MANUFACTURING FRP TANKS

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Market growth

Fiberglass reinforced plastic (FRP) tanks have been used for many years for storage of chemicals that might corrode or interact with tanks made from non-resinous materials. The original products were probably made for the chemical process and pulp bleaching industries because of the difficulties encountered with corrosion of metal tanks and the high costs and/or low strengths associated with alternate tanks such as glass-lined or thermoplastic tanks. The FRP tank industry was further strengthened when vinyl ester resins were developed, thus allowing the use of cost-effective FRP tanks in very aggressive environments.

A few years ago environmental laws were enacted that have caused another surge of growth in FRP tanks. These laws severely restricted the use of underground steel tanks, mostly used in fuel storage at service stations, because of the tendency of metal tanks to corrode and eventually leak. FRP tanks are now the preferred tanks for new underground fuel storage facilities and for replacement of the steel tanks already in service. This increase in FRP tank usage has allowed tank manufacturers to refine their manufacturing methods for higher output and better performance and has encouraged material suppliers to focus on the FRP tank market and develop products that are optimized for this application.

The light weight and high strength of FRP tanks has led to an increase in their use in industries where chemical resistance is not as critical as in storage of corrosive chemicals or fuels. These markets are widespread and call for tanks of many sizes and performance characteristics.

In spite of the broad nature of the market, some common characteristics of FRP tanks can be given.

General tank descriptions

FRP tanks can be oriented in use with the long axis either vertical or horizontal. The majority of above ground tanks are vertical and the majority of underground tanks are horizontal. Proper fittings and installation procedures are required for each orientation and, of course, for special use situations.

FRP tanks generally have a resin-rich inner layer (called a corrosion layer) next to the liquid, that is, as the inner-most layer of the tank. This layer gives high protection against chemical attack from the material being stored in the container. A chemical resistant veil is usually contained within this resin-rich inner layer. Some chopped mat could also be added to give some additional strength to the corrosion layer. A common thickness for the corrosion layer is 100 to 200 mils.

The subsequent layers (called structural layers) are composed of glass-reinforced resin with compositions and characteristics dictated by the manufacturing method used to fabricate the tank. The thickness and orientation of reinforcements within the structural layers is dictated by the design of the tank, discussed briefly at the end of this article.

Some tanks have a double-wall construction in which a space or gap is created between two layers. The interlaminar space is usually about 100 mils thick. The space allows for sensors to be inserted which can detect the presence of liquids, thus sensing loss of integrity of the tank's inner layers (leaks). One common method to create this interlaminar space is to apply a netting or membrane between layers, thus creating a path with the vessel that allows escaping liquids to be detected. Sensors, sometimes using the netting itself (which can be electrically conductive) would be inserted into the space created by the netting layer.

Another method to create the interlaminar space uses a 3-dimensional fabric (sometimes called a space fabric). This fabric can be constructed by orienting a series of vertical fiberglass columns between two thin fabric layers. The vertical fiberglass columns possess springiness which keeps the two fabric sheets apart, thus forming the space that is needed for the sensors to detect the presence of leaking liquid. Rigid, open-celled foams and honeycomb have also been used to create the interlaminar space for double walled constructions.

Fittings and accessories are usually integrated into the overall design of the tank. Above ground tanks require tie-downs to prevent movement from wind, process, or seismic loads and pressures. Underground tanks may float up with a high water table and also require tie-downs. Most tanks also require vents and manways for normal operation and servicing.

A few manufacturing methods now dominate FRP tank manufacturing. All of the methods are used for other applications, but have been modified to meet the specific needs of efficient and reliable manufacturing of tanks. We will examine each of the major methods and then discuss some of the material choices available for FRP tanks.

Contact molding for making FRP tanks

Contact molding or hand layup is the most fundamental and oldest of the FRP manufacturing methods. In this method the main part of the tank (the cylindrical portion) is made by spraying resin onto the outer surface of a cylinder (called the mandrel) and then laying the reinforcements onto the resin. The mandrel can be stationary or, more often, can be rotated to facilitate even distribution of the reinforcement layers.

The corrosion layer is made by simply spraying the resin onto the mandrel and then laying the veil onto the resin. If desired, a few layers of thicker mat or fabric can be added for additional strength. The reinforcements are then rolled with small hand rollers to ensure full wet out of the fibers.

After the corrosion layer has partially cured, additional layers (the structural layers) are applied. Resin is applied to begin each layer and then the reinforcement is layed down and the layer is rolled to get wet out. The structural layers can be cured in thickness of 350 to 400 mils, depending on the amount of exotherm (which depends upon the resin and the curing system). If the exotherm is very low, thicknesses up to 1 inch have been cured together.

A common reinforcement pattern in the structural layers is to alternate layers of chopped strand mat and fabric (often woven roving). Alternating mat and fabric increases the bonding between reinforcement layers. For ease of handling, the chopped strand mat is often applied as strips (about 8 to 12 inches wide) as the mandrel turns.

When all the structural layers have cured, the cylindrical part is removed from the mandrel, often by simply pulling the part off the mandrel, but sometimes by using a mandrel that mechanically collapses.

The end caps are made by laying the reinforcement into a mold and then adding resin and wetting out the fibers in the method described above. When cured, the parts are removed from the mold and are then adhesively bonded onto the ends of the cylinder. Any tank fittings or other attachments are usually added before bonding on the end caps.

The viscosity of the resin for contact molding should be low enough to wet the fibers easily but not so low that the resin will drain from the fibers. Viscosities in the 350 to 500 cps range are typical for contact molding operations.

An alternate method of applying the reinforcement and resin is to use a chopper gun. If a chopper is used, automated sequencing of the gun is preferred to ensure uniform application of the fibers.

When used to make tanks, contact molding has the advantage that many different types of fiber reinforcement can be used, from woven fabrics to random chopped mat, with little significant change in manufacturing methods.   This method also allows the greatest freedom in tailoring the fiber direction to match the needs of the particular part. When mats are used, the orientation of the fibers is random. When fabrics are used, the fiber direction is most often oriented around the tank (the hoop direction) and along the main axis of the tank, but can be on the bias (±45°) if desired. The fabrics usually give better overall strength to weight (that is, more efficient use of the reinforcement) because of the ability to orient such a large percentage of the fibers in the hoop direction. This orientation directly resists burst failures, the predominant failure mode of tanks. Some tanks are made using woven roving (very large fiber bundles which are loosely woven into a fabric). Woven roving gives high glass content and good strength but requires additional effort to ensure good fiber wet out.

Filament winding FRP tanks

The most common procedure for making tanks by filament winding is to wind the cylindrical portion of the tank and then adhesively bond on the ends. The ends are usually contact molded. In this manufacturing scheme, the fibers are wound onto a cylindrical mandrel that is most often removed after curing by sliding the part off the mandrel or by using a mechanical collapsing mandrel. The corrosion layer is applied to the mandrel in much the same way as in contact molding. Note that the cure of the corrosion layer is usually more advanced when using filament winding to apply the structural layers than is the case in contact molding. This harder cure is needed to prevent the structural layers from sinking into the corrosion layer due to the high tension forces that occur in filament winding.

The structural layers are applied by the filament winding machine. This machine uses a moving or traversing eyelet or pay-off head to orient tows of fibers onto the turning mandrel. Therefore, by selecting the right combination of mandrel turning speed and eyelet traversing speed, the angles of the fibers can be carefully controlled. For instance, if the eyelet traverses slowly compared to the rotation speed of the mandrel, the fibers will be oriented around the circumference of the mandrel (hoop windings or 90° windings). A complete layer of hoop windings is created as the eye slowly traverses across the entire long axis of the tank. If the traverse speed is higher relative to the mandrel rotational speed, the angles have lower angles and are called helix windings. The most common angles for helical windings are about 50° to 80° but are chosen so that each cycle of rotation and traversing creates a helical path that is slightly displaced from the previous path. In this way the entire surface of the tank is eventually covered with a layer of fibers in helical orientations. A typical FRP tank will have layers of hoop windings alternated with helix windings.

Double wall construction is accomplished with filament winding by simply applying a layer of the space material between winding layers. Some care must be taken to ensure that the gap is preserved because of the tension pressures that occur during winding, but this has not proven to be a major problem. Sensors are inserted as they are done in contact molding.

The resin is applied by soaking the fiber tows just before they go through the pay off eyelet. This requires a rapid wetting of the fibers since the wet out is usually accomplished by simply passing the fibers through a resin bath (perhaps with some rollers to encourage wet out). Therefore, the resin viscosity for filament winding is somewhat lower than for contact molding. Typical viscosities for filament winding are 250 to 350 cps.

The advantages of filament winding, when compared to contact molding, are associated with the greater efficiency possible in the automated fiber laydown of filament winding. Laydown rates of 1500 to 2000 pounds per hour are common. While a single operator is difficult since each machine requires constant care of the resin bath, removal of fuzz from the fibers, and controlling the machine operating conditions, the total manual labor is still much less than would be required with contact molding. Moreover, the fiber tension that occurs during laydown usually eliminates the need for rolling the fibers to achieve good wet out, thus saving much hand labor. Precision of fiber orientation is theoretically better with hand layup than with filament winding, but in most actual operations, the automated fiber laydown using filament winding is more accurate over the long term.

Some filament winding operations use a mandrel that stays inside the tank. This is common when a thin walled metal liner is used and the fiberglass/resin is simply a method of giving stiffness and strength to the product. When the metal liner is used, the corrosion resistance advantage of an all-FRP tank is lost.

Other filament winding operations use a thermoplastic liner. This is especially common if the entire tank (including the ends) is wound as a single unit. The thermoplastic liner can give some added chemical resistance and permeation protection. When a thermoplastic liner is used, the tank is often internally pressurized during winding so that the tension forces of winding can be withstood without collapsing the liner.

Hoop chop manufacturing

This method is a modification of filament winding. In hoop chop manufacturing, a filament winding machine is used for some of the fibers while a conventional chopper gun is also used to add fibers to the structural layers. Typically, only enough fibers are applied by filament winding to hold the chopped fibers in place and to create the hoop strength required for the burst pressure design. This combination of equipment allows a much faster operation than filament winding by itself since fibers can be added so quickly using a chopper. The chopped fibers give closure of the winding so that the multiple passes required in filament winding are no longer required.

In hoop chop, the fiber angle is mostly random (because of the chopped material) with some additional fibers from the filament winding. Therefore, efficiencies in strength per weight are not as high as with filament winding.

Hoop chop manufacturing, with unidirectional fabric, has found a special niche in field-wound tanks. Field winding is especially inviting for very large tanks where transportation would be costly or physically difficult. Field-wound tanks are often wound vertically with a computer controlled chopper gun. Hand layup of fabrics supplements the chopped material to give special axial strength capability.

Centrifugal casting FRP tanks

Centrifugal or spin casting of pipes is more common than tanks, but some very large tank producers use this method very effectively for FRP tanks. In this method the fibers and resin are applied to the inside of a spinning mandrel which uses centrifugal force to push the resin and fibers against the inside wall of the mandrel. This method builds up the tank in reverse order so the structural layers are created first and the last thing done is making the corrosion layer. Fiber angle is usually random because the fibers are often blown into the inside of the structure.

Fillers can be added quite easily by this method. A common filler is sand which adds weight and lowers cost. Some performance benefits have also been reported with sand fillers.

Materials selection

The major components of an FRP tank are generally resin, reinforcement, veil, cure system and additives. All of these materials must work together in order to achieve the best performance of the tank and the choice of each component should be considered carefully.

The resin choice is dictated by the following major factors:

- The type of service the tank might see, that is, what is the likely content of the tank and into what environment will it be placed
- The tank manufacturing method
- Resin cost
- Handling characteristics.

The resin of choice for most FRP tanks is either a premium polyester or a vinyl ester. Some chlorinated and long-chain iso-type polyesters for FRP tanks have proven to have good performance with cool water, weak acids, and some solvents. More aggressive environments would lead to the choice of a vinyl ester because they are superior to polyesters in resisting caustics and many solvents. Vinyl esters are used widely because they have better chemical resistance performance than polyesters but are much easier to use in manufacturing and less expensive than higher performance resins such as epoxies and furans. Within the vinyl ester group, several options are available. For instance, Bisphenol-based vinyl esters resist a broader range of chemicals and are reasonably tough (impact resistant). Bisphenol resins can also be modified to give slightly higher heat distortion temperatures and even better solvent resistance. If even more heat and solvent resistance is needed, novalac-based vinyl esters can be used. Other resins might be halogenated for flammability control and specially toughened for impact resistance. The performance of many of the resins can be improved by post curing the part.

Epoxies have even greater solvent resistance and thermal tolerance but are more difficult to use in manufacturing because of their high viscosity, poor sprayability, and frequent requirement for thermal curing. Cost is also higher for epoxies than vinyl esters. Furans are resistant to many chemicals and, in some cases, are the only acceptable resin. However, furans often need elevated temperature curing and have other handling problems that restrict their use.

The reinforcement in FRP tanks can be chopped roving, chopped mat, or continuous roving materials, depending on the manufacturing method. E-type glass is the most common type of fiberglass, although some corrosion-resistant glass and high-strength glass might be used for high performance or especially difficult environments.

The veil is usually a commercial-grade chemical resistant glass surface mat or fabric or, possibly, an organic fiber mat or fabric, as appropriate for the application.

Some developments in sizings are underway to further improve the chemical resistance of the FRP material. Some sizings cause stiffness of the of fiberglass which can cause problems in filament winding and so new developments in flexibility of the sizing are underway.

The cure system is standard for most FRP tanks and is, of course, highly dependent on the type of resin that is being used. Few changes are made to the cure system for FRP tank manufacturing.

Additives to the system are generally associated with resin handling or improved properties. For instance, thixotropic agents can be added to adjust the resin viscosity to allow good fiber wetout but yet prevent the resin from dripping off the fibers and running to the bottom of the mold. Other additives might include ultraviolet light absorbers to improve weather resistance, a light pigment, and anti-oxidants. Fillers, when added, are usually for flame retardance and cost.

Design requirements

The design of an FRP tank usually involves a consideration of the pressures, vacuums, and other forces (loads) that might be encountered in the operation of the tank and any environmental conditions that might require additional loading of fibers to give long term performance at the anticipated level. After examination of the expected overall loads and operating conditions, an appropriate design safety factor is applied to the loads. Using the augmented loads as guides, the strength of the tank can be calculated by considering the elastic modulus and strength of the reinforcement fibers, the directions of the fibers, lengths of the fibers, and the number of fiber layers. The directions of the fibers are dictated, in part, by the manufacturing method and so the method must be chosen before the full design can be done. This calculation of reinforcement angles and amount of reinforcement (laminate thickness) is usually done using a computer program based on composite laminate theory.

Some of the design requirements for tanks and the appropriate safety factors are given in industry specification documents such as ASTM D 3299 (Standard Specification for Filament Wound Glass Fiber Reinforced Thermoset Resin Chemical Resistant Tanks) and ASTM D 4097 (Standard Specification for Contact Molded Glass Fiber Reinforced Thermoset Resin Chemical Resistant Tanks). These standards do not cover all applications of tanks and so the manufacturer and the ultimate user should both carefully consider the intended application and decide if additional considerations warrant higher safety factors or other design features. Testing standards have also been established in UL-1316 and ASTM D 4021.

In addition to the normal design requirements of performing properly under normal operating conditions, composite tanks have a requirement of withstanding incidental impacts. This requirement is especially important in FRP tanks as they are subject to structural failures from damage originating from such impacts. These hazards would include impacts from rocks or other sharp objects which might be dumped on the FRP tank during backfilling operations. Transport damage could also result in impact damage that could lead to tank failures. Some tank manufacturers coat their tanks with special impact-resistant materials, but most rely on field inspections and proper installation techniques to prevent or detect impact damage.

Summary

Good economics and product performance can be obtained with any of the common manufacturing methods for FRP tanks. The material selection currently available appears to be good enough to sustain the expansion of the market, including many new applications. Therefore, the differences in the cost of the product from manufacturer to manufacturer are largely associated with labor costs in manufacturing. As a result, the efforts spent by the various FRP tank manufacturers to refine their own manufacturing system will likely prove to be essential in maintaining competitiveness. This favorable competitiveness will likely result in a continuation of growth in the FRP tank market.

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