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Glass Fibre-Reinforced Polyester Composites

Please note

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Glass fibre-reinforced polyester (GRP) composites are the most popular reinforced plastic materials used in the construction industry[1]. Depending on formulation and use, they may be fabricated into products that are light in weight, transparent, translucent or opaque, colourless or coloured, flat or shaped sheets, with no limit to the size of object that can be made. This Digest will describe the nature, general properties, application in construction and related fields, and durability of GRP composite materials.

General Nature and Fabrication

The two components of a GRP composite are the matrix (the continuous phase) and the reinforcing glass. Of itself, the matrix does not provide strength, but it serves to bond the reinforcing glass fibres and to transfer the load to the reinforcing phase. The matrix is based on cured thermosetting polyester resin (**CBD 159**). The raw material is supplied in the form of a viscous, syrupy liquid comprising the following basic ingredients: a linear unsaturated polyester; a cross-linking monomer (curing agent), usually styrene; and an inhibitor to retard cross-linking until the resin is to be used by the fabricator. Other ingredients that can be added by either the resin manufacturer or the fabricator of the GRP product include fillers, pigments, fire retardants, ultraviolet (uv) light stabilizers, and thixotropic agents (to prevent excess flow of the resin before cure).

When catalyst (initiator) and glass reinforcement are added, the resulting mixture is ready for production of the GRP item. During fabrication the monomer reacts with the polyester, resulting in cross-linking (**CBD 154**) of the polyester chain and final cure. The ultimate result is a rigid solid material in which the matrix has joined chemically and mechanically with the reinforcing glass fibres to provide a composite structure whose properties are very different from and significantly superior to those of either material alone.

Glass reinforcement provides strength for the GRP composite. It is used in bundles of fibres or filaments (diameter ranging from 0.005 to 0.01 mm, or more) combined to form a strand. Glass-fibre reinforcement can be of several types, the most important being chopped strand, chopped strand mat, rovings (unwoven continuous strands) or cloths (woven fabrics made from glass strands). Chopped strand mat is the most widely used form of glass reinforcement, especially in sheet materials. The strands (2 to 5 cm long) are distributed randomly. The glass content of GRP reinforced with chopped strand mat generally varies between 25 and 35 per cent; for GRP reinforced with cloth, the glass content ranges from 50 to 63 per cent.

The performance of a GRP material in a given application will depend to a large extent on the method of manufacture. GRP components for construction applications may be made by any of the conventional techniques, including hand lay-up, continuous process, spray-up, cold or hot press moulding, and filament winding.

Properties

The properties of the finished GRP composite material depend on a great number of compositional and fabrication factors, some of the most important being resin formulation, filler, curing conditions, type and amount of reinforcement, coupling agent (bonds the resin to the glass), fabrication process and workmanship.

By choice of ingredients, special properties can be achieved. For example, fire retardance can be imparted by incorporating appropriate additives, although it is preferable to modify the basic unsaturated polyester resin to provide built-in fire resistance; weathering resistance can be enhanced by the use of neopentyl glycol and methyl methacrylate; and thermo-plastic polymers can be added to reduce shrinkage during curing. GRP reinforced with chopped strand mat is essentially isotropic, whereas cloth fabric reinforcement and roving give a material that is anisotropic in character, with properties varying directionally.

Because of the great number of factors that define a GRP composite, the range of mechanical and other physical properties is very wide. For example, tensile strength at room temperature may vary from 69 MPa (10^4 psi) to 896 MPa (13×10^4 psi) or higher, wet strength retention (material saturated with water) from 50 to 95 per cent, and specific gravity from 1.2 to 1.9. The range of some physical properties given in Table 1 is typical for GRP sheet materials produced with normal care from general purpose polyester resin and reinforced with three types of glass-fibre reinforcement. More complete data on physical properties of GRP composites are available in the literature[1,2]. The latest Canadian Government standard for GRP is 41-GP-6M (Sept 1976).

Table 1. Physical properties of glass-fibre reinforced general-purpose polyester sheet (reinforced with various glass-fibre construction)[1]

Property*	Type of Reinforcement Chopped-Strand Mat or Premix**	Type of Reinforcement Parallel Roving	143*** Fabric Parallel Laminated
Glass content, weight %	25-45	50-70	62-67
Specific gravity	1.4-1.6	1.7-1.9	1.7-1.9
Tensile strength, MPa (10^3 psi)	76-160 (11-23)	550-900 (80-130)	540-600 (78-87)
Tensile modulus, MPa (10^6 psi)	5.6-12 (0.82-1.8)	-	31 (4.5)
Flexural strength, MPa (10^3 psi)	140-260 (20-38)	690-1400 (100-200)	590-720 (85-105)
Flexural modulus, GPa	6.9-14	34-49	31-38

(10^6 psi)	(1.0-2.0)	(5.0-7.0)	(4.5-5.5)
Compressive strength, MPa	120-180	340-480	280-340
(10^3 psi)	(18-26)	(50-70)	(40-50)

* Resistance to continuous heat: 150-205°C (300-400°F); heat deflection temperature (as tested by ASTM Method D648) under a stress of 1.82 MPa (264 psi): 190-260°C (375-500°F); coefficient of linear expansion, 10^{-6}/°C: 11-36 or 10^{-6}/°F: 6.0-20.0.
** Putty-like mixture consisting of resin, chopped fibres, fillers, catalyst and other ingredients, ready for moulding.
*** Code for a weave style of glass-fibre fabric, 0.23 mm (0.009 in) thick.

Applications in Construction

GRP composites used in construction can be divided into two main classes: the standard items of manufacture such as single-skin sheet (flat and corrugated) or sandwich panels, and the custom structures designed for a specific application by an architect or engineer. Details of the manufacturing processes, properties and structural capabilities for standard products have been established. Regarding the use of custom-tailored structures, the building designer should consider the basic characteristics, behaviour of the material, and the manufacturing processes when selecting the appropriate material for a particular application.

Light-Transmitting Panels

Because of their relatively high light transmission (about 85 per cent), light weight, toughness and, where appropriate, fire retardancy, transparent and translucent GRP panels (usually corrugated) have a variety of uses including glazing for skylights, luminous ceiling or roofing, inner partitions and canopies.

Opaque and Sandwich Panels

GRP sheet material is used as cladding on other structural materials or as an integral part of either a structural or a non-loadbearing wall panel. In the former it functions as a decorative cladding (non-loadbearing) on concrete or brick, providing a wide range of coloured and textured surfaces. The GRP sheet used is usually opaque, but it may be translucent or transparent.

As an integral part of either a structural or non-loadbearing panel, opaque GRP can be used in a variety of ways. It is invariably the exterior skin. The most popular panel is the sandwich type, with an inner and outer skin of GRP and a foam core of poly(vinyl chloride) (PVC), polystyrene, polyurethane or phenolic plastic. Another application for foam-cored GRP-faced sandwich panels is as wall panels in mobile homes and in boat hulls.

GRP Composite in Sectional and Modular Units

In addition to lightness, ease of fabrication of large components and simplicity of jointing make GRP composite materials particularly suitable for use in modular construction. Building components or sections are prefabricated and can be rapidly assembled on the building site. This makes them particularly suitable where access is limited or where ground cannot support traditional structures without excessive cost for foundations. Examples include living accommodation and laboratories at Antarctic bases, lighthouse towers, desert accommodation, and living accommodation on off-shore drilling rigs. The walls of sections or modules usually consist of a GRP sandwich panel with a plastic foam or honeycomb core.

Miscellaneous Applications

GRP is a very convenient material for the prefabrication of bathroom units and components. Composite made by press moulding is used in the fabrication of cold and hot water storage tanks. When the matrix is made from a special type of polyester resin, thorough testing has shown that the tank can withstand working levels of pressure and temperature. GRP composite is also used in the fabrication of window frames and concrete formwork.

Durability

Although considerable progress has been made in improving the durability of GRP composites, commercial products of these materials still deteriorate outdoors. Deterioration usually starts at the outer surface, its rate depending on the composition of the material, manufacturing method, degree of cure, nature of surface finish and service environment. Recent studies of sheet GRP materials at DBR/NRC have demonstrated that there are two main types of surface deterioration: breakdown in the glass-resin interface resulting in fibre pop-out, and surface microcracking of the matrix (Figure 1 and Figure 2). Both affect the appearance of the GRP sheet and its light transmission. If surface deterioration is severe, mechanical and other properties also suffer. Other changes occurring with outdoor exposure are discoloration and surface pitting, which can affect the physical properties of the sheet.

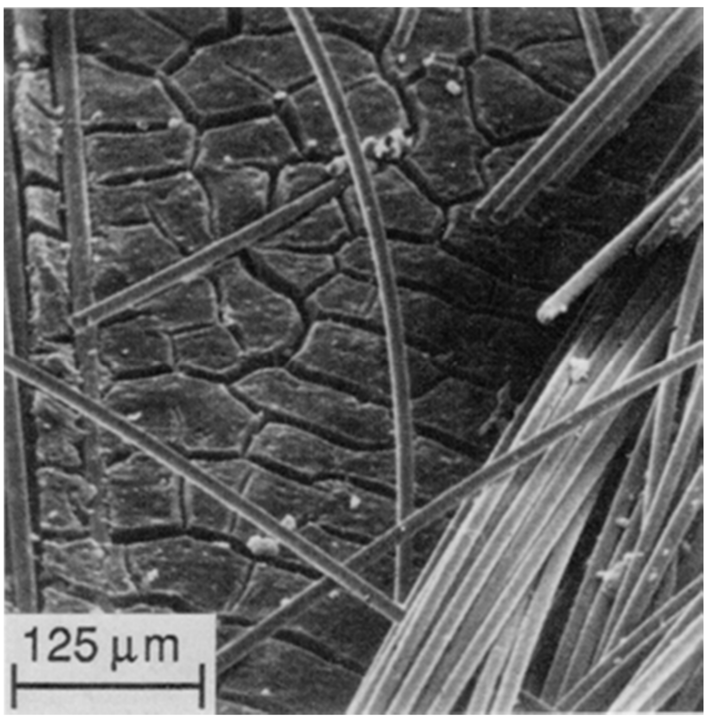

Figure 1. Surface of GRP (top side) weather outdoors for 12 years.

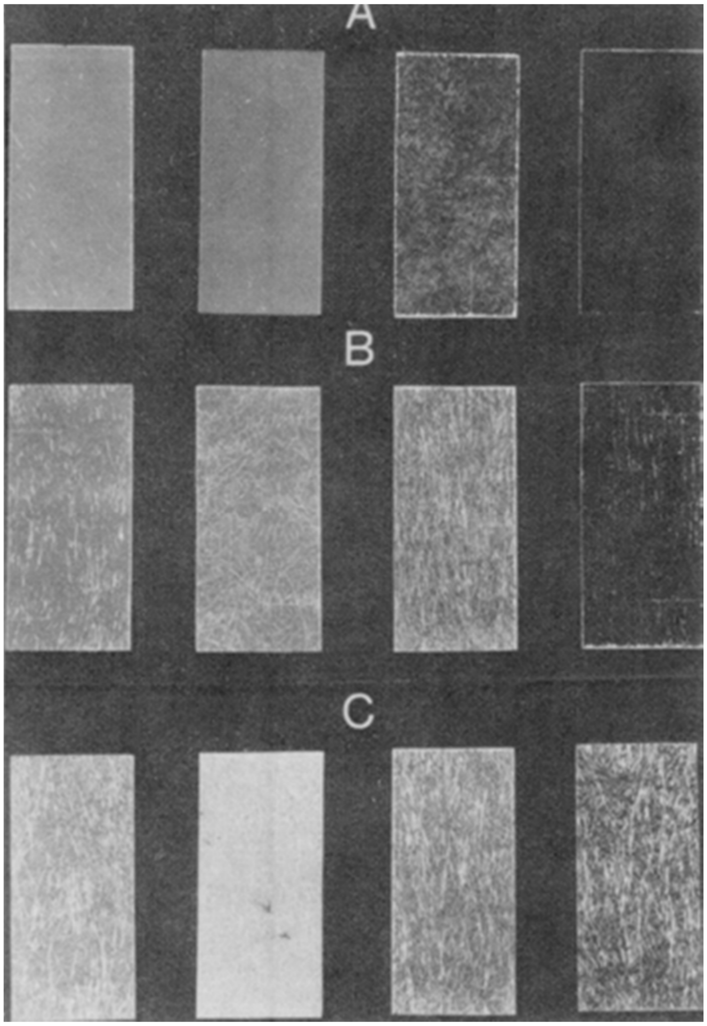

Figure 2. Different coloured flat sheets (aqua-marine, yellow, colourless, green) weathered for 5 years. A -- control B -- under side C -- upper side (original size of sheets 21.5 x 9.5 cm).

Fibre pop-out develops under the influence of environmentally induced (thermally or by moisture) stress-fatigue, which causes gradual fracture and spalling of the resin surrounding the glass. Weathering studies indicate that fibre prominence could be extensive in conventional GRP sheet after a relatively short period (five years) of exposure in the Canadian climate (Figure 2). There was considerably less fibre pop-out on the under side of a panel even after eight years of outdoor exposure. This is understandable because the exposure conditions prevailing on the unexposed side are less severe.

Surface microcracking, the other type of breakdown, generally occurs on the side of the sheet exposed to solar radiation after fibre pop-out has become relatively extensive. It takes place under the combined action of physically induced stress fatigue and radiation-induced tensile stresses in the surface layers of the resin as a result of shrinkage during weathering[1]. Unlike fibre prominence, which occurs on either side of the sheet, microcracking is confined to the surface layers (5 to 10 μm) of the exposed surface.

Fire-retardant GRP sheets have considerably lower resistance to breakdown when exposed to the outdoor environment. Tests have shown that one common type of fire-retardant GRP sheet (based on tetrachlorophthalic acid polyester) undergoes surface deterioration 2.5 to 3 times faster than sheets based on general purpose (conventional) polyester matrix.

As most of the deterioration is confined to the surface material, the surface region can be modified to increase the resistance of the GRP sheet to breakdown. For example, a gel coat as a surface finish of GRP sheets protects the glass-resin interface against the effect of moisture and temperature-induced stress-fatigue so that no fibre prominence occurs. Good resistance to both types of deterioration is achieved by coating the GRP sheets with a lacquer based on ultraviolet (uv) light stabilized acrylic resin. The acrylic coating protects the glass-resin interface against the effect of stress-fatigue and the underlying matrix against the action of ultraviolet light.

Although the appearance of GRP sheets weathered outdoors for five years was considerably affected, deterioration in mechanical properties such as tensile strength was generally moderate; for example, the exposed sheets retained 85 to 92 per cent of their initial (before exposure) tensile strength. If the surface breakdown is in an advanced stage, it can, however, have a serious effect on the mechanical properties of the GRP composite and on the light transmission of transparent or translucent panels.

Because the matrix is a plastic material and thus organic in nature and inherently combustible, GRP composites will decompose and burn when exposed to a fire. The architect or design engineer using GRP materials should, therefore, have a full understanding of their potential fire hazard and fire behaviour.

References

1. Blaga, A., GRP Composite Materials in Construction: Properties, Applications and Durability. Industrialization Forum, Vol. 9, 27-32, 1978.
2. Hollaway, L., Glass Reinforced Plastics in Construction. Engineering Aspects. New York, Wiley, 1978.