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Fiberglass and Composite Material Design Guide

The purpose of this design guide is to provide some general information on fiberglass and composite materials and to explain how to design products with these materials. If you have specific questions, please contact our engineers at Performance Composites and they will gladly assist you.

Composite Materials

Composites materials are made by combining two materials where one of the materials is a reinforcement (fiber) and the other material is a matrix (resin). The combination of the fiber and matrix provide characteristics superior to either of the materials utilized alone. Examples of composite products in nature are wood, bamboo and bone, and an example of an early man-made manufactured composite is mud and straw which has been used for over 10,000 years.

Composite materials are very versatile and are utilized in a variety of applications. Composite parts provide superior strength, stiffness and light weight, and can be formed into any shape. An ideal applications are large complex-shaped structures such as fiberglass covers. Composite products are ideal in applications where high-performance is required such as aerospace, race cars, boating, sporting goods, and industrial applications. The most widely used composite material is fiberglass in polyester resin, which is commonly referred to as fiberglass. Fiberglass is lightweight, corrosion resistant, economical, easily processed, has good mechanical properties, and has over 50 years of history. It is the dominant material in industries such as boat building and corrosion equipment, and it plays a major role in industries such as architecture, automotive, medical, recreational and industrial equipment.

The typical composite materials can be made with fibers such as fiberglass, carbon fiber (graphite), Kevlar, quartz and polyester. The fibers come in veil mat, short fibers mat, woven cloth, unidirectional tape, biaxial cloth or triaxial cloth. The resins are typically thermal set resins such as polyester, vinyl ester, epoxy, polyurethane and phenolic. The resins start as a liquid and polymerize during the cure process and harden. The weight ratio of fibers to resin can range from 20% fibers to 80% resin to 70% fibers to 30% resin. Typically the higher fiber content provides even better strength and stiffness, and continuous fibers provide better strength and stiffness. The use of composite materials provides engineers the ability to tailor the combination of fibers and resin to meet design requirement, and perform better than standard materials.

Composites materials are replacing metals and plastics in many industries and composites are the material of choice for many new applications. Please see table 1 for a comparison of cost and properties of commercial grade composite materials to aluminum, steel and wood.

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TABLE 1

	Fiberglass & polyester	Graphite & epoxy	Wood (Douglas fir)	Aluminum Sheets 6061 T-6	Steel sheets
Material Cost $/lb	$2.00-3.00	$9.00-20.00+	$0.80	$4.50-10.00	$.50-1.00
Strength, yield (psi)	30,000	60,000	2,400	35,000	60,000
Stiffness (psi)	1.2×10^{6}	8×10^{6}	1.8×10^{6}	10×10^{6}	30×10^{6}
Density (lb/in^3)	.055	.065	.02	.10	.30

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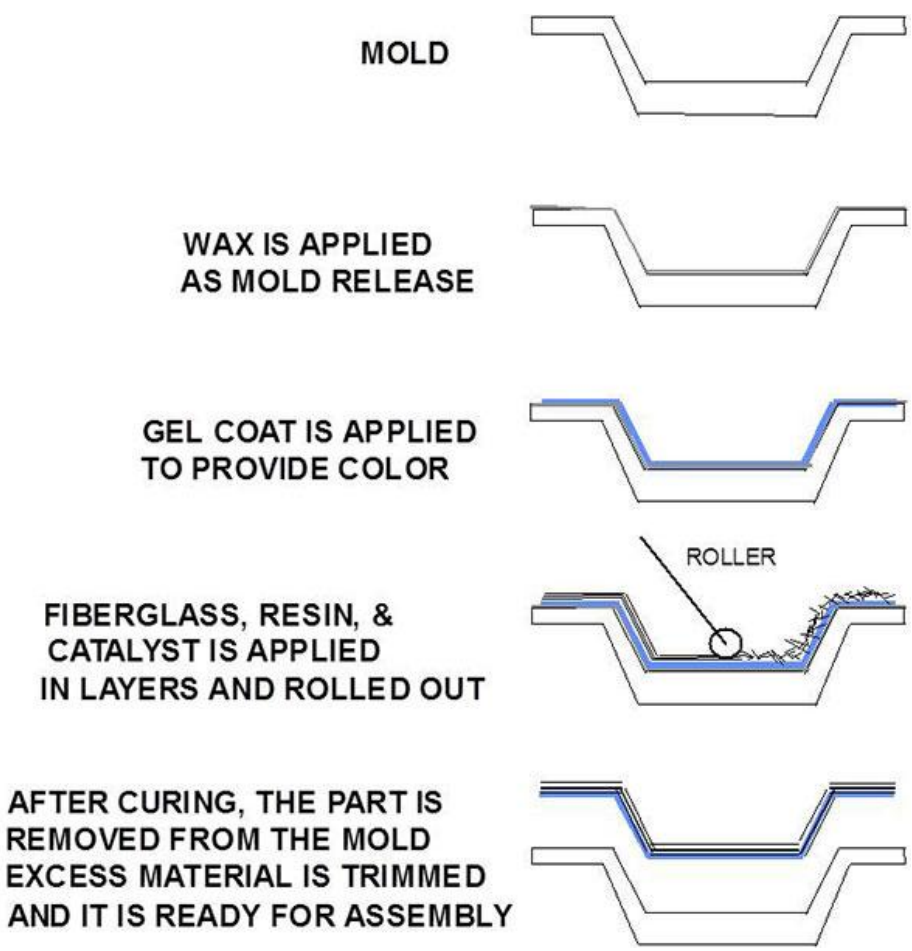
Open Mold Manufacturing process

The most common manufacturing process for fiberglass is the wet lay-up or chopper gun spray process using an open mold. The shape of the part is determined by the shape of the mold, and the mold surface is typically in contact with the exterior of the part. Mold release is first applied to the mold to prevent the fiberglass part from adhering to the mold. Gel coat, which is pigmented resin, is applied to the mold to give the part color. Fiberglass and resin are then deposited onto the mold and the fiberglass is compressed by rollers, which evenly distributes the resin and removes air pockets. Multiple layers of fiberglass are deposited until the desired thickness is achieved. Once the resin is cured, the part is removed from the mold. Excess material is trimmed off, and the part is ready for paint and assembly. There are also closed mold processes for making fiberglass parts.



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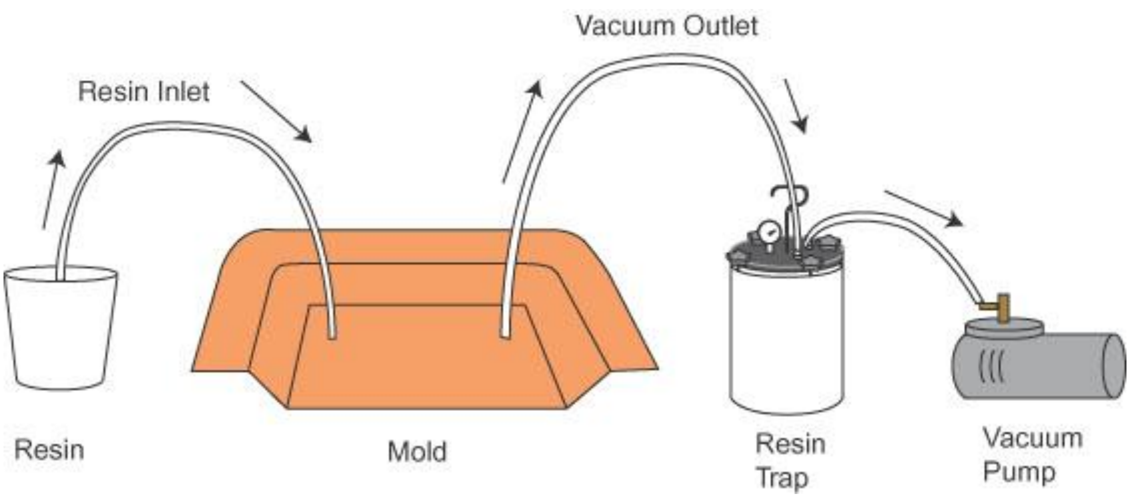
Vacuum Infusion Process (light RTM)

The Vacuum Infusion Process (VIP) is a technique that uses vacuum to pull resin into a laminate. The process is done first by loading the fabric fibers and core materials into the mold, then either using a vacuum bag or a counter mold to close the mold and create a vacuum seal. A vacuum pump is used to remove all of the air in the cavity and consolidate the fiber and core materials. Still under vacuum, resin is infused into the mold cavity to wet out the fiber. The locations of the vacuum ports and the resin insertion points need to be carefully planned to ensure full resin infusion. The advantage of the vacuum infusion process is to create a laminate with very high fiber content (up to 70% fibers by weight), thereby creating a very high strength and stiff part at minimum weight. Vacuum Infusion is also an efficient manufacturing process for complex laminate with many plies of fibers and core materials.



Prepreg manufacturing Process

Prepreg is fabric that has been pre-impregnated with resin (typically epoxy). The resin is cured to stage B, creating a gel that is neither liquid nor solid. Prepreg materials need to be kept frozen to prevent it from being fully cured. The prepreg is cut into shapes and applied to the mold in layers. A vacuum bag is then placed over the material and a vacuum pump draws all of the air out and compresses the layers together and consolidating the materials. The loaded mold is then put into an oven liquefying the resin so it will wet out the fibers. As the temperature increases, the resin will polymerizes and become hardens. The advantages of prepreg are very tight control of fibers ratio, low voids and precise location of the fabric and thickness uniformity. Prepreg materials are typically used for aerospace products and high-performance light weight parts.

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Design Information

Like any material, fiberglass has advantages and disadvantages; however, in applications such as corrosion, low to medium volume production, very large parts, contoured or rounded parts and parts needing high specific strength, fiberglass is the material of choice. Fiberglass is a designer's ideal material, because the parts can be tailored to have strength and/or stiffness in the directions and locations that are necessary by strategically placing materials and orienting fiber direction. The design and manufacturing flexibility of fiberglass, provides opportunities to consolidate parts and to incorporate many features into the part to further reduce the total part price. Some general design guidelines are listed below:

Material thickness	Typically range from 1/16" to 1/2". Can use sandwich construction to achieve lighter and stiffer parts.
Corner radius	Recommend 1/8" or larger
Shape	Will duplicate the shape of the mold. Can be heavily contoured. Undercuts can be accommodated using multi-piece molds.
Dimensional tolerance	Tool side can be $\pm$ .010" of the tool Non Tool Side $\pm$ .030"
Surface finish	Tool side can be class A Non tool side will be rough, but can be smoothed out Can be gel coated painted, or use any other surface coating
Shrinkage	.002 in/in
Electrical properties	RF Transparent Excellent insulating characteristics Can provide EMI shielding through conductive coating
Fire retardant	Resins available in fire retardant applications meeting various ASTM or UL specifications
Corrosion	Resins available for corrosion applications, especially for hot brine, most acids, caustics, & chlorine gases

Mechanics and analysis of composite materials

The mechanical properties of metal and plastics are isotropic (same strength and stiffness is all directions). The mechanical properties of composite materials are anisotropic (different strength and stiffness depending on the direction of fibers and loading). The difference between isotropic and anisotropic properties complicates the analysis of composite design, but most FEA programs have composite analysis capabilities. The anisotropic property of composite materials allows the engineer to tailor the composites materials to add strength and stiffness only in areas and directions where it is needed thereby reducing weight and costs. Our engineers are happy to help you with the analysis and design.

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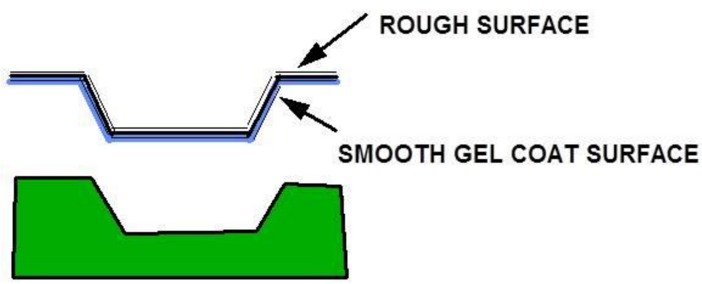
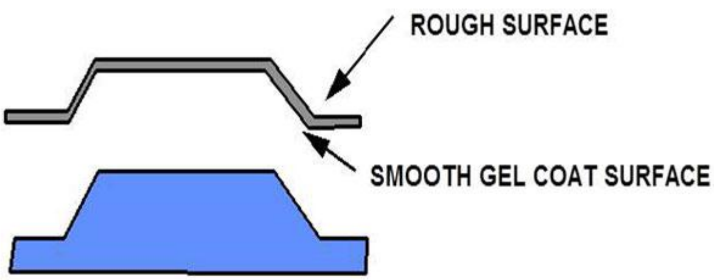
Tooling

Tooling or molds are used to define the shape of the fiberglass parts. The fiberglass part will pick up all shapes and features of the molds; therefore the quality of the part is heavily influenced by the quality of the mold. The molds can be either male or female. The female molds are the most common and they will produce a part with a smooth exterior surface while a male mold will produce a smooth interior surface (please see drawing below).



FEMALE MOLD



MALE MOLD

For very short production runs (less than 10 parts), temporary molds can be made from wood, foam, clay or plaster. These molds are economical and can be fabricated quickly, which will allow inexpensive prototype parts to be fabricated. For larger volume production, molds are typically made with fiberglass. These molds have a life expectancy of 10+ years and 1000+ cycles. Fiberglass molds are inexpensive and usually only cost 6 to 10 times the price of the part.

The mold is a mirror image of the part. To create a mold, a master (plug) is required. The master can be an actual part, or can be fabricated out of wood, foam, plaster, or clay. The exact shape and finish of the master will be transferred to the mold. Once the master is completed, it is polished, waxed and the mold is built up on the master. The fabrication technique of the mold is similar to fabricating a fiberglass part except that tooling materials (gel coat, resins, and cloth) are used to provide a durable mold that has low shrinkage and good dimensional stability. Once the mold is laminated, it is reinforced with wood, fiberglass or a metal structure to ensure that it retains the proper shape. The mold is then removed from the master and put into production.