70

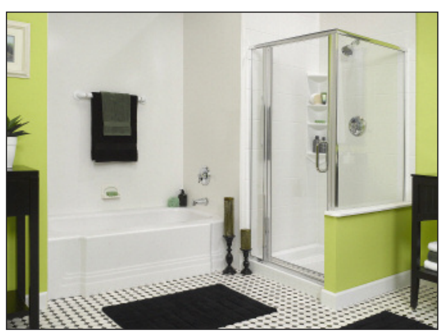
1948 - 2018

Molded Fiber Glass Companies

Technical Design Guide for FRP Composite Products and Parts

Techniques & Technologies for Cost Effectiveness

This manual is an overview of the Fiber Reinforced Plastic/Composite (FRP/Composite) material system. Materials and processes are presented along with design guidelines and comparisons to alternate materials. Because of the versatility of FRP/Composites, the designer is encouraged to collaborate with a molder and/or material supplier to optimize the application.



Definition of Composites

Composites are a combination of two or more materials yielding properties superior to those of the individual ingredients. One material is in the form of a particulate or fiber, called the reinforcement or discrete phase. The other is a formable solid, called the matrix or continuous phase. The region where the reinforcement and matrix meet is called the interface. Composite properties are determined by chemical and mechanical interaction of the combined materials. Wood and concrete are composites under this definition.

This document is limited to the application of the subset of composites called Fiber Reinforced Plastic (FRP) that combine fibers of glass or other materials (the reinforcement) with thermoset and/or thermoplastic resins (the matrix).

What are FRP/Composites?

Fiberglass reinforced plastic, commonly known as fiberglass, was developed commercially after World War II. Since that time, the use of fiberglass has grown rapidly.

The term "fiberglass" describes a thermoset plastic resin that is reinforced with glass fibers.
In this manual, the more general terms Fiber Reinforced Plastic/ Composites or FRP/Composites will be used to describe these extremely useful material systems.

Plastic resins come in two different classes - thermosets and thermoplastics. From a practical perspective, it's easy to remember that thermosets maintain their molded shape at higher temperatures and cannot be melted and reshaped. Thermoplastics will melt at a given temperature and can be solidified into new shapes by cooling to ambient temperatures. Thermosets and thermoplastics are described with more detail in the Resin Systems section of this document.

Reinforcing fibers include glass, carbon, aramid and other man-made and natural materials that are further described in the Reinforcement section of this document. These are used in a variety of forms and combinations to provide the required properties.

The plastic resin systems determine chemical, electrical, and thermal properties. Fibers provide strength, dimensional stability, and heat resistance. Additives provide color and determine surface finish, and affect many other properties such as weathering and flame retardance.

Processing of FRP/Composites involves complex chemical reactions.

Final properties are determined by many factors including the type, amount, and composition of the resin systems and reinforcements. In addition, the use of additives can greatly affect the FRP/Composite properties.

Corrosion Resistance

High Strength, Lightweight

Dimensional Stability

Parts Consolidation and Tooling Minimization

High Dielectric Strength and Low Moisture Absorption

Minimum Finishing Required

Low to Moderate Tooling Costs

Design Flexibility

Benefits and Features of FRP/Composites

There can be many benefits obtained by the use of FRP/ Composites. These benefits and characteristics should be considered early in the design process.

Corrosion Resistance

FRP/Composites do not rust, corrode or rot, and they resist attack from most industrial and household chemicals. This quality has been responsible for applications in corrosive environments such as those found in the chemical processing and water treatment industries. Resistance to corrosion provides long life and low maintenance in marine applications from sailboats and minesweepers to seawalls and offshore oil platforms.

High Strength, Lightweight

FRP/Composites provide high strength to weight ratios exceeding those of aluminum or steel. High strength, lightweight FRP/Composites are a rational choice whenever weight savings are desired, such as components for the transportation industry.

Dimensional Stability

FRP/Composites have high dimensional stability under varying physical, environmental, and thermal stresses. This is one of the most useful properties of FRP/Composites.

Parts Consolidation and Tooling Minimization.

A single FRP composite molding often replaces an assembly of several metal parts and associated fasteners, reducing assembly and handling time, simplifying inventory, and reducing manufacturing costs. A single FRP/Composite tool can replace several progressive tools required in metal stamping.

High Dielectric Strength and Low Moisture Absorption

The excellent electrical insulating properties and low moisture absorption of FRP/Composites qualify them for use in primary support applications such as circuit breaker housings, and where low moisture absorption is required.

Minimum Finishing Required

FRP/Composites can be pigmented as part of the mixing operation or coated as part of the molding process, often eliminating the need for painting. This is particularly cost effective for large components such as tub/shower units. Also, on critical appearance components, a class "A" surface is achieved.

Low to Moderate Tooling Costs

Regardless of the molding method selected, tooling for FRP/Composites usually represents a small part of the product cost. For either large-volume mass-production or limited runs, tooling cost is normally substantially lower than that of the multiple forming tools required to produce a similar finished part in metal.

Design Flexibility

No other major material system offers the design flexibility of FRP/Composites. Present applications vary widely. They range from commercial fishing boat hulls and decks to truck fenders, from parabolic TV antennas to transit seating, and from outdoor lamp housings to seed hoppers. What the future holds depends on the imagination of today's design engineers as they develop even more innovative applications for FRP/Composites.

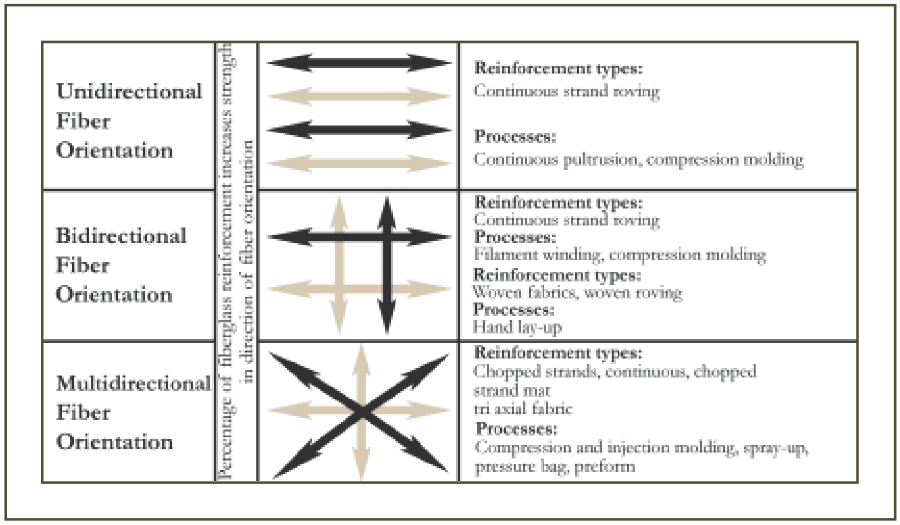
Fibers and Resins

Reinforcements

Much of the strength of FRP/Composites is due to the type, amount and arrangement of the fiber reinforcement. While over 90% of the reinforcements in use are glass fibers, other reinforcements have established a critical niche.

E-glass is the most commonly used fiber reinforcement. It is strong, has good heat resistance, and high electrical properties. For more critical needs, S-Glass offers higher heat resistance and about one-third higher tensile strength (at a higher cost) than that of E-glass.

Carbon Fibers (graphite) are available in a wide range of properties and costs. These fibers combine light weight with very high strength and modulus of elasticity. The modulus of elasticity is a measure of the stiffness or rigidity in a material. For high stiffness applications these reinforcements are hard to beat, with a modulus of elasticity that can equal steel. FRP/Composites with carbon fiber reinforcement also have excellent fatigue properties. The primary use of carbon fibers is in aircraft and aerospace, in which weight savings are a major objective. While its cost limits carbon's use in commercial applications, it is used extensively where material content is low, such as sporting equipment.



Aramid, or aromatic polyamide fibers (Kevlar® or Twaron®) provide high strength and low density (40% lower than glass) as well as high modulus. These fibers can be incorporated in many polymers and are extensively used in high impact applications, including ballistic resistance.

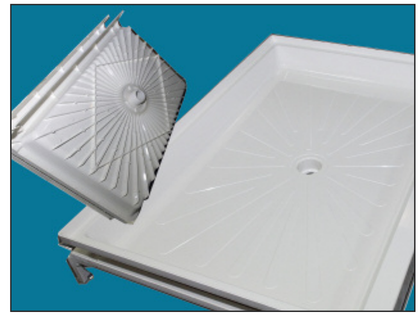
Natural Fibers such as Sisal, Hemp and Flax have been used for many applications with low strength requirements. They are limited to applications not requiring resistance to moisture or high humidity.

Arrangement of the glass fibers - how the individual strands are positioned – determines both direction and level of strength achieved in a molded FRP/Composite. The three basic arrangements of glass fiber reinforcement are unidirectional, bidirectional and multidirectional.

Unidirectional arrangements provide the greatest strength in the direction of the fibers. Unidirectional fibers can be continuous or intermittent, depending on specific needs determined by part shape and process used. This arrangement permits very high reinforcement loading for maximum strengths. The fibers in a bidirectional arrangement are in two directions – usually at 90^0 to each other, thus providing the highest strength in those directions. The same number of fibers need not necessarily be used in both directions. High fiber loading can be obtained in woven bidirectional reinforcements.

Multidirectional or random arrangements provide essentially equal strength in all directions of the finished part.





Reinforcement Forms

Reinforcements are supplied in several basic forms to provide flexibility in cost, strength, compatibility with the resin system, and process requirements. Regardless of the final form, all fiber reinforcements originate as single filaments. A large number of filaments are formed simultaneously and gathered into a strand. A surface treatment is then applied to facilitate subsequent processing, maintain fiber integrity, and provide compatibility with specific resin systems. After this treatment, the strands are further processed into various forms of reinforcements for use in molding FRP/Composites.

Continuous Strand Roving

This basic form of reinforcement is supplied as untwisted strands wound into a cylindrical package for further processing. Continuous roving is typically chopped for spray-up, preform or sheet molding compounds. In the continuous form, it is used in pultrusion and filament-winding processes.

Woven Roving

Woven from continuous roving, this is a heavy, drapable fabric available in various widths, thicknesses and weights. Woven roving costs less than conventional woven fabric and is used to provide high strength in large structural components such as tanks and boat hulls. Woven roving is used primarily in hand lay-up processing.

Woven Fabrics

Made from fiber yarns, woven fabrics are of a finer texture than woven roving. They are available in a broad range of sizes and in weights from $2^{1}/_{2}$ to 18 oz./sq. yd. Various strength orientations are also available.

Reinforcing Mat

Made from either continuous strands laid down in a swirl pattern or from chopped strands, reinforcing mat is held together with a resinous binder or mechanically stitched. These mats are used for medium-strength FRP/Composites. Combination mat, consisting of woven roving and chopped strand mat bonded together, is used to save time in hand lay-up operations. Hybrid mats of glass and carbon and aramid fibers are also available for higher-strength reinforced products.

Surfacing Mat

Surfacing mat or veil is a thin fiber mat made of monofilament and is not considered a reinforcing material. Rather, its purpose is to provide a good surface finish because of its effectiveness in blocking out the fiber pattern of the underlying mat or fabric. Surfacing mat is also used on the inside layer of corrosion-resistant FRP/Composite products to produce a smooth, resin-rich surface.

Chopped Fibers

Chopped strands or fibers are available in lengths from $^{1}/_{8}$" to 2" for blending with resins and additives to prepare molding compounds for compression or injection molding and other processes. Various surface treatments are applied to ensure optimum compatibility with different resin systems.

Resin Systems

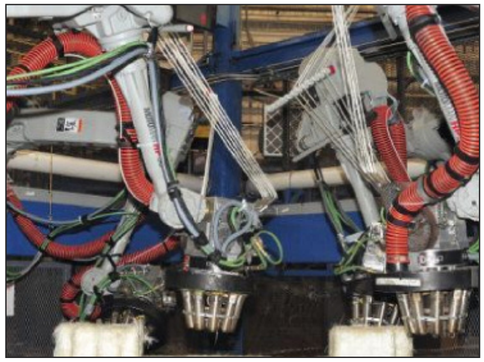
The matrix or resin is the other major component of an FRP/Composite. Resin systems are selected for their chemical, electrical and thermal properties. The two major classes of resins are thermosets and thermoplastics.

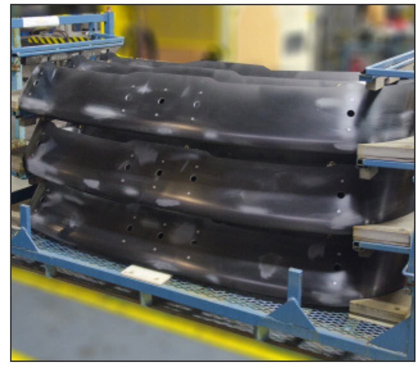
Thermoset Resins

Thermosetting polymers are usually liquid or low melting point solids that can easily combine with fibers or fillers prior to curing. Thermosets feature cross-linked polymer chains that become solid during a chemical reaction or "cure" with the application of a catalyst and heat. The high level of cross-linking provides for reduced creep compared to thermoplastics. The thermoset reaction is essentially irreversible.

Among the thermoset resins for FRP/Composites, the family of unsaturated polyesters is by far the most widely used. These resins are suitable for practically every molding process available for thermosets.

Polyesters offer ease of handling, low cost, dimensional stability, and a balance of good mechanical, chemical, and electrical properties.





They can be formulated for high resistance to acids, weak alkalies and organic solvents. They are not recommended for use with strong alkalis. Other formulations are designed for low or high-temperature processing, for room temperature or high-temperature cure, or for flexible or rigid end products.

Vinylesters provide excellent resistance to water, organic solvents and alkalis, but less resistance to acids than polyesters. Vinylesters are stronger than polyesters and more resilient than epoxies. Molding conditions for vinylesters are similar to those for polyesters.

Epoxies are another family of thermoset resins used in FRP/Composites. They have excellent adhesion properties and are suited for service at higher temperatures – some as high as 500°F. Epoxy-matrix FRP/Composites are processed by any of the thermoset methods. Epoxies are more expensive than polyesters, and cure times are longer, but their extended range of properties can make them the cost/performance choice for critical applications. Epoxy/fiber structures have generally higher fatigue properties than polyesters.

Polyurethanes are a family of resins that offer very high toughness, high elongation, faster cure times and good coupling to a variety of reinforcements. Polyurethanes are easily foamed in a controlled process to produce a wide range of densities.

Additives are easily incorporated into resin systems to provide pigmentation, flame retardance, weather resistance, superior surface finish, low shrinkage and other desirable properties.

Gel coats consisting of a special resin formulation provide an extremely smooth next-to-mold surface finish on FRP/Composites. They are commonly applied in hand lay-up and spray-up processes to produce a tough, resilient, weather-resistant surface. Gel coats, which may be pigmented, are sprayed onto the mold before the reinforcement and resin are introduced.

Other thermosetting resin systems, generally formulated with chopped strand or milled fiber reinforcement for compression or transfer molding are:

Phenolics-Good acid resistance, good fire/smoke, and thermal properties.

Silicones -Highest heat resistance, low water absorption, excellent dielectric properties.

Melamines -Good heat resistance, high impact strength.

Diallyl phthalates -Good electrical insulation, low water absorption.

Thermoplastic Resins

Thermoplastic polymers can soften and become viscous liquids when heated for processing and then become solid when cooled. The process is reversible allowing a reasonable level of process waste and recycled material to be reused without significant effect on the end product. Thermoplastic resins allow for faster molding cycle times because there is no chemical reaction in the curing process. Parts may be formed as fast as heat can be transferred into and out of the molding compound.

Polypropylene and polyethylene are the most common thermoplastic resins used in FRP/Composites. They have excellent resistance to acids and alkalies and have good resistance to organic solvents. Their relatively low melting points allow for rapid processing at lower cost.

Nylon and Acetal are highly resistant to organic solvents and may also be used where increased mechanical properties are required.

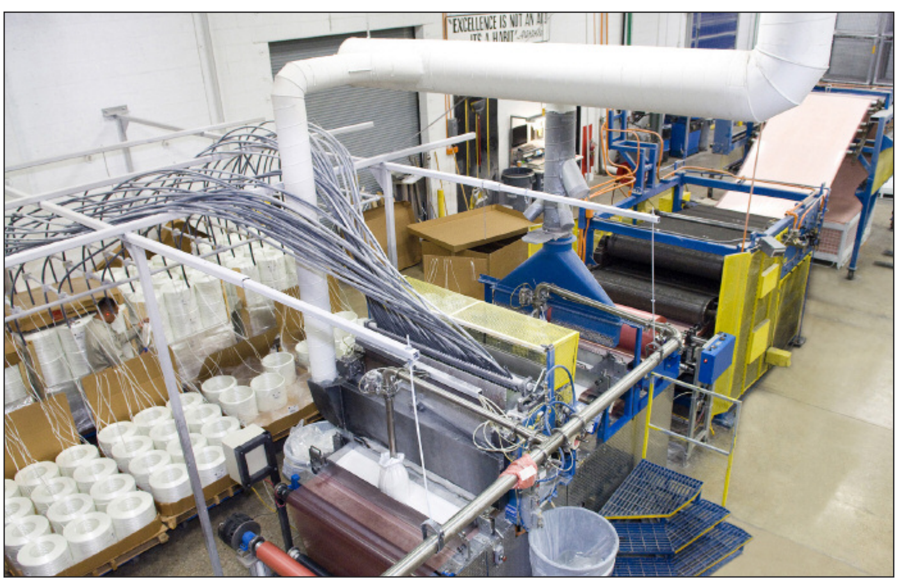
FRP/Composite Material Combinations

The molding experience of thousands of applications in the past five decades has enabled FRP/ Composites polymer chemists to develop a number of standard resin-reinforcement-additive combinations that are used for most production needs. Industry research teams also stand ready to custom design new blends of materials to provide the exact needs of new applications. Because most high production-volume FRP/ Composite parts are made by compression molding, several ready-to-mold material forms have been developed to facilitate and speed the molding process. Each of these forms is designed to best produce a specific type of finished product and provide a distinctive set of property and appearance features.

Liquid Composite Molding (LCM)

A fiber preform of the part is produced by forming fibers and a resin binder in a controlled manner to the same shape as the part to be molded. The combination is cured to provide physical integrity during handling and molding operations.

Parts molded using LCM with preforms are particularly suited for boxlike, deep-drawn shapes in FRP/Composite parts. The fibers stay in place during molding and also ensure good wet-out of the matrix resin, which is added at the press. The result is uniform properties in the plane of the part walls because there is no flow of reinforcement during molding. The fiber content of preform-molded parts can be controlled from 15 percent to a maximum of approximately 50 percent by weight. Fiber lengths vary from $^{1}/_{2}$” to 3”.



Another form of reinforcement used with LCM as well as most other molding processes is called mat. This material is a random distribution of fibers in roll or sheet form. Its use is limited to parts that are relatively flat, have curvature in only one plane, or have a slight compound curvature.

FRP/Composite Compound Forms

A few ready-to-mold compound forms have been developed to support the highest volume production while maintaining good mechanical properties in complicated parts. Of these, sheet molding and bulk molding compounds (SMC/BMC) are based on thermoset resins while thermoplastic resins are used in glass mat thermoplastic and long fiber-reinforced thermoplastic (GMT/LFTP).

•Sheet Molding Compound (SMC)

SMC contains long glass fibers (1” to 2”) dispersed in a resin matrix. The fiber arrangement can be directional, random, or a combination of both. SMC is manufactured in a highly automated, continuous flow process. The compound takes the form of a flexible, leather-like sheet that is easily cut, weighed and placed in the mold for curing to the desired part configuration.

Standard SMC contains up to 35 percent of randomly oriented fibers by weight. Because there is no mixing or extruding involved in preparing sheet molding compound, the fibers remain undamaged and at their original lengths. This plus the higher fiber loading provides very good mechanical properties in compression-molded SMC parts, especially those having relatively thin cross sections.

FRP/Composite parts molded from SMC are characterized by high strength, very smooth surfaces and excellent detail in complex shapes. However, because SMC flows in the mold, fiber orientation and properties can vary throughout a part, particularly in deep-drawn shapes.

Several variations of SMC are available. One contains 8" to 12" unidirectional fibers and another contains continuous unidirectional fibers. Other versions have higher fiber contents of up to 65 percent by weight and are used for structural applications.

•Bulk Molding Compound (BMC)

BMC is a mixture of short (1/8 to 1/2 in.) fibers with resin containing filler, a catalyst, pigment and other additives required by the application. The premixed material, having the consistency of modeling clay, is usually extruded into rope or log shapes for easy handling.

The strength of BMC-molded FRP/Composite is lowest of those made from ready-to-mold forms because the mixing operation degrades the fibers and the fiber content is lowest. In addition, properties are subject to fiber orientation because the compound must flow to fill the mold. However, BMC is economical and satisfies a wide variety of high-volume, compression-molded parts requiring fine finish, dimensional stability, complex features, and moderate overall mechanical properties.

•Compression-Molded Reinforced Thermoplastic

Reinforced thermoplastics can be compression molded into many parts using processes similar to those for SMC and BMC. There are two material forms available for such molding.

Glass Mat Thermoplastic (GMT) is a fiberglass reinforced sheet that has been available for many years. It is typically 30% – 50% glass fiber in a polypropylene matrix. When heated above its melting point, GMT can be compression molded very similar to SMC.

Long Fiber-reinforced Thermoplastic (LFTP) is a process that has more recently been commercialized. This process uses a special thermoplastic extruder to compound thermoplastic pellets with long fibers of up to 2 inches. The melted resin/fiber material is ejected from the extruder as a charge that is immediately compression molded, very similar to BMC.

The properties of these moldings vary depending on the fiber fraction and type of thermoplastic used. Typically such materials are lower weight and have high impact resistance, but have lower modulus and lower heat resistance than those using thermoset resin.

The most common thermoplastic resins are polypropylene and polyethylene; however, engineering plastics such as thermoplastic polyesters or nylon can be used to achieve higher properties.

FRP/Composite Molding Methods

Responding to the requirements of a demanding market place, the FRP/Composite industry is ever on the move developing new resin systems, new types of reinforcements, and new combinations of these materials.

And in keeping with these advancements, processes continue to be improved, refined and further automated to provide better output while reducing handling time and costs. Today's presses feature ever-closer control of processing times, temperatures and pressures, as well as part dimensions. Overall part size capability continues to increase, permitting the commonplace production of sizes and weights of FRP/Composites not possible just a few years ago.

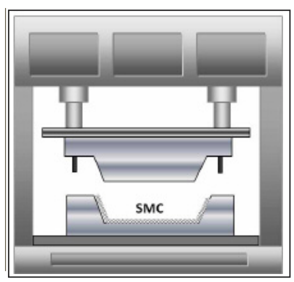
FRP/Composite Molding Methods

In addition to the wide variety of material combinations, there are many choices available for processing FRP/Composite products. These choices provide for even greater flexibility in optimizing the shape, properties and production cost of FRP/Composite components. Matched die molding, contact molding and more specialized molding methods represent the top-level choices. The designer is encouraged to collaborate with a molder and/or material supplier to optimize the application.

Matched Die Molding

Matched die molding methods produce highly consistent, net-shape and near-net shape parts with two finished surfaces and low labor cost. These methods include compression; low pressure, low temperature compression; transfer compression; resin transfer, injection; and structural reaction injection molding.

• *Compression Molding*



Compression molding is the primary choice for most high-volume FRP/Composite parts made from BMC, SMC, Liquid Composite (preform), GMT, or LFTP. The high-pressure molding process produces high-strength, complex parts in a wide variety of sizes. Matched metal molds are mounted in a hydraulic or mechanical molding press. The material charge is placed in the open mold. The heated mold halves are closed, and pressure is applied. Molding time, depending on part size and thickness, ranges from about one to five minutes. Inserts and attachments can be molded in.

Compression-molded FRP/Composites are characterized by net size and shape, two excellent finished surfaces, and outstanding part to part repeatability. Trimming and finishing costs are minimal.

•*Low Pressure-Low Temperature Compression Molding*

This method uses composite or nickel-shell molds that may not be heated, but usually are constructed with coils to heat or control mold temperature.

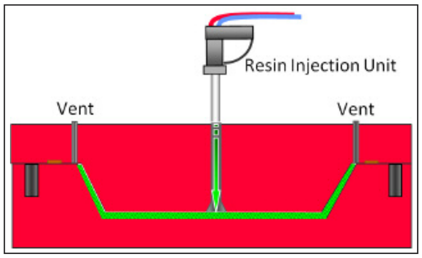
The molding process is an economical compression molding method for manufacturing intermediate volumes of parts using a low-pressure cure and inexpensive molds.

Preform or mat reinforcement is placed on the lower mold half and a resin/filler mixture is added. The mold is closed under moderate pressure of 20 to 200 psi, and the FRP/Composite part cures. This is suited mainly for relatively simple shapes, without ribs or bosses.

•*Transfer Compression Molding*

This process is characterized by molding operations using a transfer cylinder that is usually built into the tool. The material charge made of resin, reinforcement and additives is moved to the transfer cylinder and subsequently forced into the closed mold cavity or cavities by the transfer piston. It is best suited for very thick parts, like transformer bobbins, and is very effective for multiple-cavity molds.

•Resin Transfer Molding (RTM)



Suitable for medium-volume production of rather large FRP/Composite components, resin transfer molding is usually considered an intermediate process between the relatively slow spray-up with lower tooling costs and the faster compression-molding methods, which require higher tooling costs. RTM parts, like compression-molded parts, have two finished surfaces, but molded parts require secondary trimming. Gel coats may be used to provide a high-quality, durable finish. Reinforcement mat or woven roving is placed in the mold, which is then closed and clamped. Catalyzed, low-viscosity resin is pumped in under pressure, displacing the air and venting it at the edges, until the mold is filled. Molds for this low-pressure system are usually made from FRP/Composites or nickel-shell faced FRP/Composite construction.

•Injection Molding

Reinforced thermoset molding compounds can be injection molded in similar equipment commonly used for thermoplastic resins. The principle difference lies in the temperatures maintained in various areas of the system. With thermoplastics, the injection screw and chamber are maintained at a relatively high temperature, and the die is cooled so the molded part sets up. In contrast, for a thermoset FRP/Composite, the screw and chamber are cooled so the resin does not cross-link and gel, and the die is heated so it does cross-link and cure. Injection molding offers high-speed production and low direct labor costs. Combined with the excellent mechanical properties available from a long-fibered BMC, the result is a capability for high volumes of complex parts with properties approaching those of compression or transfer molded parts.

•Structural Reaction Injection Molding (SRIM)

This method is suitable for medium-to-high volume FRP/Composite parts requiring superior strength with no loss in toughness or flexibility. The SRIM process also produces parts with high impact resistance and lower weight, and is excellent for larger part sizes.

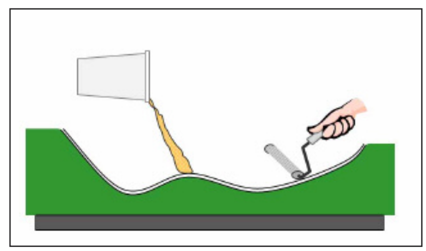
Like injection molding, resin is injected into a closed mold. However, the SRIM process utilizes a preform or reinforcing mat, which is placed into the mold prior to closure, resulting in even distribution of glass and uniform mechanical properties.

SRIM parts offer two finished surfaces, but the polyurethane systems typically used do not provide a good cosmetic surface or a high level of dimensional durability. For structural applications, however, the low temperature and pressure characteristics of SRIM make large structural shapes practical.

Contact Molding Methods

Contact, or open mold methods provide a lower tooling cost when only one finished surface is required. These methods also allow for a shorter product development cycle because of the simplified tooling fabrication process.

•Hand Lay-Up

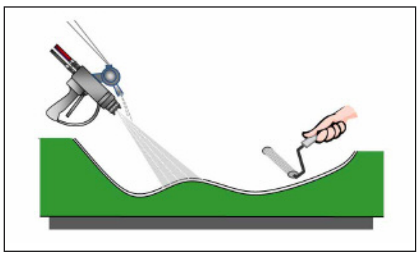


The simplest and oldest of the fabrication processes for FRP/Composites, hand lay-up, is used in low-volume production of large components such as boat hulls and associated parts.

A pigmented gel coat is first sprayed onto the mold for a high-quality surface. When the gel coat has cured, glass reinforcing mat and/or woven roving is placed on the mold, and the catalyzed resin is poured, brushed or sprayed on. Manual rolling then removes entrapped air, densifies the FRP/Composite and thoroughly wets the reinforcement with the resin. Additional layers of mat or woven roving and resin are added for thickness. A catalyst or accelerator initiates curing in the resin system, which hardens the FRP/Composite without external heat.

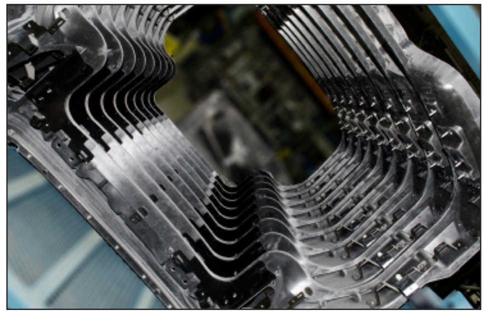
Hand lay-up offers low-cost tooling, simple processing and a wide range of part size potential. Design changes are made easily. Parts have one finished surface and require secondary trimming.

•Spray-Up

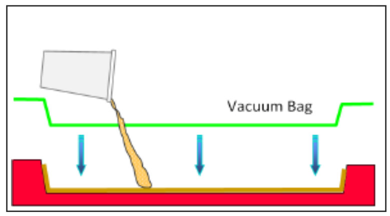


Similar to hand lay-up in simplicity, spray-up offers greater shape complexity and faster production. It too uses a low-cost open mold (one finished part surface), room temperature curing resin, and is suited for producing large FRP/Composite parts such as tub/shower units and vent hoods in low to moderate quantities. Cure is usually at room temperature, but can be accelerated by application of moderate heat.

Chopped fiber reinforcement and catalyzed resin are deposited in the mold from a combination chopper/ spray gun. As with lay-up, manual rolling removes entrapped air and wets the fiber reinforcement. Woven roving is often added in specific areas for thickness or greater strength. Pigmented gel coats can be used to produce a smooth, colorful surface.



•Vacuum Bag Molding



Vacuum bag processing uses a vacuum to eliminate entrapped air and excess resin from a lay-up form on either a male or female mold. A non-adhering film (usually polyvinyl alcohol or nylon) is placed over the lay-up and sealed at its edges. A vacuum is drawn on the bag formed by the film, and the FRP/Composite is cured, either at room temperature or with moderate heat to speed the process. Compared to hand lay-up, the vacuum method provides higher reinforcement concentration and better adhesion between reinforcement layers.

•Vacuum Infusion Molding

The infusion process differs from vacuum bag molding in that all the reinforcements are placed in the mold dry, often combined with cores or other special inserts. Vacuum is then applied to compact the reinforcement and eliminate air. Resin is introduced with the vacuum drawing the resin throughout the reinforcement. Very large parts can be made by this method although it requires a very low viscosity resin and a relatively long fill time as well as bleeder film and other venting.
The resin infusion process results in very low void content and excellent mechanical properties due to the

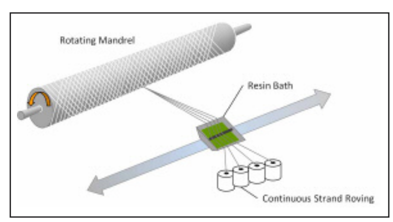
relatively high glass content. Fiber content is determined by fiber architecture and pressure. This process is environmentally friendly since there is no resin exposure.

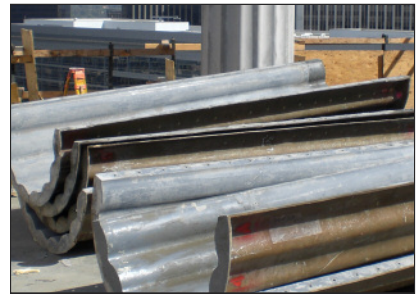
•Autoclave Molding

Autoclave molding is a further modification of vacuum bag. The process produces denser, void-free FRP/Composites because higher heat and pressure are used in the cure. Autoclaves are essentially heated pressure vessels (usually equipped with vacuum systems) into which bagged lay-ups, on their molds, are cured at pressures of 50 to 100 psig. Autoclaves are normally used to process high-performance components based on epoxy-resin systems for aircraft and aerospace applications.

Other Significant Molding Methods

•Filament Winding





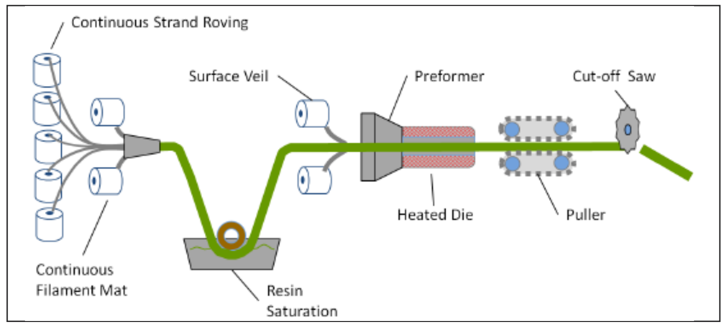
Continuous, resin-impregnated fibers or roving are wound on a rotating mandrel in a predetermined pattern, providing maximum control over fiber placement and uniformity of structure. In the wet method, the fiber picks up the low-viscosity resin either by passing through a trough or from a metered application system. In the dry method, the reinforcement is impregnated with resin prior to winding.

Integral fittings and vessel closings can be wound into the structure. When sufficient layers have been applied, the FRP/Composite is cured on the mandrel and the mandrel is removed.

Filament winding is traditionally used to produce cylindrical and spherical FRP/Composite products such as chemical and fuel storage tanks and pipe, pressure vessels and rocket motor cases. However, the technology has been expanded, and with computer-controlled winding machines, other shapes are now being made. Examples are helicopter tail booms and rotor blades, wind turbine blades and aircraft engine cowls.

Precision robotic waterjet cutting is used to ensure part to part trimming accuracy.

•Pultrusion



Constant section-reinforced FRP/Composite shapes, such as structural I-beams, channels, solid rod, pipe, and ladder rails are produced in continuous lengths by pultrusion. The reinforcement, consisting of a combination of roving, mat, cloth and surfacing veil, is pulled through a resin bath to wet-out the fibers, then drawn through a forming block that sets the shape of the composite and removes excess resin, and through a heated steel die to cure the resin. The finished shape is cut to lengths by a traveling cutoff saw.

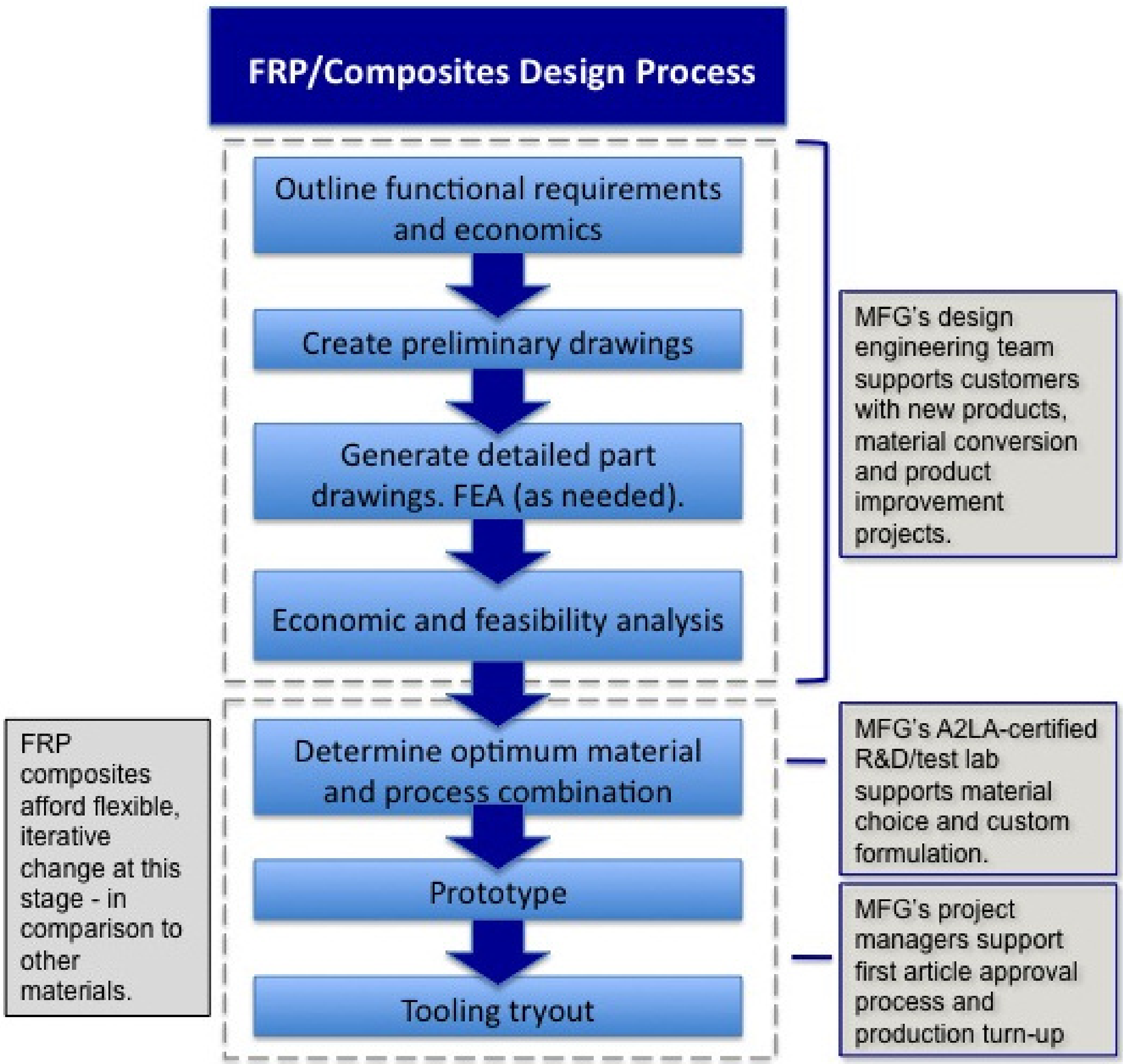
Very high strengths are possible in pultruded shapes because of high fiber content (to 75 percent) and orientation parallel to the length of the FRP/Composite shape. Pultrusion is easily automated, and there is no practical limit to product length manufactured by the process.

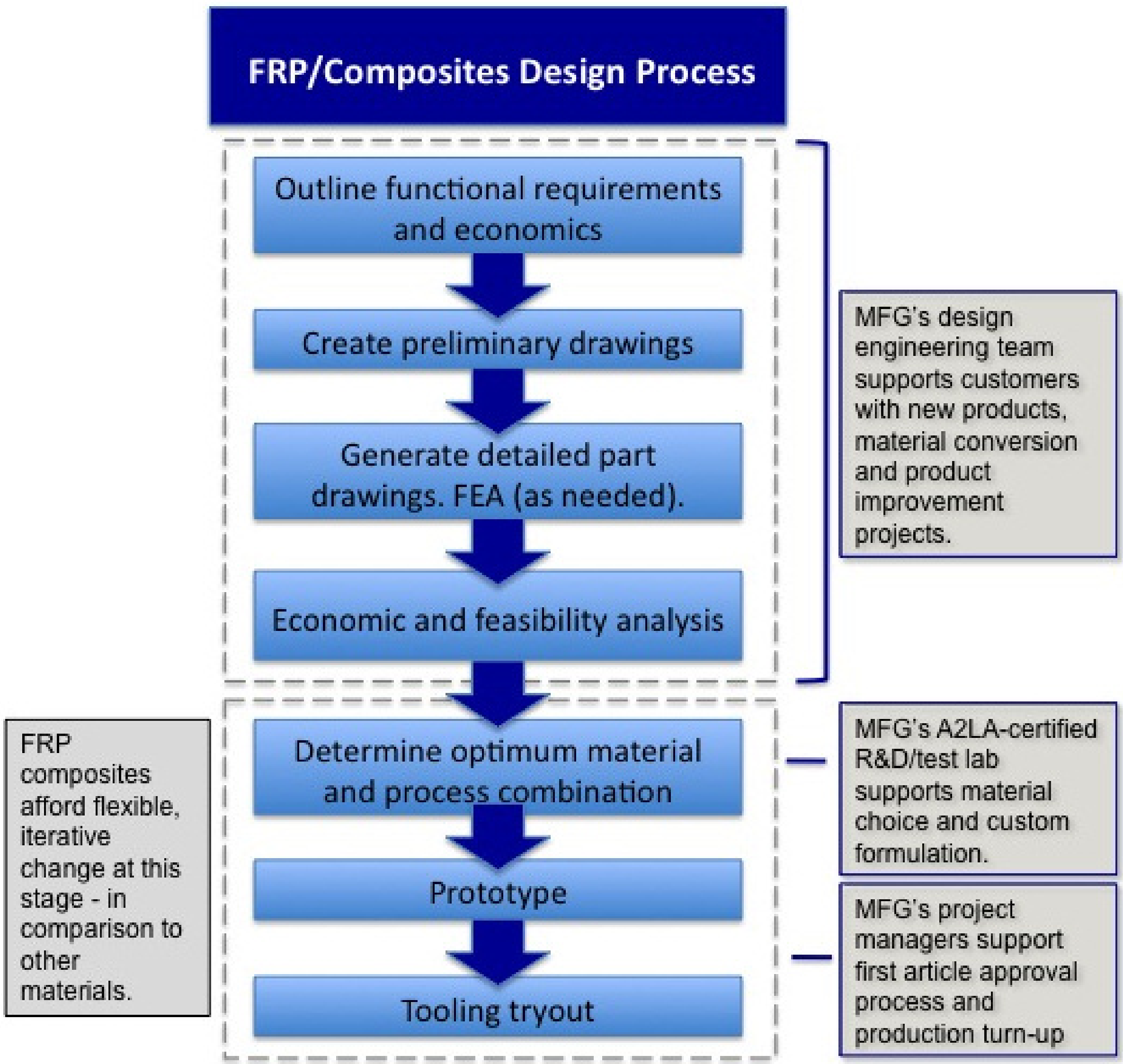
•Continuous laminating

Sheet FRP products, such as clear or translucent glazing panels, flat and corrugated construction panels and electrical insulation panels, are made by a continuous laminating process. Chopped rovings, reinforcing mat and fabric are combined with resin and sandwiched between two carrier film sheets. The material then passes between steel rollers to eliminate entrapped air and to establish finished laminate thickness, then through a heated zone to cure the resin. Wall thickness can be closely controlled.

A wide variety of surface finishes and textures can be applied, and panel length is unlimited. Corrugations are produced by molds or by rollers just prior to the curing stage.

Strong, lightweight FRP/Composite domes use self-supporting sandwich construction to protect sensitive electronic equipment from the Sahara to Antactica while remaining transparent to the electromagnetic signals.


FRP/Composites Design Process
Outline functional requirements and economics
Create preliminary drawings
Generate detailed part drawings. FEA (as needed).
Economic and feasibility analysis
Determine optimum material and process combination
Prototype
Tooling tryout
MFG's design engineering team supports customers with new products, material conversion and product improvement projects.
MFG's A2LA-certified R&D/test lab supports material choice and custom formulation.
MFG's project managers support first article approval process and production turn-up
FRP composites afford flexible, iterative change at this stage - in comparison to other materials.


FRP/Composites Design Process
Outline functional requirements and economics
Create preliminary drawings
Generate detailed part drawings. FEA (as needed).
Economic and feasibility analysis
Determine optimum material and process combination
Prototype
Tooling tryout
MFG's design engineering team supports customers with new products, material conversion and product improvement projects.
MFG's A2LA-certified R&D/test lab supports material choice and custom formulation.
MFG's project managers support first article approval process and production turn-up
FRP composites afford flexible, iterative change at this stage - in comparison to other materials.

FRP/Composite Design Process

Fiber reinforced plastics can be formulated to withstand a variety of service environments and to satisfy many specific end-use requirements. These can include a broad service temperature range, electrical insulation properties, corrosion resistance, abrasion resistance and flammability. Many applications require considerable strength – tensile, flexural, compressive or impact. Surface finishes can be highly refined or they may be textured. In many cases, color can be molded in. Parts can be large or small, simple or complex. Because of the versatility of FRP/Composites and the many material and process choices, the designer is encouraged to collaborate with a molder and/or material supplier to optimize the design process and its end product.

Consideration of many of these requirements leads to the choice of reinforcement, resin system and processing method. These decisions are governed by the three basic principles of designing with FRP/Composites:

- Mechanical strength depends on the amount and arrangement of the glass fiber reinforcement.
- Chemical, electrical and thermal performance depend on the formulation of the resin system.
- Molding process is determined by production requirements, and size, shape and complexity of parts.

Now, in addition to these factors, a fourth principle must be considered:

- Total value received results from good design based on judicious selection of materials and process.

The following section provides a step-by-step method for optimizing cost/performance in FRP/Composite molded parts.

1 Determine Functional Requirements

The design process starts with determining the functional requirements of the component or assembly being designed. These considerations include:

Mechanical Properties

Tensile, compressive and flexural strength; elongation and impact resistance.

Physical Properties

Hardness and density; dielectric strength; volume resistivity and arc resistance; thermal conductivity, heat distortion and heat resistance; flammability and thermal expansion coefficient.

Chemical Properties

Resistance to acids, alkalies and organic solvents; water absorption; resistance to ozone, ultraviolet radiation and weathering.

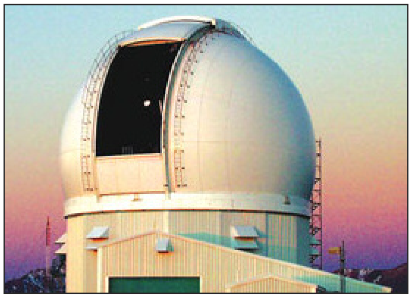
Fitness for Service

Surface quality and cosmetic appearance; dimensional stability, fabrication and end-use tolerancing, and compatibility with other materials.

Other function-related requirements may involve machinability, abrasion resistance and properties needed to meet Underwriters' Laboratory, National Sanitary Foundation standards or other code authority.

2 Determine Economic Requirements

The next step in the design process is to establish cost targets. Evaluation of the economics of a specific application requires a systems approach so the FRP/Composite component(s) is viewed in the context of its total contribution to the end use. This, of course, broadens the design process beyond a simple comparison of material costs between FRP/Composites and

other candidates. Such considerations should include at least these items:

- Tooling cost, including peripheral equipment such as cooling fixtures, machining fixtures and assembly tools.
- Process capabilities compared with general fabrication and end-use tolerancing. Tolerances outside of normal process capabilities add cost premium.
- Secondary operations, such as machining and assembling.
- Finishing cost, such as trimming, sanding, polishing, plating and painting.

Other cost-producing operations that require studying and comparing include packaging, storing, quality control, inventory control and shipping. Such a thorough economic evaluation of the proposed FRP/Composite application provides three valuable benefits:

- First, it presents a true picture of the total systems cost, making subsequent design decisions more cost effective.
- Second, it reveals other cost-savings areas (such as parts consolidation) that may not have been obvious initially – savings that can be designed into the product.
- And third, it enables the designer to determine exactly how much performance is worth buying, in keeping with present or projected selling prices and other market considerations.

3 Determine the Material and Process

With functional and economic requirements established, the designer can now proceed to this most critical stage of the FRP/Composite design process. The designer who understands the wide range of material and process options will use this step to add a great deal of value to the end product. Coincidentally, good choices here will also minimize project risk and cost during the development and production cycles. The unique synergy of the FRP/Composite part design, materials and molding methods at this point will effectively define the product economics and performance over the long term.

Partnering with a molder and material suppliers throughout the design process will reward the project engineer regardless of his or her experience level, but this step may represent the single most significant opportunity for optimizing performance and cost.

In many cases, material and process involve a single selection. For example, if sheet molding compound is chosen as the most suitable material, compression molding is the logical process. In some cases, however, two or more processes are available, even though definite reinforcement and resin selections have been made. For instance, polyester bulk molding compound can be either compression or injection molded. In such a situation, other factors, such as part configuration, fabrication and end-use tolerances, and production volume, may determine the optimum process.

In all cases, cost/performance evaluation should be the deciding factor. Cost of materials, tooling and labor must all be considered and measured against performance. And each candidate production method must be considered to determine the best choice.

Finally, the basic advantages offered by FRP/Composites should be reviewed. Although the initial design may have had only one or two of these "basics" as its objective, opportunities to reduce cost and improve product performance in other areas are often brought to light by considering them all once again.

4 Create Initial Sketches

The purpose of initial sketches is to help design engineers focus their basic concepts and to make these concepts consistent with end-use requirements. Keeping in mind the basic attributes of FRP/Composite materials and processes help avoid producing a direct copy of a part as it might be designed to suit the characteristics of metals or of unreinforced plastics. This is especially important if the other materials are highly cost-competitive and where the savings of a few ounces of material per part can add up to a significant amount over a large production run.

The designer must decide on an approach that will produce a part sufficiently strong to meet mechanical requirements, with the chemical, thermal and electrical properties, as well as appearance qualities to meet specifications. Initial sketches are necessary to perform stress analysis and start the detail empirical design. High-performance FRP/Composite products usually result from effective use of both disciplines, validated with laboratory testing.

Stress analysis involves using engineering equations for calculating stresses at critical areas, resulting in the determination of optimum configuration and minimum part thickness for those areas. Such

studies are often performed using finite element analysis methods and special computer programs that eliminate the tedious manual calculations. This design approach is used for FRP parts where performance requirements are severe and where material cost considerations are critical. Empirical design is based on the designer's familiarity with FRP/Composite materials and processes in related applications. Assumptions are made concerning part thickness, surface finish and other features and characteristics, based on past experience with similar parts plus all additional available information. A preliminary cost estimate is usually made to determine whether the design approach meets all production requirements.

5 Make Detailed Part Drawings

In committing the design to production drawings, many details must be considered and resolved. As elsewhere in the design effort, consulting with a reliable custom molder at this point is a wise move for advice concerning design details, such as radii, holes, inserts, ribs, bosses, as well as for guidance on surface finish, molded-in color, reduced stress concentration, and other features and refinements. This is also a critical point to consider current design and manufacturing methods such as:

- Design for Six Sigma
- Design for Manufacturability
- Lean Manufacturing

Collaboration with a custom molder to optimize tolerances for cost and performance and to help develop the most efficient production flow concepts will form the basis for near- and long-term economic benefits during the production life cycle.

6 Economic and Feasibility Analysis

As detailed drawings are completed, a final economic analysis should be prepared to confirm the preliminary economic study, to calculate investment and return on investment, and to establish the total delivered cost of the FRP/Composite component.

A mock-up or simulation may be helpful to establish the technical feasibility of the initial design concept. This need not be an exact prototype or detailed replica of the part to be molded. An approximation can aid visualization of the finished FRP/Composite part and its relationship to parts associated with it in the final product. In addition, a mock-up helps visualize possible problems involving tooling, assembly, inspection or handling. Correcting such problems at this stage is much less expensive than later in the production program.

7 Develop a Prototype

A working prototype – one that closely duplicates the expected final design in configuration and performance – is the next step. The best FRP/Composite prototype is one produced from partially completed production molds because it will be almost identical to a production part. This may be facilitated with the help of molders that are skilled in low-volume FRP/Composite processes that are particularly suited for producing prototype parts economically.

The easiest prototypes to fabricate are those for applications involving contact molding processes. Such prototypes are readily checked against performance and dimensional requirements. They are then adapted, or the mold is modified and another prototype molded. The mold or the processing technique is adjusted until a satisfactory part is produced.

Through molding and testing a series of prototypes and gradually refining the design, the final configuration and dimensions are established. The process produces an FRP/Composite part that provides the required function and uses the minimum material commensurate with design objectives of strength, dimensional stability and surface finish.

8 Tooling Tryout

As the prototypes undergo final refinements to meet design objectives, the tooling is completed and the design is ready for pilot production. Provisions for heating or cooling are added, and surface finishes are applied to facilitate part release. Duplicate tools may be built if production volume dictates.

During tool tryout runs, it is important to control closely the variables of temperature, pressure and cycle times so the parts produced can be evaluated in terms of end-use objectives. Such control is also necessary to ensure reproducibility of production run parts.

Comparisons

•How Reinforcing Systems Compare in Compression-Molded FRP Parts

Characteristic or Property	Preform	SMC	BMC
Part Complexity, Wall Thickness	Best for uniform wall components with deep-drawn shapes. Parts can be several feet long or in diameter.	Best for complex configurations. Bosses and ribs are easily formed because the compound flows during molding. Parts can be several feet long or wide.	Best for moderate-sized (1-2'), bulky, thick-walled parts with complex configurations such as ribs and bosses.
Strength	Highest strength of the resin/fiber systems. Reinforcing fibers do not flow during molding but maintain their random orientation. Properties are isotropic in plane of part walls.	Moderate strength, which can be increased with higher glass content – to as much as 65 percent for structural parts. Nonuniformity of properties is a function of composite flow during molding.	Least strong of the choices; relatively poor strength uniformity because reinforcing fibers become oriented during molding as the material flows.
Surface Finish	Glass pattern can be minimized with use of fillers such as calcium carbonate and surfacing veils (to provide resin richness at the surface). Class A automotive surfaces can be achieved with no long-term waviness.	Very smooth surfaces are possible, requiring minimal secondary operations to produce Class A automotive-type finishes. However, large parts often have long-term waviness.	Very smooth surfaces are possible, similar to those of SMC parts, but usually with a higher degree of long-term waviness.
Molding Characteristics	Typically molded at 200 - 500 psi, lower cost tools acceptable, usually requires more work than SMC to trim flash and finish parting line. Can be in-mold coated.	Requires up to 1000 psi for molding, excellent quality tooling and presses required, in-mold coating possible, minimal flash and part line finishing necessary.	Requires 800 to 1500 psi, high quality tooling essential, can be injection molded, minimal flash and part line finishing necessary.
Part Size	Good process for medium to very large parts; excellent application for large vertical walls and deep draws.	Good application for medium to large parts; part size limited by available molding pressure. Not recommended for deep drawn parts.	Small but heavy parts; not well-suited for deep drawn parts.
Typical Applications	Deep tub or boxlike shapes such as housings for industrial electrical equipment; large, smooth components such as automobile hoods and truck roofs.	Complex ribbed parts such as automobile front-end panels, business-machine housing, instrument bases.	Blocky electrical insulators, under-hood automotive components.

DESIGN DETAILS

		Compression Molding			Resin Transfer Molding	Cold Press Molding	Spray-Up & Hand Lay-Up
		Preform Molding	Sheet Molding Compound	Bulk Molding Compound			
Minimum Inside Radius, in.		1/8	1/16	1/16	1/4	1/4	1/4
Molded-in holes		yes*	yes*	yes*	no	no	no
Trimmed-In Mold		yes	yes	yes	no	no	no
Core Pull & Sides		no	yes	yes	no	no	no
Undercuts		no	yes	yes**	yes**	no	yes**
Minimum Recommended Draft (no in-mold coating)		1/4 *in. to* 6 *in. depth*: 2° to 3° 6 *in. depth and over*: 3° or as required			2° 3°	2° 3°	1°
Minimum Recommended Draft (in-mold coating)		4° or as required			not applicable		
Minimum Practical Thickness, in.		0.045	0.080	0.060	0.080***	0.080	0.060
Maximum Practical Thickness, in.		1/4	1/2	1	1/2	1/2	no limit
Normal Thickness Variation, in.		± 0.010	± 0.010	± 0.010	± 0.020	± 0.020	± 0.030
Maximum Thickness Build-Up, Heavy Build-Up and Increased Cycle		2-to-1 max.	as required	as required	2-to-1 max.	2-to-1 max.	as required
Corrugated Sections		yes	yes	yes	yes	yes	yes
Metal Inserts		not recommended	yes	yes	no	no	yes
Bosses		no	yes	yes	not recommended	not recommended	yes
Ribs		not recommended	yes	yes	not recommended	not recommended	yes
Molded-In Labels		yes	yes	yes	yes	yes	yes
Raised Numbers		yes	yes	yes	yes	yes	yes
Finished Surfaces (Reproduces Mold Surface)		two	two	two	two	two	one

* Parallel or perpendicular to ram action only. *** Can be 0.060 in. if glass content is less than 20 percent.
** With slides in tooling or split mold.

Property Comparisons of Fiberglass/Composites and Alternative Materials

Property	Glass Fiber	Specific Gravity	Density	Tensile Strength	Tensile Modulus	Elon-gation	Flexural Strength	Flexural Modulus	Compress. Strength	Impact Strength,	Flamma-bility	Specific Heat	Thermal Coeff. of	Heat Distort.	Thermal Conduc-	Dielectric Strength	Water Absorption	Mold Shrinkage
Units	%		lb./in.^{3}	10^3 psi	10^6 psi	%	10^3 psi	10^6 psi	10^3 psi	ft. lb./in. of Notch		BTU/ lb. °F	10^{-6} in./in. °F	°F at 264 psi	BTU/hr./ ft.^{2}/°F/in.	V/mil.	% in 24 hr.	in./in.
ATM Test Method	D790	D792		D638	D638	D638		D790	D695	D256	UL-94		D696	D648	C177	D149	D570	D955
Fiberglass Reinforced Thermosets																		
Polyester preform, low profile	24	1.74	0.063	11.5	1.70	2.5	28.5	1.32	20.0	20.8	*	0.30	14.0	400+	1.3	400	.8	0.000
(Compression) general purpose	25	1.55	0.056	13.5	1.80	2.5	27.0	1.10	25.0	18.0	*	0.30	14.0	350+	1.5	400	.25	0.001
high glass	40	1.70	0.061	21.5	2.25	2.5	38.5	1.50	32.0	23.0	*	0.30	14.0	400+	1.5	400	.4	0.0005
Carbon/Epoxy Fabric				23.0	2.10	1.0	25.0	2.00					*			N/A		
Polyester SMC LP low profile	30	1.85	0.067	12.0	1.70	<1.0	26.0	1.60	24.0	16.0	*	0.30	12.0	400+	1.5	400	.2	0.001
(Compression) general purpose	22	1.78	0.064	10.5	1.70	0.4	21.2	1.40	23.0	12.0	*	0.30	12.0	350+	1.5	400	.2	0.001
high glass	50	2.00	0.072	23.0	2.27	1.7	45.0	2.00	32.0	19.4	*	0.30	15.0	500	1.5	375	.5	0.0005
Carbon/Vinyl Ester		1.50		22.0	6.0	0.4	71.0	4.00					*			N/A	.13	
Polyester BMC (compression)	22	1.82	0.066	6.0	1.75	<0.5	12.8	1.58	20.0	4.3	*	0.30	8.0	500	1.5	200	.5	0.001
Polyester BMC (injection)	22	1.82	0.066	4.9	1.53	<0.5	12.7	1.44	—	2.9	*	0.28	4.0	—	1.5	250	.5	—
Polyester (pultruded)	55	1.69	0.061	30.0	2.50	—	30.0	1.60	30.0	25.0	*	0.31	—	400+	1.50	350	.5	0.003
Polyester (spray-up, lay-up)	30	1.37	0.049	12.5	1.00	1.3	28.0	0.75	22.0	14.0	*	—	—	400+	—	300	.5	0.002
Polyester woven roving (lay-up)	50	1.64	0.059	37.0	2.25	1.6	46.0	2.25	27.0	33.0	V-0	0.23		400+	1.92	—	0.50	0.008
Epoxy (filament wound)	80	2.08	0.075	80.0	4.00	1.6	100.0	5.00	45.0	45.0	V-0	—		—	—	—	—	—
Polyurethane, milled fibers (RRIM)	13	1.07	0.039	2.8	—	140.0	—	0.05	—	—	V-0	—		—	—		—	—
glass flake (RRIM)	23	1.17	0.042	4.4	—	38.9	—	0.15	—	2.1							—	—
Fiberglass Reinforced Thermoplastics																		
ABS	20	1.22	0.044	11.0	0.90	2.0	15.5	0.87	14.0	1.4	HB	—	21.0	220	1.4	465	0.14	0.002
Acetal	25	1.61	0.058	18.5	1.25	3.0	28.0	1.10	17.0	1.8	HB	—	47.0	325	—	580	0.29	0.004
Nylon 6	30	1.37	0.049	23.0	1.05	3.0	29.0	1.20	24.0	2.3	HB	—	17.0	420	5.8-11.4	500	1.10	0.004
Nylon 6/6	30	1.48	0.053	26.0	1.20	1.9	35.0	1.30	26.5	2.0	HB	0.30	13.0	480	1.5	400	0.90	0.002
Polycarbonate	10	1.26	0.045	12.0	0.75	9.0	16.0	0.60	14.0	3.7	V-1	0.29	18.0	300	4.6	500	0.14	0.001
Polyester (PBT)	30	1.52	0.055	19.0	1.20	4.0	28.0	1.40	18.0	1.8	HB	0.11	12.0	430	7.0	375	0.06	0.003
Polyester (PET)	30	1.56	0.056	21.0	1.30	6.6	32.0	1.42	25.0	1.8	HB	—	17.0	420	6.5	520	0.05	0.003
Polyphenylene ether (PPO)	20	1.21	0.044	14.5	0.92	5.0	18.5	0.75	17.6	1.7	HB	0.30	20.0	310	3.8	500	0.06	0.003
Polyphenylene sulfide	40	1.64	0.059	22.0	2.05	3.0	37.0	1.90	21.0	1.5	V-0/5V	0.25	11.0	510	2.0	380	0.01	0.002
Polypropylene	20	1.04	0.037	6.5	0.54	3.0	8.3	0.52	25.0	3.0	HB	—	24.0	295	8.4	440	0.03	0.003
SAN	20	1.22	0.044	14.5	1.25	1.8	19.0	1.10	17.5	1.0	HB	—	21.0	215	2.8	490	0.10	0.002

*Polyester thermosets can be formulated to meet a wide range of flame smoke and toxicity specifications.

Property Comparisons of Fiberglass/Composites and Alternative Materials

Property	Specific Gravity	Density	Tensile Strength	Tensile Modulus	Elon-gation	Flexural Strength	Flexural Modulus	Compress. Strength	Impact Strength, Izod	Hardness	Flammability	Specific Heat	Thermal Coeff. of Expansion	Heat Deflect. Temp.	Thermal Conduc-tivity	Dielectric Strength	Water Absorption	Mold Shrinkage
Units		lb./in.^{3}	10^3 psi	10^6 psi	%	10^3 psi	10^6 psi	10^3 psi	ft. lb./in. of Notch	Rockwell Except as Noted		BTU/ lb. °F	10^{-6} in./in. °F	°F at 264 psi	BTU ft./ hr. ft.^{2} °F	V/mil.	% in 24 hr.	in./in.
ASTM Test Method	D792		D638	D638	D638	D790	D790	D695	D256	D785	UL-94		D696	D648	C177	D149	D570	D955
Unreinforced Thermoplastics																		
ABS	1.05	0.036	6.0	0.30	5.0	11.0	0.32	10.0	4.4	R107-115	HB	—	53.0	195	0.96	350-500	0.30	0.006
Acetal	1.42	0.050	8.8	0.41	40.0	13.0	0.40	16.0	1.3	M78-80	HB	0.35	45.0	230	1.56	500	0.22	0.020
Nylon 6	1.14	0.041	11.8	0.38	38.0	15.7	0.40	13.0	1.0	R119	HB	0.40	46.0	167	1.20	305	1.80	0.016
Nylon 6/6	1.13	0.041	11.8	0.40	60.0	17.0	0.41	15.0	0.9	R120	V-2	0.30	45.0	170	1.70	385	1.50	0.016
Polycarbonate	1.14	0.041	9.0	0.34	110.0	13.5	0.33	12.5	12.0	M70	V-2	0.30	37.0	265	1.35	380	0.15	0.006
Polyester (PBT)	1.31	0.047	8.5	0.28	50.0	12.0	0.34	8.6	1.2	M68-78	HB	—	53.0	130	1.02-1.67	420-550	0.08	0.020
Polyester (PET)	1.34	0.048	8.5	0.40	50.0	14.0	0.40	11.0	0.7	M94-101	HB	0.34	—	100	0.87	—	0.15	0.020
Polyphenylene ether (PPO)	1.06	0.038	9.5	0.38	50.0	12.8	0.36	12.0	5.0	R115	V-1	0.2-0.4	33.0	265	0.92	400	0.07	0.005
Polyphenylene sulfide	1.30	0.047	9.5	0.48	1.0	14.0	0.55	16.0	<0.5	R123	V-0	—	—	275	1.67	380	<0.02	0.007
Polypropylene	0.89	0.032	5.0	0.10	200.0	5.0	0.18	3.5	0.5-2.2	R50-96	HB	0.45	40.0	135	1.21	600	0.01	0.018
SAN	1.08	0.039	9.8	0.40	0.5	14.0	0.50	14.0	0.4	M80-85	HB	0.33	34.0	200	0.70	515	0.25	0.005
Metals																		
AISI 1008 cold-rolled steel	7.86	0.284	48.0	30.0	37.0	—	—	48.0	—	B34-52	—	0.10	6.7	—	35.0	—	—	—
ASTM A-606 HSLA cold-rolled steel	7.75	0.280	65.0	30.0	22.0	—	—	65.0	—	B80	—	0.11	6.8	—	25.0	—	—	—
AISI 304 stainless steel	8.03	0.290	80.0	28.0	40.0	—	—	80.0	—	B88	—	0.12	9.6	—	9.4	—	—	—
2036-T4 wrought aluminum	2.74	0.099	49.0	10.2	23.0	—	—	49.0	—	R80	—	0.21	13.9	—	92.0	—	—	—
ASTM B85 die-cast aluminum	2.82	0.102	48.0	10.3	2.5	—	—	48.0	—	Bhn 85	—	—	11.6	—	53.0	—	—	—
ASTM AZ91B die-cast magnesium	1.83	0.066	33.0	65.0	3.0	—	—	33.0	—	Bhn 85	—	0.25	14.0	—	41.8	—	—	—
ASTM AG40A die-cast zinc	6.59	0.238	41.0	10.9	10.0	—	—	41.0	—	Bhn 82	—	0.10	15.2	—	65.3	—	—	—

Chemical Properties of Fiberglass Composites and Alternative Materials

Polyester thermosets are available in many formulations. They can be formulated for good to excellent resistance to acids, weak alkalies and organic solvents. However, they are not recommended for use with strong alkalies.

Epoxies are highly resistant to water, alkalies and organic solvents. Although standard epoxies have only fair resistance to acids and oxidizing agents, they can be formulated for better resistance to these chemicals.

Polyurethane moldings are normally used for their toughness and structural properties. They are highly resistant to most organic solvents but are not recommended for use with strong acids or alkalies, steam, fuels or ketones.

ABS provides good resistance to most organic solvents and is highly resistant to weak acids and alkalies. It is attacked by sulfuric and nitric acids and is soluble in esters, ketones and ethylene dichloride.

Acetal is highly resistant to strong alkalies and can be continuously in hot water. Properties are affected only slightly by most organic solvents. It is not recommended for use in strong acids.

Nylons are inert to most organic solvents. They resist alkalies and salt solutions but are attacked by strong mineral acids and oxidizing agents. Because the resins are hygroscopic, dimensional stability suffers.

Polyphenylene ether/oxide (PPO) provides excellent resistance to aqueous media but is softened by aromatic hydrocarbons. Dimensional stability over a wide temperature range is excellent.

Polycarbonates resist weak acids and alkalies, oil and grease. They are attacked by strong acids, alkalies, organic solvents and fuels.

Thermoplastic polyesters resist most organic solvents, weak acids and weak alkalies but are not recommended for use in strong acids and alkalies or for prolonged use in hot water.

Polypropylene provides excellent resistance to acids, alkalies and organic solvents, even at higher temperatures, but is soluble in chlorinated hydrocarbons.

Polyphenylene sulfide provides outstanding resistance to most chemicals over a wide temperature range to 375°F. It is unaffected by strong alkalies or aqueous organic salt solutions.

Polystyrene has good resistance to alkalies, most organic solvents, weak acids and household chemicals. It is not recommended for use with strong acids, ketones, esters or chlorinated hydrocarbons.

Cold-rolled carbon steels are rusted by water, oxygen and salt solutions. Resistance to alkalies is good, but they should not be used with acids.

Stainless steels have good resistance to alkalies and organic solvents. However, resistance to acids (especially hydrochloric and sulfuric) and chloride solutions is poor.

Aluminum has poor resistance to acids (especially hydrochloric and sulfuric) and chloride salts. It forms a hard oxide coating when exposed to air and requires a surface treatment for appearance when exposed to weather.

Magnesium has poor resistance to salt spray, industrial atmospheres and acids except hydrofluoric. However, resistance to alkalies is good.

Zinc offers good atmospheric resistance but is not recommended for use with strong acids, bases or steam.

These data are given only to suggest general property ranges of various materials for comparison. They do not reflect exact properties of any given molded or machined part.

Molded Fiber Glass Companies

MFG Is a Full Spectrum Composite Manufacturing Supplier

Molding Process Capability

• Open Molding (Hand Lay-up, Spray-up)
• Vacuum Infusion Processing (VIP) or RTM-lite
• Resin Transfer Molding (RTM)
• DCPD RIM (Reaction Injection Molding)
LCM with Preform Reinforcement – MFG PRiME™ Process
• Compression Molding - SMC
• Direct Long Fiber Thermoplastic Molding (D-LFT)

Value-Added Processes

• Robotic Gel Coating
• In-Mold Coating (IMC)
• SMC/BMC Compounding
• Directed Fiber Preforming, APP
• Bonding and Assembly
• Robotic Routing and Water Jet
• Prime and Topcoat Paint Capabilities
• In Line Sequencing

13 Strategically Located Factories in North America Provides Nimble and Cost-Efficient Fabrication

The best value supplier is strategically located for your needs – perhaps near your operations, supply source, market or a specific labor market. MFG has established the largest full-service network of molding factories in North America. This factory network is supported by a shared foundation of engineering, design, R&D, procurement and program management that ensures consistent quality and service company-wide. This structure allows us to provide the most competitive cost structure possible.

Molded Fiber Glass Companies
2925 MFG Place, P.O. Box 675
Ashtabula, OH 44005-0675
(800) 860-0196 • (440) 997-5851
www.moldedfiberglass.com