller furnishes technical or other advice to Buyer, whether or not at Buyer's request, with respect to processing, further manufacture, other use or resale of the products, Seller shall not be liable for, and Buyer assumes all risk of, such advice and the results thereof.

The information provided is believed to be accurate at the time of preparation, or prepared from sources believed to be reliable, but it is the responsibility of user to investigate and understand other pertinent sources of information, to comply with all laws and procedures applicable to the safe handling and use of the product and to determine the suitability of the product for its intended use.

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Composites Applications Guide

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