CRANE Composites

FRP Encyclopedia

Form 7606 | Updated 1/13/13

What is FRP?

FRP, fiberglass reinforced plastic, is a composite made from fiberglass reinforcement in a plastic (polymer) matrix. A construction analogy would be the steel reinforcing bars in a concrete matrix for highways.

By reinforcing the plastic matrix, a wide variety of physical strengths and properties can be designed into the FRP composite. Additionally, the type and configuration of the reinforcement can be selected, along with the type of plastic and additives within the matrix. These variations allow an incredible range of strength and physical properties to be obtained. FRP composites can be developed specifically for the performance required versus traditional materials: wood, metal, ceramics, etc.

Engineers can design the FRP composite to provide the needed characteristics, and avoid cost penalties of an over-engineered product.

What is Fiberglass?

Fiberglass fibers are made from molten glass extruded at a specified diameter. The fibers are gathered into bundles and the bundles combined create a roving. Rovings are a continuous rope, similar to twine, and are wound on a mandrel to form a ball called a doff. Reinforcements for FRP are made from rovings that are chopped into short strands, woven into a cloth or used as continuous roving.

There are many factors that affect the reinforcement characteristics of fiberglass:

- Fiber and bundle diameter and type of glass
- Direction of the fiberglass reinforcement
- The amount of fiberglass reinforcement
- The physical contact (wetout) of the fiber with the polymer

All of these factors must be taken into account when designing an FRP composite so that the required physical property strengths are met.

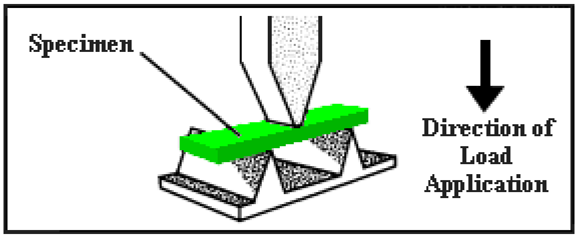
What are Plastic/Polymers?

There are two basic types of plastics/polymers: *thermoplastic* and *thermoset.*
In general, FRP composites utilize a thermoset plastic.

A plastic in which the polymer molecules are not crosslinked (not chemically bonded to other polymer molecules) is a thermoplastic. Since the molecules are not connected by crosslinks, it allows the molecules to spread farther apart when the plastic is heated. This is the basic characteristic of a thermoplastic; the plastic will soften, melt, or flow when heat is applied. Melting the plastic and allowing it to cool within a mold will form the finished product. Typical thermoplastics are: polyethylene (PE)– used in making garbage bags; polyvinyl chloride (PVC)– used for house siding; and polypropylene (PP)– used as carpet fibers, packaging, and diapers.

A plastic in which the polymer molecules are crosslinked (chemically bonded) with another set of molecules to form a "net like" or "ladder-like" structure is a thermoset. Once crosslinking has occurred, a thermoset plastic does not soften, melt, or flow when heated. However, if the crosslinking occurs within a mold, the shape of the mold will be formed. Typical thermoset plastics are: unsaturated polyester (UP)– used for bowling balls and boats; epoxy– used for adhesives and coatings; and polyurethanes (PURs)– used in foams and coatings.
In addition to these basic characteristics, polymers provide the FRP composite designer with a myriad of characteristics that can be selected, depending on the application. Combined with reinforcement of the polymer matrix, a vast range of characteristics are available for FRP composites.

Flexural Strength
The flexural strength of a material is defined as its ability to resist deformation under load. For materials that deform significantly but do not break, the load at yield, typically measured at 5% deformation/strain of the outer surface, is reported as the flexural strength or flexural yield strength. The test beam is under compressive stress at the concave surface and tensile stress at the convex surface. (Also known as bending strength)



ASTM D790:
Specimen of 1/8" x 1/2" x 5" is placed on two supports and a load is applied at the center. The load at yield is the sample material's flexural strength.

Flexural Modulus
The flexural modulus is the number that is associated with the stiffness of a material. Flexural modulus is a measure of how a material will deform and strain when weight or force is applied. It describes the ability of a material, with a specific cross-section, to resist bending when placed under stress. This property is important in civil, mechanical, and aerospace engineering and design, and is frequently used to select correct materials for parts that will support loads without flexing.

Tensile Strength
Tensile strength means resistance of a material to a force tending to tear it apart, measured as the maximum tension the material can withstand without tearing. It is the capacity of the material to resist a tensile load regardless of deflection.

Tensile Modulus
Tensile modulus is a measure of the stiffness of an isotropic elastic material. It is defined as the ratio of the uniaxial stress over the uniaxial strain. It is determined from the slope of a stress-strain curve traced during tensile tests conducted on a sample of the material. A tensile modulus is a number derived through experimentation that describes the strength of a material in tension. The equation for tensile modulus is Force / (Area of Cross Section x Strain).

In layman's terms, it describes how much tension an object can withstand, such as a rope with a weight on it. The bigger the tensile modulus, the more stress it can withstand.

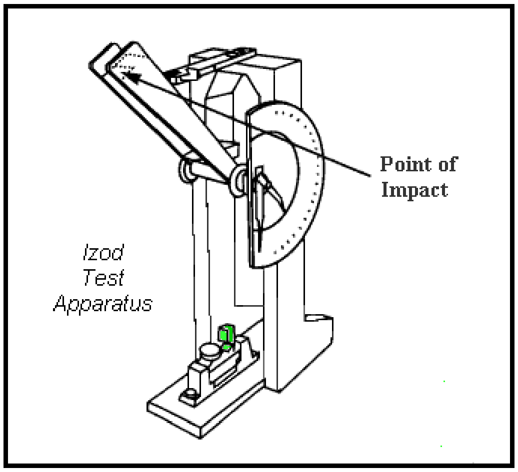
Barcol Hardness
The Barcol hardness test characterizes the indentation hardness of materials through the depth of penetration of an indentor, loaded on a material sample and compared to the penetration in a reference material. The method is most often used for composite materials such as reinforced thermosetting resins or to determine how much a resin or plastic has cured. The test complements the measurement of glass transition temperature, as an indirect measure of the degree of cure of a composite. The hardness of an FRP composite is a direct result of the resin matrix and how it is cured. The more rigid the resin the higher the level of hardness, where as the more flexible laminate will have a lower hardness level. As a resin matrix cures and crosslinks, the hardness value continues to rise. When the resin fully cures, the hardness properties will be at the highest value.

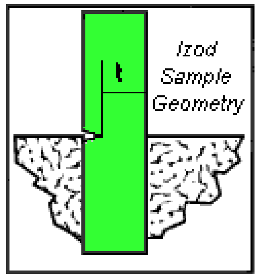
FRP hardness is measured by a simple hand-held device called an "Impressor". An Impressor uses a needle and a spring gauge a reading on a dial or digital display. The three most common measurements of hardness are:
- Shore D
- Barcol 935
- Barcol 934

For most FRP thermoset composites, the Barcol 934 Impressor will likely have a reading between 35 and 40 once the resin matrix has fully cured.

Izod Impact Strength Testing of Plastics

Several methods are used to measure the impact resistance of plastics - Izod, Charpy, Gardner, tensile impact, and many others. These impact tests allow designers to compare the relative impact resistance under controlled laboratory conditions and, consequently, are often used for material selection or quality control. However, these tests generally don't translate into explicit design parameters. The Izod impact test is the most common test in North America. The figure below, from Quadrant Engineering Plastic Products, depicts the Izod impact strength test apparatus.





ASTM D256:
A pendulum swings on its track and strikes a notched, cantilevered plastic sample. The energy lost (required to break the sample) as the pedulum continues on its path is measured from the distance of its follow through. Sample thickness is usually 1/8 in. (3.2 mm) but may be up to 1/2 in. (12.3 mm).

The test method generally utilized in North America is ASTM D256. The result of the Izod test is reported in energy lost per unit of specimen thickness (such as ft-lb/in or J/cm) at the notch ('t' in graphic at right). Additionally, the results may be reported as energy lost per unit cross-sectional area at the notch (J/m^2 or ft-lb/in^2). In Europe, ISO 180 methods are used and results reported based only on the cross-sectional area at the notch (J/m^2).

Polymeric materials that are sensitive to the stress concentrations at the notch ('notch-sensitive') will perform poorly in the notched izod test. Engineers use this knowledge to avoid using such polymers in designs with high stress concentrations such as sharp corners or cutouts. Unnotched specimens are also frequently tested via the Izod impact method to give a more complete understanding of impact resistance. Izod impact tests are commonly run at low temperatures - down to -40°F (-40°C) or occasionally lower - to help gauge the impact resistance of plastics used in cold environments.

Gardner Impact Test

Falling dart impact, also known as Gardner impact, is a traditional method for evaluating the impact strength or toughness of a plastic material. The test is often used to specify appropriate materials for applications involving impact or to evaluate the effect of secondary finishing operations or other environmental factors on plastic impact properties.

The test sample rests on a base plate over an opening of specified diameter. An "impactor" sits on top of the test sample with a nose of specified radius in contact with the center of the test sample. A weight is raised inside a guide tube to a predetermined height, then released to drop onto the top of the impactor, forcing the nose through the test sample. The drop height, drop weight, and the test result (pass / fail) are recorded.

The most common method to analyze this data is called the "Bruceton Staircase" method. A number of samples are used to bracket the pass/fail energy level. Then a series of 20 impacts are conducted. If a test sample passes, the drop height is increased by one unit. If a test sample fails, the drop height is decreased by one unit. The results from the 20 impacts are used to calculate the Mean Failure Height the point at which 50% of the test samples will fail under the impact.

Moisture Absorption

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environments. Moisture absorption of FRP is important because the mechanical properties, such as compressive and fatigue strength, significantly degrade due to moisture absorption.

Coefficient of Linear Expansion

This is a measurement of how much the length of a material will change when the material is heated or cooled. The coefficient of linear expansion of a substance is the fraction of its original length by which the substance expands per degree rise in temperature. When an object is heated or cooled, its length changes by an amount proportional to the original length and the change in temperature. Higher numbers mean that the material will expand or lengthen more for each degree rise in temperature. Smaller numbers indicate relative stability to changes in temperature.

R Value

An R-value is a measure of the thermal resistance to heat/cold flow through a given thickness of material; the higher the R-value, the greater that resistance.

Taber Abrasion

Taber abrasion is a test to determine a plastic's resistance to abrasion. Resistance to abrasion is defined as the ability of a material to withstand mechanical action such as rubbing, scraping, or erosion. Abrasion can be difficult to compare but haze variation or weight loss are often evaluated.

Thermal Conductivity (K factor)

Thermal conductivity is the measure of the ability of a material to transfer heat. Given two surfaces on either side of the material with a temperature difference between them, the thermal conductivity is the heat energy transferred per unit time and per unit surface area, divided by the temperature difference. Higher numbers indicate that more heat is transferred through a material in the same amount of time.

How Durable is FRP?

FRP products are extremely durable versus traditional products. The thermosetting resin properties provide chemical, moisture, and temperature resistance, while the fiberglass reinforcement increases strength and provides good performance over a wide temperature range (the properties of thermoplastics are greatly affected by temperature).

How Cleanable is FRP?

FRP finishes can be either smooth or embossed. Testing has shown that either finish performs (cleans) as well as a finish on stainless steel. Tests for bacteria and mold growth indicate that FRP does not support the growth of either. An embossed finish has the added benefit of providing a more scuff resistant surface than smooth.
Independent testing by Mirinz Laboratories of an embossed FRP finish versus a smooth finish at a meat processing facility indicated that "Over the four week period, bacterial counts at all levels (eye, waist and knee) were generally within the Marinz guidelines and found to be no higher in bacteria counts than that of the existing stainless steel and smooth plastic panels." – Form 6315. FRP finishes meet USDA/FSIS requirements for sanitary finishes.

Does FRP Burn?

FRP can be modified with additives to meet the code requirements of the particular application, either building construction or use in OEM equipment. One common testing method for building materials is ASTM-E84 "Tunnel Test". A test in which the flammability and smoke development are measured and indexed against the performance of Red Oak in the same test. IMPORTANT: Flame Spread and Smoke Development Ratings: The numerical flame spread and smoke development ratings are not intended to reflect hazards presented by FRP products or any other material under actual fire conditions. These ratings are determined by small-scale tests conducted by Underwriters Laboratories and other independent testing facilities using the American Society for Testing and Materials E-84 test standard. These ratings should be used for material comparison purposes only.

Like other organic building materials (e.g., wood), products made of FRP resins will burn. When ignited, FRP may produce dense smoke very rapidly. All smoke is toxic. Fire safety requires proper design of facilities and fire suppression systems, as well as precautions during construction and occupancy. Local codes, insurance companies and any special needs of the product user will determine the correct fire-rated interior finish and fire suppression system necessary for a specific installation.

FRP Terms

- **ABS (Acrylonitrile-Butadiene-Styrene)** – A group of tough, rigid thermoplastics derived from the reaction of acrylonitrile, styrene, and butadiene gas. These materials are polymerized together in a variety of ratios to produce ABS resins.
- **Accelerator** – A highly active oxidizing material suspended in a liquid carrier used to accelerate the decomposition of peroxide catalysts into highly reactive free radicals. These free radicals react readily with polymer and monomer molecules to cure a thermoset resin. Examples are diethylaniline, dimethylaniline, cobalt naphthanate, and cobalt octoate. A cleaning fluid used to remove uncured plastic resin from brushes and clothing. See accelerator
- **Air-Inhibited Resin** – A resin in which surface cure will be inhibited or stopped by the presence of air.
- **BMC (Bulk Molding Compound)** – A combination of resin paste and chopped glass combined with a "sigma" blade mixer under conditions of very high mechanical "working" stress. The compound is delivered to the press in the form of a ball, slab or an extruded log and dropped into the bottom of a mold; the material is flowed outward until it assumes the shape of the mold.
- **Catalyst** – A substance (usually a peroxide) which readily forms free-radicals. These free radicals react with polymer and monomer molecules to speed up the curing of thermoset resins. Catalyst content can vary from 0.2% to 2.0% with higher catalyst levels giving faster cure times. Examples are methyl ethyl ketone peroxide and benzoyl peroxide.
- **Color Pigments** – Ground coloring materials supported in a thick liquid. Added to the resin, they give it color.
- **Crazing** – Hairline cracks either within or on the surface of a laminate, caused by stresses generated during cure, removal from a mold, impact or flexing.
- **Crosslinking** – Chain-reaction polymerization which results in chemical links (bonds) between individual polymer chains. This occurs in all thermosetting resins. Styrene monomer and methyl methacrylate monomer are the most common crosslinking agents used in polyester resins.
- **Cure** – The total crosslinking or polymerization of resin molecules which permanently alters the properties of the resin changing it from a liquid to a solid.
- **Cure Time** – The time required for the liquid resin to reach a cured or fully polymerized state after the catalyst has been added.
- **Delamination** – Failure of internal bending between layers of the laminate.
- **Dimensional Stability** – Ability to retain constant shape and size under various environmental conditions, such as temperature and humidity.
- **End** – As applied to fibrous reinforcements, a bundle of essentially parallel (i.e., entwined) fibers, usually glass.
- **Exotherm Curve** – A graph of temperature plotted against time during the curing cycle. Peak exotherm is the highest temperature reached during the curing reaction.
- **Exothermic Heat** – Heat given off during a polymerization reaction by the chemical ingredients as they react and the resin cures.
- **FBVF (Fiberglass Backed Vacuum Forming)** – Combining a thermoformed thermoplastic sheet with a fiberglass mat or roving using the spray-up or hand lay-up process.
- **Filament** – A single, hair-like fiber of glass characterized by extreme length, which permits its use in yarn with little or no twist and usually without the required spinning operation.
- **Fill or Sanding Resin** – A general purpose polyester resin used to soak and fill reinforcing material in the initial lay-up of a surfacing application; usually contains wax.
- **Fillers** – Any one of a number of inexpensive substances which are added to plastic resins to extend volume, improve properties and lower the cost of the article being produced. Examples are calcium carbonate, alumina trihydrate, feldspar, and calcium sulfate.
- **Fire Retardancy** – Reduction in the ability of a plastic to ignite and burn. This is accomplished by using compounds (resins or additives) that contain halogens (bromine or chlorine) or phosphorous. Usually alumina trihydrate filler is also used because of its ability to release water when exposed to high heat.
- **Foams, Urethane** – Polyurethane resins are produced by reacting diisocyanates with polyols to form polymers having free isocyanate groups. These groups, under the influence of heat or certain catalysts, will react with each other, or with water, glycols, etc., to form a foam.
- **Foams, Flexible** – A thermoplastic urethane foam which is adaptable and often used for cushioning in the furniture and automotive industries.
- **Foams, Rigid** – A thermoset urethane foam which has a higher density, higher modulus, and harder surface than flexible urethane foams.
- **Gel** – A partial cure of plastic resins; a semi-solid, jelly-like state similar to gelatin in consistency.
- **Gelcoat** – A thin surface coat, either colored or clear, of non-reinforced plastic resin. It is occasionally used for decorative purposes but also provides a protective coating for the underlying laminate.

- **Gel Time** – Time required to change a flowable liquid resin into a non-flowing gel.
- **HDPE (High Density Polyethylene)** – A thermoplastic material composed of polymers of ethylene. It has relatively high rigidity and can be modified, e.g. with isoprene, to have high impact strength.
- **Hand Lay-Up** – The oldest and simplest molding technique in which reinforcing materials and catalyzed resin are laid into or over a mold by hand. These materials are then compressed with a roller to eliminate entrapped air.
- **Hardener** – *See catalyst.*
- **Inhibitor** – A substance that retards polymerization, thus extending the shelf life of polymers and monomers. Also used to extend the gel time and cure time of a thermoset resin.
- **Laminate** – A material composed of successive layers of resin and fiberglass bonded together.
- **Lamination** – The compilation of layers of glass matte and resin, and eventual bonding of these layers together.
- **Fiberglass Mat** – A flat, coarse fabric composed of glass fibers. There are three types: chopped-strand mat, continuous strand mat, and surfacing veil.
- **Monomer** – A single molecule capable of polymerizing.
- **Non-Air-Inhibited Resin** – A polyester resin using phthalic anhydride as the starting point. A surfacing agent is added to exclude air from the surface of the resin.
- **Orthophthalic Resin** – A polyester resin using phthalic anhydride as the starting point. Most thermoset polyester resins use two types of anhydrides in their production: phthalic anhydride and maleic anhydride. A higher percentage of phthalic anhydride yields a less reactive resin.
- **PE (Polyethylene)** – A thermoplastic material composed of polymers from ethylene. It is normally a translucent, tough, waxy solid which is unaffected by water or by a large range of chemicals.
- **PVC (Polyvinyl Chloride)** – A thermoplastic material composed of copolymers of vinyl chloride. A colorless solid resistant to water, concentrated acids and alkalis.
- **Polyester Resin** – The term generally used for unsaturated polyesters. Formed by the reaction of a dibasic organic acid or anhydride and a polyhydric alcohol to form a series of ester linkages.
- **Polymer** – The end product, usually a solid, produced from monomers.
- **Porosity** – The formation of undesirable clusters of air bubbles in the surface or body of the laminate.
- **Pot Life** – The length of time that a catalyzed resin remains workable.
- **Preform Fiber** – Glass formed over a screen shaped like the mold in which the preform will be used. It eliminates the need for over-lapping or mitering the corners in molding. Used primarily to form deep draws or complex parts.
- **Prepreg** – Glass roving or cloth loaded with B-stage resin, catalyst, and pigment ready for placement in a mold.
- **Promoter** – *See accelerator*.
- **Release Agent** – A lubricant, often wax, is used to prevent the adhesion of the molded part to the mold. An internal lubricant such as zinc stearate is used in high temperature molding to obtain release where wax would melt or be absorbed.
- **Resin** – A liquid plastic substance used as a matrix for glass fibers. It is cured by crosslinking.
- **Roving** – Continuous strands of glass fibers which are grouped together and wound on a tube like untwisted yarn.
- **Shelf Life** – The length of time a non-catalyzed resin maintains specified working properties while stored in a tightly sealed opaque container.
- **Sizing** – The treatment applied to the glass fiber to allow the plastic resins to flow freely around and bond to them.
- **SMC (Sheet Molding Compound)** – An integrated, ready-to-mold fiberglass reinforced polyester material. The compound is composed of a filled thermosetting resin and a chopped or continuous strand reinforcement. The primary use is in matched die molding.
- **Spray-Up** – Covers a number of techniques in which a spray gun is used to simultaneously deposit fiberglass and catalyzed resin on a mold.
- **Stage (of Resin**) – The condition of a partially cured resin polymer when it is only partially soluble in monomer or acetone but still plastic and still heat fusible.
- **Staple Fiber** – A glass fiber of short length formed by blowing molten glass through holes.
- **Styrene Monomer** – A water-thin liquid monomer used to thin polyester resins and act as the crosslinking agent.
- **Substrate** – Any material which provides a support surface for other materials.
- **Tack** – The stickiness of an adhesive measurable as the force required to separate an adherent from it by viscous or plastic flow of the adhesion.

- **Thermoplastic** – A plastic material that can be readily softened and reformed by heating and be re-hardened by cooling.
- **Thermoset** – A plastic material that will undergo or has undergone a chemical reaction caused by heat, catalyst, ultraviolet light, etc., leading to the formation of a solid. Once it becomes a solid, it cannot be reformed.
- **Thickeners** – Material added to the resin to thicken it so that it will not flow as readily.
- **Thinners** – Material added to plastic resins to thin it. They may also be crosslinking agents.
- **Thixotropic** – The property of becoming a gel at rest, but liquefying again on agitation.
- **Viscosity** – A measure of the resistance of liquid to flow.
- **Wet-out** –The ability of a resin to saturate fiberglass reinforcement.
- **Yarn** – A twisted strand or strands of glass fibers which can be woven, braided, served, and processed.