

Reinforced Thermosetting Plastics for Ground Vehicle Application—SAE J762a

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Reinforced Thermosetting Plastics for Ground Vehicle Applications

1. SCOPE

This information report is intended to establish an engineering approach to the selection and use of reinforced thermosetting plastic materials. A further purpose is to acquaint the engineer with the varied processes and fibrous reinforced thermosetting plastic materials available and their general range of properties and application for ground vehicles.

2. INTRODUCTION

Reinforced thermosetting plastic materials are molded in the form of premixes (bulk molding compounds), laminated mat, sheet or fabric molding compounds, preforms, or combinations thereof. Products molded from these forms range from flat sheet and tubes to completely molded contoured parts of varying cross section. Materials included in this report are those reinforced thermosetting plastics used primarily in ground vehicles. This report deals primarily with systems using polyester resins as the continuous binder phase, as this resin family has proved more practical from the economic standpoint. These thermosetting reinforced plastic materials are converted to useful products by chemical reactions, using temperature and pressure. After processing, they are not capable of being reshaped to any practical degree.

Reinforced thermosetting plastics are a heterogeneous group of materials capable of being processed by a variety of fabrication techniques.

No continuous series of physical properties or composition components exists that can serve as a framework for a classification system. Therefore, classification of reinforced thermosetting plastic materials for this report will be through fabrication methods and end use applications.

A general outline and description of the component materials, primarily resins, reinforcements used in thermosetting reinforced plastics, and the various fabrication methods as related to end use application, are given in greater detail.

Nomenclature and terms related to reinforced thermosetting plastics are presented in Appendix C.

General guidelines for design engineers are provided in paragraph 5 and Appendix B, Tables B-1 to B-5.

3. GENERAL DEFINITIONS

3.1 REINFORCED THERMOSETTING PLASTIC - Reinforced thermosetting plastic is a composite material with one continuous resinous binder phase (any thermosetting resin) and a reinforcing fibrous phase for controlling the processing, mechanical, and physical properties.

3.2 COLORING AGENT - A pigment or dye is an organic or inorganic substance added to the formulation to impart color to the molded material. Normally 1/2-3 parts pigment paste or dye are used per 100 parts of resin. However, it is difficult to hide the reinforcement completely without the use of a covering coat.

3.3 COMPOUNDING MATERIALS - The following materials are employed in the compounding of reinforced thermosetting plastics.

Essential:

- (1) Thermosetting resin binder (primarily polyesters although other thermosetting resins are not excluded).
- (2) Reaction initiator (catalyst or hardener).
- (3) Fibrous reinforcement (natural, synthetic, or inorganic).

Optional:

- (4) Fillers (organic or inorganic).
- (5) Internal mold lubricants.
- (6) Coloring agents (pigment or dye).
- (7) Inhibitors.

The selection of the first three components is dependent on the application. The selection of mineral fillers, mold lubricants, and inhibitors, if any, is dependent on the choice of resin and fabrication requirements. The color agent is dependent upon the esthetic requirements of the application.

3.3.1 Fillers - Fillers are used as extenders or modifiers to reduce cost and to control molding, physical, and mechanical properties of the product. They may be naturally occurring minerals such as clays, ground limestone, whiting, gypsum, talc, litharge, chalk, and silicates, or organic materials such as wood flour. The filler particles are usually small, in contrast to those of reinforcements, but there is some overlap between the functions of the two. Fillers serve to reduce shrinkage, improve surface finish, and increase hardness. They also may tend to improve shelf life and modify other properties. And they serve as a carrier for the fiber and prevent resin separation during molding.

3.3.2 Inhibitors - Inhibitors are sometimes used in small quantities to prolong shelf life and prevent premature curing. Generally, it is desirable to avoid the use of inhibitors, since they tend to increase the mold cycle time.

3.3.3 Internal Mold Lubricants - An internal mold lubricant is normally a wax or metallic stearate which is added to the formulation and which on molding exudes to the plastic-mold interface to facilitate repeated mold parting.

3.3.4 Reaction Initiator (catalyst or hardener) - A substance which markedly speeds up the cure or conversion of a formulation when added in minor quantity as compared to the amounts of the primary reactants. Some phenolic resins are converted with heat alone. The styrene, vinyl-toluene, and diallyl phthalate monomer component resins (that is, polyesters) require an organic peroxide reaction initiator. Epoxy resins use a hardener system of an amine, acid, or basic organic compound for conversion.

3.3.5 Reinforcement - The reinforcement is a relatively strong material, fibrous in nature, bound in the resin to control the processing and physical and mechanical properties. Reinforcements may be of organic or inorganic origin, natural or synthetic. Chemical, physical, and mechanical properties determine their end use application. Reinforcements are available in various forms, such as cloth, mat, continuous strand, or short fiber bundles. The most commonly used material is glass; however, asbestos, sisal, and synthetic material can be used.

3.3.6 Thermosetting Resin - A plastic which, when cured by the application of heat or chemical means, changes into a substantially infusible and insoluble product.

4. GENERAL FABRICATION METHODS

Currently the greatest volume of molded reinforced thermosetting plastic parts for ground vehicle applications is fabricated with matched dies as medium pressure moldings from premix (bulk molding compounds) sheet molding compounds, glass fiber mat, cloth, or preform reinforcement. Additional applications of lesser volume are produced by low pressure molding using principally hand lay-up, vacuum, pressure bag molding, spray-up, centrifugal casting, and filament winding.

The types of molding processes employed in the field of reinforced thermosetting plastics as well as the typical applications are outlined in Table 1.

5. MATERIAL CHARACTERISTICS AND DESIGN CRITERIA

5.1 SURFACE FINISH - Reinforced plastic parts can be used as-molded or painted. For economic reasons it is desirable to use the as-molded finish whenever practical. Although such a finish is not equivalent to painted automotive sheet metal in gloss and smoothness, it is not unattractive and can often be used where it does not conflict with adjacent painted components of the same color. A gel coat finish is normally specified for open die molded parts where appearance is a factor.

The consistent attainment of smooth, high gloss finishes at moderate cost is an area of intensive effort by material suppliers and molders. Recent developments have made significant progress in improving the as-molded finish.

When used adjacent to painted surfaces of the same color, reinforced thermosetting plastic parts are normally painted, even if surface finish is not a consideration. This is because an exact color match is difficult to attain consistently, and because even an exact match will not be maintained after exposure to sun and rain. The highest quality "glamour" finishes—comparable to painted automotive sheet metal—will require painting to achieve the required smoothness and gloss.

The specification and control of "glamour" finishes is one of the areas of concern facing reinforced thermosetting plastic users. This is true largely because of the cost involved in consistently attaining such finishes. Common practice has involved sanding to remove fiber pattern and other surface imperfections, wiping with filler to fill voids, and priming to seal the surface. Sanding and priming may be repeated several times prior to finish painting, depending on the quality of the original substrate and the finish required. High gloss finishes accentuate surface imperfections which might be difficult to see prior to painting.

Surface finish characteristics may be classified in four groups:

5.1.1 Fiber Pattern is due to the shrinkage of the resin upon curing which leaves the fiberglass bundles raised slightly above the surface. The resulting texture is typical of reinforced thermosetting plastics and may be used as is when a smooth glossy surface is not desired or necessary. Fiber pattern in mat or preform matched die molded parts may be subdued somewhat by using surfacing mat or veil to keep the coarse fiber bundles away from the surface. Premix and sheet molding compounds appear to be inherently capable of providing reduced fiber pattern. Fiber pattern can also be subdued by reducing the resin shrinkage through high filler contents. In recent developments, it appears that "low-shrink," thermoplastic modified thermosetting resin systems may be capable of essentially eliminating fiber pattern. High filler contents and low-shrink resins currently entail a small sacrifice in physical properties. The use of a gel coat eliminates fiber pattern, but is normally available only on open die molded parts. Molded-in texture, such as leather grain, is very effective in masking fiber pattern and can be used as-molded, or painted with little preparation. Defects in textured finishes are difficult to touch up or repair.

Table 1 - General Fabrication Methods

Type	Pressure Molding Description	Application
1. High pressure (1500-3000 psi) Compression	Molding of dry reinforced materials High pressure in heated cavity	Electrical parts, bushings, pulleys, terminal blocks, gears
Transfer	Molding by transfer of material from hot compression chamber to hot cavity	As above
Injection molding	Molding under high pressures, mass of re- inforcement and thermosetting resin are forced into hot cavity	Electrical parts, bushings, gears
2. Medium pressure (100-1500 psi) Mat or cloth	Molding of wet reinforced materials Molding of woven or nonwoven fabric saturated with resin and cured under heat and pressure	Trays, truck and auto body parts
Preform	Molding as above, but using a preformed felt manufactured to appropriate size and shape. Used where mat or cloth cannot be tailored to appropriate size and shape	Truck and auto body sections, ma- chinery housings
Premix (bulk molding com- pound)	Molding of wet mixture or resin and mac- erated reinforcement cured under heat and pressure	Heater housings, pump impellers, electrical outlet boxes, fender extensions, hood and quarter panel scoops, air foils
Sheet molding compound	Molding of precombined, thickened mix- ture of resin, filler, and reinforcing fibers in sheet form, and curing under heat and pressure	Truck and auto body parts, exter- ior automotive parts
3. Low pressure (0-100 psi)	Molding or fabrication with little or no pressure	
Hand lay-up	Method of fabrication using wet resin im- pregnated mat or cloth shaped over either a male or female mold and cured chemically with or without external heat or pressure	Experimental or prototype auto parts, very short run items, lam- inated sheet stock
Spray-up	Method of simultaneous spraying of resin and chopped fiberglass onto mold sur- face to build up part thickness, cured as above	As above
Bag and autoclave	As above in hand lay-up, but employing bag to exert air pressure on lay-up	As above, but produces higher rein- forcement to resin ratio
Centrifugal casting	Molding method using mixture of resin and chopped reinforcement, and employ- ing centrifugal force to exert pressure on part during molding	Pipe, cylindrical parts
Filament winding	Method of producing parts with uni- directional reinforcement by saturating continuous filaments of reinforcement with a wet resin and either wrapping or molding to produce the desired shape	Tubing, tanks, product shape is re- stricted to surface of revolution
Continuous pultrusion	Resin impregnated glass strands are drawn through a die for shape, curing is com- pleted by drawing through an oven	Rods, tubing, channel section

5.1.2 Flow Marks are surface ripples caused by material flow in a mold. If present, they are most commonly located near the edges of a part. Since premix and sheet molding compounds involve significant flow of reinforcement during molding, they are somewhat susceptible to flow marks. While these can be controlled somewhat through molding technique, ripples, if present, will require surface preparation similar to fiber pattern when "glamour" finishes are required.

5.1.3 Pinholes and voids may be encountered in any type of molding. They are caused by entrapment of air or volatiles during the molding operation. Objectionable pinholes on parts not to be painted may be masked by wipe-in fillers used at the molding press. Both open pinholes and porosity located just below the surface can be troublesome on parts which are painted, since they can cause fisheyes and blisters in the finish paint film. Such problems are not confined

on parts which have had minimum surface preparation and on those subjected to a paint bake cycle.

5.1.4 Bond burns is a finish imperfection even though the bonding is on the back side of the part. This is due to telegraphing of the bond (a light ripple in the surface caused by shrinkage of the adhesive during cure). The fabricator can normally solve this problem by properly selecting adhesives and by insuring complete cure of the parts prior to bonding, that is, postbaking. It is desirable to avoid designs which place bonded areas in the center of a large highlighted surface where defects are most noticeable.

5.2 COMPATIBILITY WITH PAINT FINISHING OPERATIONS - When reinforced thermosetting plastic parts are to be painted, certain precautions must be taken by the molder to insure compatibility with finishing operations. He must avoid the use of mold release materials which impair adhesion. The molder must also develop his product to withstand paint baking cycles when required. Possible problems include warpage due to relief of molded-in stresses, and blisters and fisheyes due to voids and pinholes in the laminate. A postcure baking operation may be required to stress relieve parts and expose hidden air bubbles prior to painting.

5.3 RESISTANCE TO WEATHERING AND SUNLIGHT - Parts which are to be exposed to ultraviolet light from the sun will require special compounding unless protected by painting. Resins are normally compounded with ultraviolet stabilizers. In some cases, special resins or crosslinking monomers may be used. Generally, the use of a surfacing veil or gel coat is recommended to avoid premature exposure of glass fibers at the surface. Premature exposure causes a poor appearance, leads to moisture absorption, and tends to accelerate the weathering process. The pigments used for molded-in colors must also be stable.

5.4 HEAT RESISTANCE - General purpose resins are normally compounded to provide a balance of good resiliency (resistance to impact and fatigue crazing) with moderate resistance to high temperatures (180 - 240 F) depending on glass content, environment, and loading). It is possible to compound resins for resistance to 400 F or higher at a sacrifice in resiliency.

5.5 RESISTANCE TO FUELS, LUBRICANTS, COOLANTS, AND CHEMICALS - Polyester resins can be supplied to provide resistance to fuels, lubricants, and common solvents, or to common aqueous chemicals (salts, acids, alkalis, coolants, and the like). Parts exposed to such fluids or chemicals will normally require some means of covering surface glass fibers to prevent wicking and subsequent leakage, loss of strength, or both. A gel coat or other means of providing a resin-rich surface is commonly used on the side exposed to chemical attack.

5.6 ABRASION RESISTANCE - Reinforced thermosetting plastic materials are not as suitable as some other plastics for applications involving severe wear or abrasion. Where moderate conditions are expected, special compounding can provide some benefits. Compounding with solid lubricants can also be utilized to provide parts suitable for light bearing applications.

5.7 JOINING AND ASSEMBLY - Reinforced thermosetting plastic parts are commonly joined by adhesive bonding, riveting, or bolting. Sufficient sized washers should be used in bolted assemblies to distribute the load and avoid cutting the reinforced thermosetting plastic with the bolt head. A number of plastic fasteners are also available which may be assembled simply from one side. Hollow rivets may be used for simple permanent joining where appearance and other factors permit. For permanently sealed joints and joints where visible fasteners are undesirable, adhesive bonding may be used. Bonded joints should be loaded in shear rather than in peel or cleavage. Rivets are occasionally used to reinforce joint ends in cases where peel or cleavage may tend to initiate failure. Any mold release agents used in the manufacture of parts to be bonded must be of a type which will not interfere with adhesion. Joint areas are typically sanded or grit blasted to obtain maximum adhesion.

5.8 FLAME RESISTANCE - Reinforced thermosetting plastic parts made with fire-retardant resins systems are available. A variety of tests are commonly used, many of which are based on ASTM D 635 or are modifications thereof.

5.9 ELECTRICAL PROPERTIES - Reinforced thermosetting plastics materials share with most other plastics the characteristic of having good electrical insulating properties. This combination of insulating ability and mechanical strength, rigidity, and heat resistance makes reinforced thermosetting plastic materials particularly useful for replacing complicated assemblies, involving both structural metal components and insulating materials, with a single molded part. Premix materials are most commonly used in such applications. These materials have the additional advantage of high resistance to arcing and tracking across electrical contacts under adverse conditions.

5.10 LIGHT AND HEAT TRANSMISSION - Reinforced thermosetting plastic materials can be compounded to provide a wide range of light and heat transmitting properties. While they cannot be made transparent, a high degree of translucency is possible, allowing the level of the contents in hoppers and tanks to be readily seen. Through proper compounding, materials can be obtained which, when molded into parts, combine high values of light transmission and low values of heat transmission.

5.11 DESIGN - Table 2 includes general rules providing guidance in the design of reinforced thermosetting plastic parts. A notation of "possible" indicates a less common and, in some cases, less desirable feature.

6. SPECIFIC PROCESSING METHODS

For convenience, the numerous processing methods are grouped under two general headings—matched die molding and open die molding.

6.1 MATCHED DIE MOLDING - When medium to high production is required, the most efficient and economical method to mold reinforced thermosetting plastics is by the positive pressure matched die process. Positive pressure assures complete fill out of the cavity during the mold cycle.

Table 2 - Designing Reinforced Thermosetting Plastic Parts

	Matched Die Molding			
	Premix	Mat and Pre-form	Open Die Molding	Centrifugal Casting
Minimum inside radius, in.	0.030	0.125	0.25	2.0
Molded-in holes	Yes	Yes	Large	—
Trimming required after molding	No	No	Yes	Yes
Undercuts	Yes	No	Possible	—
Draft, deg				
Recommended	2+	2+	2+	0
Minimum	1	1	0 - Possible	—
Thickness, in.				
Minimum	0.060	0.030	0.060*	0.060
Maximum	1.0	0.25	0.50	0.50
Thickness tolerance, in.**	±0.002 to ±0.005	±0.006 to ±0.010	±0.020 to ±0.040	±0.010 to ±0.020
Wall section change	Any	2:1†	Any	None
Metal inserts	Yes	Yes	Yes	—
Surfacing veil	No	Yes	Yes	No
Size, sq ft, max	25	200	2000	—
Bosses	Yes	Possible†	Yes	No
Ribs	Yes	No†	Possible	No
Gel coat	No	Possible	Yes	Possible
Shape limitations	Moldable	Moldable	Almost any	Cylindrical
Translucency	No	Yes	Possible	Yes
Molded surfaces	All	All	One	One

*Not including gel coat.

**Dependent on nominal thickness.

†Newer developments such as the sheet molded compound process could provide more design latitude in these cases.

For physical properties of matched die molded reinforced thermoset plastics and flat sheet laminates, refer to Appendix A for Tables A-1, A-2, and A-3 and to Appendix B for test methods.

6.1.1 Types of Reinforcement Used

6.1.1.1 Fibrous glass mat:

(a) Continuous strand mat or chopped strand preforms or mat.

(b) Long fiber sheet molding compounds.

6.1.1.2 Premix (bulk molding compounds):

(a) Glass, sisal, or inorganic filler reinforced.

6.1.2 Manufacturing Processes

6.1.2.1 Mat and Preform - Mat and preform parts are made by the wet process; that is, the reinforcement is placed into the mold and a fluid resin, usually compounded with fillers, is then added. Closing of the mold acts to distribute the resin throughout the part and to expel air. Since the initial size and shape of the reinforcement approximates that of the finished part, little glass displacement takes place, and physical properties should be essentially equal in all directions. Preforms are generally used in parts with compound curves and deep draws, while mat can be used for shallow parts and for simple curves. Design latitude is somewhat more restricted regarding ribs, drastic section changes, etc., than for premix or sheet molding compounds.

6.1.2.2 Premix (bulk molding compound) - Premix (bulk molding compounds) of the type covered in this report are soft, putty-like, wet mixes. The ingredients are either batch mixed in a sigma blade mixer or mixed automatically and continuously in a continuous-type mixer. The compounds are molded in polished, chrome-plated, steel molds, although limited production has been obtained using aluminum, zinc, and epoxy molds which close to stops. Therefore, it is essential that the mold charge be preweighed to insure sufficient quantity and proper caliper. The compound can be preweighed and hand molded into ball-like charges or extruded into various diameter extrusions and cut to proper (weight) lengths. The proper placement of these charges in the mold governs the extent and location of weld and flow lines on the part. This method of fabricating offers a wide latitude of part design and is capable of large volume production molding.

6.1.2.3 Sheet Molding Compound - Sheet molding compound is a precombined mixture of resin, fillers, and reinforcement in sheet form. The viscosity of the resin component is greatly increased after compounding to provide an essentially dry stock for molding. During flow in the mold, this high viscosity acts to reduce segregation and fiber alignment as compared to premix, while the sheet configuration shortens the flow distance. Reinforcement content and fiber length is comparable to mat-preform parts. As with premix, proper placement of the charge in the mold governs the extent and location