Fundamentals of fiberglass

Introduction

Composites are materials made up of two individual components who's combined physical strength exceeds the properties of either of them individually. The reinforced plastic composite consists of a fibrous reinforcing network embedded in the cured resin matrix. The thermosetting type resin is a plastic that cures from a liquid to a solid through a chemical reaction of its two components. Once this reaction occurs, the material can not be reformed.

A typical thermosetting epoxy resin has a tensile strength below 10,000 psi and is quite brittle. When such a resin is reinforced with glass fibers the resulting composite can have a tensile strength between 45,000-50,000 psi. It also becomes extremely resistant to impact damage. This high strength for the relatively low weight is the fundamental reason that fiberglass composites are popular. Another significant reason is their tailorability. Since the reinforcement can be added in any direction, layers can be built up which are perfectly oriented with the stress the part is to encounter. This saves additional weight by removing unnecessary material from areas with little stress. Other reasons for composite popularity are how easily these materials can be formed into complex shapes, that they have superior resistance to most environments and they can be used by most individuals without a major investment in equipment.

Fiberglass is only one type of reinforcement. Other common types are carbon fiber and Kevlar® . These will be explained shortly in greater detail where their importance and variety can be covered adequately.

Brief Glossary Of Composite Terms

MOLDING: Molding is the process of constructing a part within a mold. Typically, precut reinforcement is placed one layer at a time into the mold and saturated with resin. When the part has achieved the desired thickness and orientation, it is left to cure. When it is demolded, it will have the exact shape of the mold surface.

LAMINATING: Laminating originally referred to applying a thin protective coating of resin and reinforcement over a surface such as wood. The term's use has broadened to include virtually any finished composite part, molded or otherwise. A current example would be: "The part tested was a 10-ply vacuum bagged laminate".

LAMINATION SCHEDULE: A list of the individual layers and orientation of the plies used to construct a composite part. Typically specifies the ounce weight of the reinforcement and the weave style.

CASTING: Casting refers to pouring a large mass of resin into a cavity. The cavity can be a mold when casting parts, or it can be the backside filler for a tool when making the mold itself. Specialized casting resins are necessary which generate less heat during their cure and thus create less distortion in the final part. Fibrous fillers can be added as needed to strengthen the casting.

SCULPTING: Sculpting is usually accomplished by carving a shape out of polyurethane foam and then laminating the surface. This can be done to create a plug for the molding process, or to shape a finished part in the case of moldless construction.

Reinforcement Types, Properties, and Styles

The physical properties of composites are fiber dominant. This means that when resin and fiber are combined, their performance remains most like the individual fiber properties. For example, it is not satisfactory to merely average the tensile strengths of fabric and resin to determine the strength of a panel. Test data shows that the fibrous reinforcement is the component carrying the majority of the load. For this reason, fabric selection is critical when designing composite structures.

The average fabricator has a choice of three types of reinforcing materials with which to construct a project. These are fiberglass, carbon fiber, and Kevlar®. All three have their attributes and short comings, and are available in numerous forms and styles.

The most widely accepted and least expensive reinforcement if fiberglass . It has been used successfully in many applications since the 1950's, and much is known about its properties. It is relatively lightweight, has moderate tensile and compressive strength, is tolerant of both damage and cyclical loading, and is easy to handle and machine.

Carbon fiber is a modern reinforcement characterized by extremely low weight, high tensile strength, and high stiffness. The material handles easily and can be molded much like fiberglass. However, some advanced techniques are necessary to achieve the maximum properties of this material. Carbon fiber is also the most expensive of the reinforcing fibers. This fact often limits its use to parts needing selective reinforcement or high stiffness with the least weight.

Kevlar®, the most common aramid type fiber, offers a third reinforcement option. Kevlar exhibits the lowest density of any fiber reinforcement, high tensile strength for its weight, and superior toughness. It is priced favorably between fiberglass and carbon fiber. Kevlar is puncture and abrasion resistant, making it the reinforcement of choice for canoes, kayaks, and leading edges of airfoils. On the down side, Kevlar is difficult to cut and machine during part fabrication. A pair of sharp scissors should be dedicated solely to cutting Kevlar. It also has a low service temperature and poor compressive properties. It is possible to combine Kevlar with other materials creating a hybrid laminate to compensate for the shortcomings.

The following is a chart comparing the relative properties of reinforcing fabrics. The legend is as follows: P=Poor, F=Fair, G=Good, E=Excellent

Specifications	Fiberglass	Carbon	Kevlar®
Density	P	E	E
Tensile Strength	F	E	G
Compressive Strength	G	E	P
Stiffness	F	F	G
Fatigue Resistance	G-E	G	E
Abrasion Resistance	F	F	E
Sanding / Machining	E	E	P
Conductivity	P	E	P
Heat Resistance	E	E	F
Mositure Resistance	G	G	F
Resin Compatibility	E	E	F
Cost	E	P	F

Forms Of The Reinforcement

These three reinforcements can be purchased in many forms and weaving styles. All three are generally available in tow (pure unidirectional fiber form), veil mats , and woven fabrics. Fiberglass is also offered in a pressed chopped strand mat option.

TOWS OR ROVINGS : Material in this form exhibits the highest properties achievable for a given fiber family. They are typically supplied on spools so that they may be fed into filament winders or unrolled and cut as they are needed for selective stiffening. The fibers must remain in tension as the resin cures or the mechanical advantage is lost. Once in service, kinks in the tow must first be pulled straight before the fiber will hold a load. Obviously, the straighter the initial fabric placement , the better. It is possible to wind extremely strong tubes using this form of material.

VEIL MATS. Veil mats are thin plies of continuous strand fibers that are looped randomly throughout the roll of material. It has the consistency of tissue paper. A light binder is present to hold the veil together. While it is not intended for structural use, it has two very important functions. First, it can be placed I the mold directly behind the surface coat to minimize the print through of the heavier reinforcing cloths applied later. This thin outer coating also permits some surface sanding of finished parts without cutting into the reinforcing fabric below. The second largest use is with sandwich cores. A veil mat may be placed directly over the core to maintain the optimum bond-line thickness. Veil is also effective at keeping excess resin from draining into the cells of honeycomb cores when a vacuum is not being used.

CHOPPED STRAND FIBERGLASS MAT . This material is just what the name implies. The fibers are typically 3-4 inches in length and are randomly oriented. Chopped strand mat is not a very strong material because of the short fiber length. However, it is isotropic. This means that it is equally strong in all directions. Mat and fillers are the only composite reinforcements exhibiting this trait. This is the least expensive reinforcement form and is thus the most widely used. It is suitable for molds and part production. The random orientation effectively hides fabric print through of gelcoats and makes molds which are equally stiff in all directions. It should be noted that chopped strand mat is only compatible with polyester resin.

WOVEN FABRICS. Woven fabrics are strong reinforcements because the fibers are bundled into yarns oriented in just two directions. The warp and fill yarns run at 0 and 90 degrees respectively. Thus, fabrics are anisotropic, or strong in only two directions. Fabrics need to be oriented so the fiber yarns run parallel to the expected loads. If extra strength is needed in a different direction, another ply must be added at an angle to the first. The most common angles are +/- 45 degrees.

Styles Of Woven Fabrics

There are many styles of woven fabric to choose from. The most common are the plain weave fabrics where the warp and fill threads cross alternately. Plain woven fabrics are generally the lease pliable, but are easy to cut and handle because they don’t unravel badly. However, their strength is compromised due to the severe “prebuckling” already present in the fabric. As stated under tows, fibers only produce their greatest strength when they are perfectly straight. The frequent over/under crossing of the threads reduces the strength of plain weave types, though they are still adequate for all but the highest performance applications.

Twill weaves and satin fabrics are highly pliable and stronger than the plain weave styles. In a satin weave, 1 filling yarn floats over 3-7 other warp threads before being stitched under another warp thread. Threads run straighter much longer in this loosely woven type, maintaining the theoretical strengths of the fiber. Obviously, pliability is higher and these fabrics conform easily to complex shapes. Once cut, however, they can unravel easier because each thread is not held as tightly. Twill weaves offer a compromise between the satin and plain weave types, as well as an often desirable herringbone cosmetic finish.

Practical Guide To Selecting Reinforcements

One must first consider the needs of the finished part. List how stiff , lightweight, abrasion resistant, or damage tolerant the structure needs to be. Don't forget to consider cost as well. Compare the list to the description of the materials and the chart referenced above to select the best compromise. It is in relation to performance versus cost that fiberglass remains quite a value.

In general, any plain weave fabric can be used for laminating a protective layer over wood. If the laminate is for marine use, no fewer than two layers should be considered. Lightweight fabrics are good if the protective layer is to be transparent such as on strip built canoes. Medium weight plain weaves between 6 and 10 ounces/ sq yd. are perhaps the most versatile. Typically called boat cloths , they are inexpensive, strong, and easily formed. They are often combined with layers of mat when building molds, or used to protect the core in moldless construction.

The aerospace satin and twill weaves should be used wherever the highest physical properties are needed.

Selecting Resin

Resin selection is based on fabric compatibility, service conditions, and the desired characteristics of the finished part. There are two common types of thermosetting resin to choose from: epoxy and polyester. Moldmaking, molding, laminating and casting operations can be performed with either system. Epoxy is the higher performance and higher priced system. It is used in weight critical, high strength, and dimensionally accurate applications. Polyester resins are less expensive, offer more corrosion resistance, and are more forgiving than epoxies. For this reason, they are the most widely used.

Certain resins are not compatible with all fabrics. For instance, Kevlar often exhibits adhesion problems, so epoxy or the highest grade polyester should be used. Also, fiberglass mats have a polyester soluble binder. Epoxies cannot dissolve this, and should never be used with mat. Check material compatibility thoroughly when designing the project.

The following are some loose recommendations for resin selection.

ADHESIVE APPLICATIONS. When an application require adhesive properties, epoxies are strongly advised. Choose the epoxy with the pot-life closest to the working time required. Milled glass fiber can be blended to create a structural filler paste when needed.

MOLDING APPLICATIONS are best done with part # 77 POLYESTER MOLDING RESIN or any medium to long life epoxy. Precut the fabric reinforcement and keep it readily at hand. Use brushes, squeegees, and saturation rollers to wet-out the fabric. For parts which will be used in heavily corrosive environments, select our part # 90 ISOPHTHALIC POLYESTER RESIN or our part # 1110 VINYL ESTER RESIN.

GENERAL PURPOSE REPAIR AND THIN LAMINATIONS are best accomplished with a waxed polyester resin like part # 83. If an epoxy is chosen, use a short pot-life version which will cure faster when spread in thin sections.

MINIMUM DISTORTION. Epoxies always provide the most dimensionally stable parts and molds, but a premium grade polyester resin such as part # 90 ISOPHTHALIC POLYESTER RESIN can be used successfully.

CASTING: Thick sections can be cast with the part # 2000/2120 slow cure epoxy system or with part # 99 CLEAR POLYESTER CASTING RESIN . Standard resins are not recommended to be poured in a mass large enough for casting.

Selecting Tools

Compared to classical machining and toolmaking, few dedicated tools are necessary when working with composites. However, there are a number of items which make the job easier while improving production quality.

Convenience items like clean mixing tubs, scales , and other measuring equipment, quality scissors , and plenty of gloves are simple items which are often overlooked. Squeegees, brushes and rollers are the recommended applicators for saturating the reinforcement with resin. Squeegees and saturation rollers can also be used to work air from the laminate and compress the layers of fabric. Razor knives and jig saws are needed to trim finished parts and molds. Use quality composite blades with a medium tooth count to speed the cut. Mechanical sanders, grinders, and buffers are helpful on larger jobs, but the work can be done by hand given enough time and effort. The final equipment recommendation would be a fabric cut-rack to hold and store the material. The rack supports the fabric horizontally on its tube, and can be made with simple construction materials.

Estimating Material Weights And Cost

Accurate material estimates are necessary for two reasons.First, they obviously are needed for proper ordering, material stocking, and bidding of projects. More importantly though, estimates offer the opportunity to calculate the weight or cost of the part using a variety of laminating schedules before beginning to build.

Unlike estimating coverage when painting, resin usage will vary depending on the type of reinforcement being used. The heavier the fabric, the more resin it will take to wet it out. A good hand laminate consists of about 50% fabric and 50% resin by weight. For example, if an application requires 3 sq yds of a 4 oz/sq yd fabric (total fabric weight = 12 ounces), 12 oz of resin will also be needed. However, if 3 yards of 10 oz/sq yd fabric is chosen (total fabric weight = 30 ounces), 30 oz. of resin will be needed.

Glass mat requires a minimum of 2 ounces of resin for each ounce of mat. Therefore, it the application calls for 20 sq feet of 1-1/2 oz/sq ft mat, it will require a minimum of 60 ounces of resin. Remember that mat is specified in ounces per square foot, where fabrics are specified in ounces per square yard. 1-1/2 oz/ sq ft chopped mat actually weighs 13.5 oz/ sq yd!

Since there are so many possible combinations of materials, one should calculate the weight and cost of a single layer using a variety of reinforcements. These can then be added or subtracted form the theoretical laminate until the design properties are achieved.

Worksheet For Estimating Materials

1) Begin by calculating the surface area of the project. Estimate irregular shapes by measuring the approximate sized rectangles necessary to contain the tapered areas. Multiply the length times the width for each rectangle, and then add all of individual rectangles together to get the total surface area of the part. If the calculation is in square feet, divide by 9 to get square yards.
2) Make a list of each type of reinforcement being considered for the lamination. Multiply the square yards calculated above times the ounce weight of the fabric. This is the total weight of one layer of that material. It is also the amount of resin required to saturate it. When this is known for two or three different types of materials, it is possible to calculate the weight and cost of a laminate constructed from any combination of these fabrics. To convert the ounce weight to pounds, divide by 16. Those inexperienced in saturating fiberglass tend to use far too much resin. A well saturated laminate is uniformly translucent, without milky appearing dry spots, but for the sake of weight and cost, has little excess resin in it.
3) The final step is to calculate gel coat, primer coat, and surfacing primer usage.

All but the very lightest of molded laminations require a gel coat. This gel coat should be 15-20 mils in thickness.

A 20 mil gel coat will require one gallon of gel coat mix for each 80 square feet of mold surface. If a lighter surface coat is desired, spray part # 1041-B Duratec Surfacing Primer into the mold in place of the gel coat.It can be applied thinner (10-12 mils), and thus lighter.Duratec is also the perfect finish coat for covering moldless foam or plywood laminations.

When covering plywood with fiberglass, additional resin will be required to prime the wood as well. For most woods this coat will require about 3 ounces of resin for each square foot of surface. This is in addition to the resin required to saturate the fiberglass.Just to be safe, add 20% more resin to the original estimate.

An Example:
The following example will help clarify material estimation as well as cover some aspects of design.

Construction has been started on a plywood John Boat. The boat is 12 feet long, 4 feet wide at the bottom, each side is 2.5 feet tall, and the transom is 2x5 feet. The ¾" plywood supports the loads, but fiberglass needs to seal and protect both the inside and the outside of the boat. Fiberglass has been chosen over Kevlar to keep costs low. How much material will it take, and how much weight will be added?

1) Begin by calculating the surface area for each piece.

Floor
12ft x 4ft = 48 sq. ft

Sides
12ft x 2.5ft = 30sqft x 2 = 60 sq ft

Transom
2ft x 5ft = 10sqft

Total
118sqft

There are 118 sq ft per layer, and 2 layers will be added to both the inside and the outside of the boat. Next, divide 118 sq ft by 9 sq ft to find the total square yards per layer. This conversion is necessary so the area can be compared to the fabric weights which are listed in square yards.

118 sq ft / 9 sq ft =13.5 sq yards

The fabrics under consideration are 10 ounce and 7.5 ounce plain weaves. The fabric weights will be multiplied by the surface area to determine total weight of one layer of fabric.

10 oz/sq yd x 13.5 sq yds = 135 total oz. / 16 = 8.5lbs/layer

7.5 oz/sq yd x 13.5 sq yds = 101.25 total oz/16 = 6.5 lbs/layer

With a 50/50 fabric-resin raitio, the resin will also weigh the same as the fabric.

Since the boat will only be used near sandy shores, the 7.5 ounce fabric is selected, saving 4 pounds total/ layer (2lbs fabric, 2 lbs resin).If the shore had been rocky, the 10 ounce fabric might have been a better choice for long term durability despite the extra weight.

2) Calculate all extra resin and surfacing primer consumption as stated above. The plywood will need a prime coat of polyester resin.It will tak 3 oz per sq ft of surface area to sufficiently coat the surface.

3 oz x 118 sq ft = 354 oz / 16 = 22 lbs of resin.

The surface coat will be created by spraying on part # 1041-B Duratec Surfacing Primer. One gallon will easily cover the 118 sq ft with a 12 mil layer of the material.

Conclusion

This guide is intended to help the beginner conceptualize the fiberglass composite process. Due to the recent advances and availability of other high performance composite materials, some of them have been included in this document as well. The importance of fiber selection is stressed, and a chart comparing the strengths and weaknesses of the three available reinforcements is included as a convenient reference. Design projects around these fabric properties, then select a resin system that is compatible with the fabric and final service conditions the part will see. Material estimates are also important in the design process.Variations in the lamination schedule can be compared at the design stage, and the laminate can be tailored to the service conditions and budget of the project. The example of the three step material estimation process should make these estimates painless. Obviously, there is more information available on these subjects, but these fundamentals demonstrate the ease with which the advantages of composites can be achieved.