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## **FIBERGLASS REINFORCED PLASTICS FOR CORROSION RESISTENCE**



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# Fiberglass-Reinforced Plastics for Corrosion Resistance

This article covers the various resins used in corrosion resistant FRP equipment, as well as methods of equipment fabrication.

Fiber-Glass-Reinforced plastics (FRP) are used for many varied applications; from boats and bathtubs to missiles. This article is concerned with the use of fiber-glass reinforced plastics for corrosion-resistant equipment applications in the chemical process industries, and in water and waste treatment areas.

What is a fiber-glass-reinforced plastic? How is it fabricated? What are the advantages of FRP? What design considerations must be considered in using equipment made of FRP? And finally, what are the considerations in buying corrosion-resistant equipment?



Examples of equipment currently fabricated out of fiberglass-reinforced plastics include tanks and vessels, pipe, ducting, hoods, fans, scrubbers, stacks, grating, and specialty fabrications. One of the fastest growing areas is the use of FRP for pollution-control equipment.

## What is FRP?

The term FRP, which is common throughout the industry, refers to plastic that has been reinforced with glass fibers. Many reinforcements can be used for plastic materials-including polyester fibers, carbon fibers and, of course, glass fibers. For corrosion-resistant equipment, approximately 95% of the applications normally involve the use of glass fibers (with some polyester fibers being used on certain specific occasions.).

Glass fibers can be added to virtually all of the thermoplastic and thermoset resins. For corrosion resistant equipment, the resins used are primarily those of the thermosetting type. These are resins that, once they have “hardened,” remain in their cured configuration when subjected to heat-up to their distortion temperature or the temperature at which they will degrade. Examples of thermoset resins include the epoxies, polyesters, and vinyl-esters. There are other thermosetting materials, but



these four are used in the vast majority of applications for fiber-glass reinforced plastics. The term “polyester” is a generic one that refers to a wide range of materials. It can include everything from a general-purpose resin used in boats and bathtubs to the most exotic, high-temperature corrosion resins. For corrosion-resistant equipment, specialized corrosion-resistant-grade resins are available.

A number of companies manufacture isophthalic polyester resins, which have a distinct place in the hierarchy of corrosion-resistant materials. Very frequently, to reduce costs, a customer will have equipment built with one of the premium-grade resins used for the corrosion inner liner, the balance of the structural laminate being built with an isophthalic polyester resin.

One type of corrosion-resistant resin in use is the vinyl ester resin. The vinyl-esters are similar in corrosion resistance to the bisphenol A polyester resins, but for many applications, possess improved physical properties, especially impact an

## Methods of Fabrication

**Hand Lay-up:** This is the most basic of fabrication techniques for fiber-glass-reinforced plastics.

Sometimes, it is also referred to as “contact molding.” A simple mold, whether male or female, is

used. It is first coated with an appropriate release agent and the layup fabrication is started. The first material applied is normally a 10-mil layer of resin and special corrosion resistant glass called “C-glass”. This reinforcing glass is in the form of a very thin veil or surfacing mat, similar in appearance to the “angel hair” used for Christmas decorations. This first 10-mil layer gives a high-resin, low glass content corrosion barrier.



In the hand-lay-up process, this 10 mil layer is followed by a minimum of two layers of fiberglass in a mat form. This mat consists of chopped glass fibers, randomly oriented, with a binder that holds them into a coarse cloth like form that can be cut, handled and applied. Resin, catalyzed to cure at a predetermined rate, is applied by means of brush or spray gun. The resin is worked into the chopped-glass mat by means of rollers, similar to paint rollers. The resin content of these mat layers is approximately 70% to 75%.



When the wall thicknesses are  $\frac{1}{4}$  inch or more, (typically, when past the first two layers of chopped mat), a stronger glass reinforcement is used. This reinforcement is known in the trade as “woven roven,” and consists of continuous glass filament woven in a pattern similar to a coarse cloth. The woven roving reinforcement and chopped mat are put in alternate layers, with the final layer being chopped mat.



**Spray up:** This is very similar to hand lay-up, and is also included in the general category of “contact molded” fabrication. Spray up is simply an automated way of depositing the chopped glass. Fabrication still starts with the 10 mils of surfacing vein glass in a continuous fiber form, similar to a thin rope. It is pulled through a gun head that chops it into short lengths and sprays it toward the mold. At the same time catalyst and resin are sprayed through the gun head. Thus, the catalyst, resin and glass are all

deposited at one time. The resulting spray lay-up is rolled to obtain good wet-out of the glass and to remove any entrained or entrapped air. For heavier laminates, woven roving is still used between alternate layers of chopped glass laminate.

**Filament Winding:** In this fabrication method, which is primarily applicable to round or cylindrical parts continuous glass fiber, again in the form of a very thin rope, are pulled through a bath of catalyzed resin. In the bath, the glass fibers are thoroughly wetted and the excess resin removed. The resin-impregnated fibers are then wrapped around a rotating mandrel. Typically, this is mounted in a winding machine resembling a lathe. The glass fibers traverse the length of the rotating mandrel, laying the fibers in a predetermined pattern.



Typical products that are produced by filament winding include pipe of various sizes and large diameter tanks. Depending upon the application, fabrication of the part will start with a number of layers of high-resin-content “C-glass” surfacing mat (usually 20 to 50 mils total), followed by approximately 100 mils of the randomly dispersed chopped fibers, and then followed by the filament winding.

## Strength Characteristics of FRP

Three rules of thumb should be kept in mind when considering the structural or strength properties of reinforced thermoset plastic materials. First, the strength is directly proportional to the glass content. In other words, the higher the glass as a percent of the total weight of the laminate, the stronger the laminate. Second, the longer or more continuous the glass filaments, the higher the strength properties. For example, filament-wound construction (where the glass is in continuous-filament form) will have higher strength than will chopped mat, where the glass fibers are short and randomly



dispersed. By the same token, woven roving will have higher physical properties than will chopped mat.

Third, the physical properties, and more specifically, the tensile strengths, are influenced by the direction or orientation of the glass fibers. For example, the strength of filament wound pipe is greatest parallel to the orientation to the continuous glass fibers. For filament wound pipe, if the fibers of filaments were put in a 90 degrees orientation to the axis of the pipe, the hoop strength would be at its maximum. For random chopped mat or woven roving, the strengths are equal in both directions of a plane. At right angles to that plane, the strength is minimal.

Here are some of the basics that you have to understand before you will be able to design equipment or set purchase specifications intelligently. We have examined some of the resins used in the making of fiber-glass reinforced plastics, as well as methods of fabrication. Now, let us look at the advantages of this material for process-industry equipment.

**Corrosion Resistance:** Perhaps the prime reason for using fiber-glass-reinforced plastics (FRP) is because of their inherent corrosion resistance. In many cases, they are the only materials that will handle a given service environment; and in other cases, their corrosion resistance is combined with their economy to make them the most economical acceptable solution. Corrosion resistance of FRP



is a function of both the resin content and the specific resin used in the laminate. Generally speaking, the higher the resin content, the more corrosion resistant the laminate. This is why when building the laminate; the surface nearest the corrosive medium is made of a layer that is 90% resin and 10% glass (i.e. the surfacing-veil layer). For the most-corrosive media, this is followed by a layer of approximately 75% resin and 25% glass. High-glass-content layers are achieved with woven roving or by filament winding and are usually limited to those applications where

the corrosive service is less severe or where the corrosion medium is separated by means of a layer high in resin.

## Weight Advantages

Another very distinct advantage of FRP is its low weight-to-strength ratio. As a rule of thumb, for the same strength, FRP will weigh approximately one seventh as much as steel and half as much as aluminum.



Lightweight properties are important when considering the cost and ease of installation, especially for pipe and tanks. FRP's inherent lightweight is an advantage when equipment must be mounted on existing structures, such as scrubbers, on mezzanines or rooftops, and for specialty applications such as FRP tank trailers.

**High Strength-** While not as important for corrosion-resistant equipment, high strength does play a major role in the design of FRP equipment for such applications as missiles, pultruded shapes, etc. For filament wound pipe and duct, the high strength gives the lightweight features discussed earlier.

**Economy-** Often, a major advantage of FRP is its lower cost. When comparing materials for corrosion service, rubber lining, titanium, Monel, Hastelloy, Carpenter 20, and the exotic stainless materials are very frequently alternatives to FRP. In these cases, FRP may offer both a satisfactory solution to corrosion problems and the lowest cost. There is no rule of thumb for comparing costs of FRP with other materials. These costs depend upon the application, the design considerations, the pressures (or vacuums) involved, the product configurations, and raw material cost and availability.



**Flexibility-** Too many people overlook the versatility of FRP. It is best for many applications because you can do things with it that cannot be done economically with other materials. You can mold almost any configuration, or piece of equipment, for which you can build a temporary or permanent mold. For ductwork, for example, you can make all types of elbows, rectangular to circular transitions, Tee inlets, and flanges all in a wide proliferation of round and rectangular sizes and shapes at minimal tooling cost. It is also possible to use FRP to line existing structures (though this is a separate subject that will not be discussed here).



## Design Considerations

**Resin Selection –** The first consideration in designing any piece of equipment with FRP is to select the appropriate resin. The user can only make this selection. Any qualified fabricator or resin manufacturer will be most happy to make recommendations and provide test coupons for in plant testing.



We recommend that you start with the various resin manufacturers' literature. Most of these include tables for the more commonly encountered corrosive media and make recommendations for their resins in these applications.



If you do not find your application listed in the literature, we suggest you contact either the resin manufacturer or a knowledgeable fabricator for further

information. They may also have case histories available for other applications of a similar nature.

When the service is still questionable or unknown, the last step is to undertake in plant evaluation by means of test coupons installed in the process stream. All qualified fabricators will provide coupons. In many cases where the application is critical and other materials have not performed satisfactorily an actual installation of a test spool into the existing system is recommended.

**Control of Dimensions and Tolerances –** As mentioned earlier, any piece of equipment for which one can build a permanent or temporary mold or tool can be built out of FRP. It is easy, therefore, to control the dimensions of one surface. For a part built externally on a mandrel, it is easy to fairly accurately control the I.D. or inside dimensions of that part. If a female mold is used, it is easy to control the O.D. or outside dimensions of the part.

It becomes a much more expensive process to control both inside and outside dimensions. This requires either compression-molding of the part or machining it after fabrication. Please keep in mind that economies can be achieved if you will design for the control one tolerance dimension only.

### **Design for Stiffness –**

One of the areas that needs to be considered in designing with FRP is its lower modulus of elasticity, or stiffness. In cylindrical



shapes, such as pipe and duct, stiffness is usually important only if the duct or pipe will be subjected to vacuum loading. In this case, the walls will have to be designed to handle a buckling mode of failure, or have to be stiffened by means of ribs or sandwich construction to decrease the elasticity. Primarily, consideration of modulus of elasticity, or stiffness, in FRP comes into plan when designing rectangular shapes, such as rectangular ducts or rectangular tanks. Long, flat panels fabricated of

FRP tend to bow or deflect excessively. This deflection needs to be limited by some means of increasing the stiffness of the wall. Sandwich-panel construction or reinforcing ribs is usually the most economical way of achieving this stiffness. Ribs can be added to the sidewalls of tanks at a nominal additional cost and still save dollars over metallic materials.



**Pressure Application – FRP** can be used for pressure applications, but thorough design analysis and consideration must be given to ensure adequate safety factors. Fiber-glass-reinforced pipe has been used for applications up to 1,200 psi. Large diameter (7 ft dia. x 17 ft high) vessels have been built for pressures up to 160 psi at 220° F. Even higher-pressure applications have been achieved in the military area with exotic reinforcement materials and epoxy resins.

Fabrication techniques and design considerations are spelled out in Section 10 of the ASME code. It is reasonable to ask your fabricator to build your pressure equipment to these general requirements but deleting the requirement for actual code approval and the prototype testing.



## Considerations in Buying FRP

**Design for FRP** – If you are going to get the most economy for your dollar, you must design originally for FRP. Work with a qualified fabricator to translate your process or installation requirements into the most economical FRP design. Do not prepare your design and drawings on the basis of steel and then send these drawings to a fabricator, asking for a quote in FRP.

**Establish Specification Before Inquiring** – Many of the most knowledgeable purchasers of FRP have developed their own FRP specifications. Copies can usually be obtained from these companies, which are generally willing to share their knowledge in these areas. Purchasing FRP is somewhat different from purchasing steel vessels and equipment. An appropriate analogy would be if the steel-vessel fabricator were to manufacture his own steel from scratch, rather than purchase steel plates from a basic-steel company.

An FRP manufacturer starts with basic raw materials and builds his own laminate. Because there is still a reasonable amount of “art” in FRP fabrications, developing complete specifications for your vendors is important to ensure quality at the lowest possible cost.

Quality, experience, attention to details, robust processes, and the latest technology are some of the keys to a successful FRP project. Understanding all of the components of an FRP project as laid out in this paper will help you to insure that you get the best results and the best solution for your particular situation.





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