2.3. General Properties of FRP Composites

Overview

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).

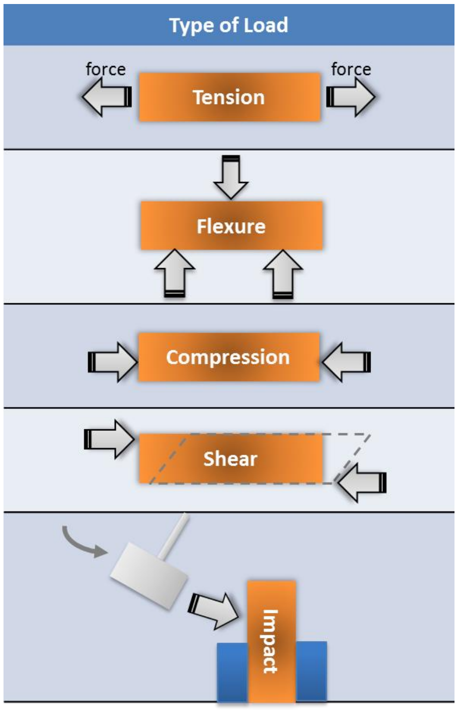


Figure 2-6. Assessing these types of forces is important to composite performance.

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.

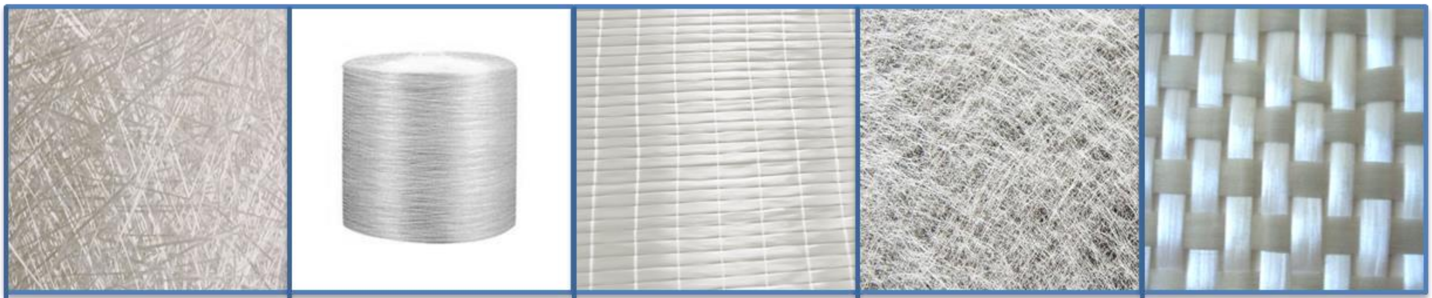
Table 2-2. Glass types used in FRP composites

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 <u>less</u> 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) <u>Source</u>: CompositesWorld, "The Fiber", 2009



Chopped Strand Mat	Roving	Unidirectional Woven	Veil	Woven
•Fibers are randomly oriented, isotropic, short fiber length, least expensive	•Fiberglass bundles on spools for filament winding or used in spray lay-up with a chopper gun	•Woven roving, high strength in a specific direction, 0° or 90-degree	•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	•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.

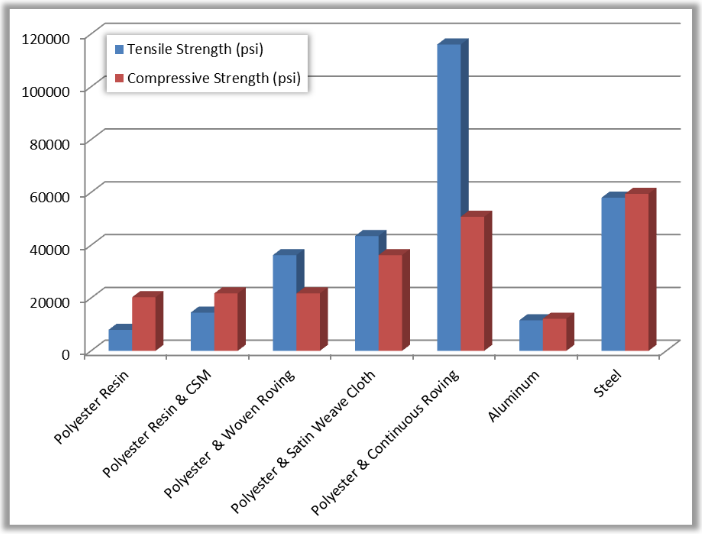


Figure 2-8. A comparison of tensile and compressive strength in polyester composites of different fiberglass types.

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.

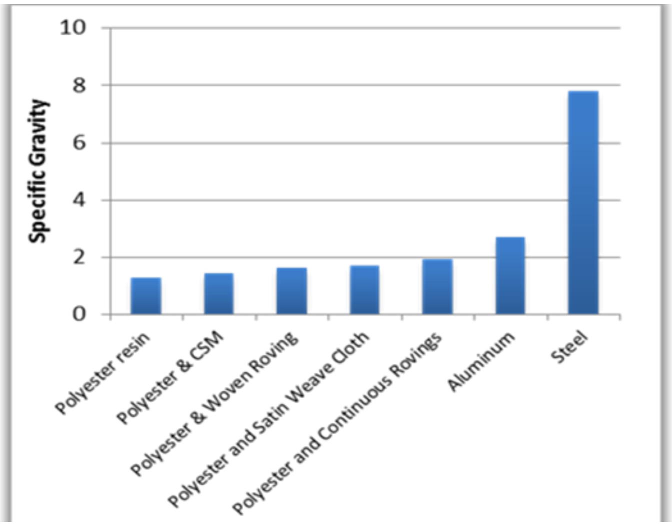


Figure 2-10. This graph shows that the specific gravity of polyester resin and polyester-reinforced composites is lower than aluminum and steel.

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).

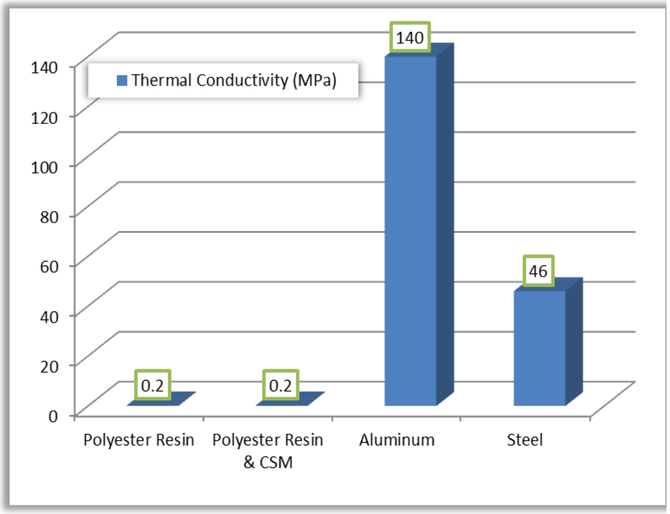
Coefficient of Thermal Expansion (CTE) (α)

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 ≈10^{-16} S/m, semiconductors ≈10^{-4} to 10^{6} S/m, and common metals ≈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.

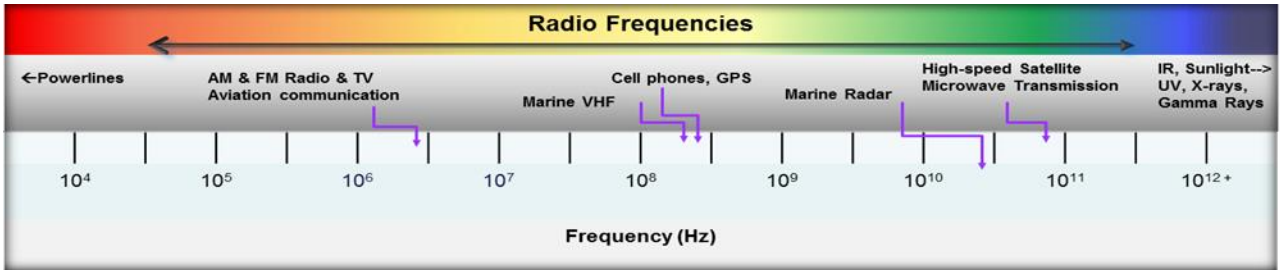


Figure 2-12. Radio frequencies.

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:

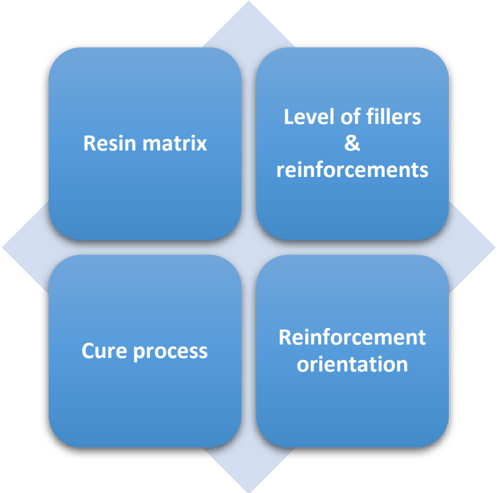


Figure 2-13. Level of shrinkage of overall part.

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.