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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000679
Canadian Building Digest, 1982-10-01

Canadian Building Digest
Division of Building Research, National Research Council Canada

CBD-227

Reinforced Thermosetting Plastic Pipe

Originally published October 1982.

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This digest, the last in a series of three digests,[1,2] describes briefly the general nature of reinforced thermosetting materials and discusses in detail two major types of pipe products in this class.

Because of their high cost, reinforced thermosetting plastic-based pipes constitute only a small proportion of the total plastic piping in use. These pipes are utilized where strength and/or resistance to higher temperatures are required. The materials from which they are made offer many more compositional variations and greater design flexibility than thermoplastics, making it important for the designer to have a good understanding of their nature.

Composition

Thermosetting plastic materials are always used in conjunction with reinforcement and fillers. The mechanical strength and the resistance to heat and other service conditions of thermosetting plastic pipe depend on the type of resin used as the matrix, the type and construction of the reinforcement, the nature of the fillers and the method of fabrication.

Some of the best-known thermosetting resins used as matrices in fibre-reinforced composites for pipes are polyesters, epoxies and phenolics. The reinforcement may be organic (e. g., synthetic fibre) or inorganic (e.g., glass or asbestos fibre). Glass fibre is, however, the most common reinforcement used in plastic pipe. It may be continuous fibre (e.g., rovings), woven fabric, nonwoven mat or chopped strand. The two glass compositions normally used in manufacturing glass fibre are E (electrical -- low alkali content, high strength) glass and C (chemical -- high corrosion resistance) glass. Both glass compositions are unaffected by salt solutions, alkalis and most organic materials, but C glass is more resistant to acids.

Reinforced thermosetting plastic pipe may consist of 15 to 70 per cent glass fibre, 0 to 50 per cent filler (including sand), and 30 to 75 per cent resin. It may also contain small amounts of thixotropic agents,* pigments or dyes. Thus, reinforced thermosetting plastic pipe material can be formulated to handle a wide range of different situations, making it a very versatile product. Pipe manufactured from thermosetting resin, glass-fibre reinforcement, and sand or other aggregates is sometimes referred to as reinforced plastic mortar pipe (RPMP).

Fabrication

The methods used in manufacturing reinforced thermosetting plastic pipes and fittings include pressure molding, contact molding, centrifugal casting, pultrusion and filament winding. Filament winding is the most commonly used process as it results in products of higher strength than those made by other methods, as well as good uniformity and high density.

There are two basic methods of filament winding. In one method, biaxial winding, the resin-impregnated glass fibre rovings are deliberately arranged in both the circumferential and longitudinal directions of the pipe to give the required strength. In the other method, helical winding, the resin-impregnated continuous fibre rovings are wound at a controlled helix angle in each selected direction on a removable mandrel. Subsequent curing (crosslinking) may require the application of heat. Most pipes made by either of the two filament-winding methods have an inner layer (liner) consisting of a smooth resin-rich surface reinforced with tissue made of glass, thermoplastic polyester or acrylic fibre selected to provide maximum abrasion and corrosion resistance. The inside liner of some pipe products is made for a specific application.

Properties and Applications

Reinforced thermosetting plastic pipe is produced as a standard product with a full line of fittings. It is especially suited to applications such as water distribution, sewage, and effluent disposal under many highly corrosive conditions; for example, those resulting from chemical processing. This type of pipe finds an application in virtually every major industry in conveying hundreds of industrial chemicals, including hydrochloric acid, sodium hydroxide and chlorine; sour crude oil (in flow lines) for petroleum production, its largest application; salt water in flow, flood, injection and disposal lines; and natural gas at pressures up to 8.3 MPa (1200 psi) and 66°C (150°F).

The most commonly used reinforced thermosetting plastic pipe products are based on polyester or epoxy resins which are described in greater detail in the following pages. The typical properties, general characteristics and applications of these pipe products are presented in Table 1 and in Table 2.

Table 1. Typical Properties of Filament Wound Thermosetting Piping Materials[7,8]

Property**	Method	Range or Average Value
Density, g/cm^3	ASTM D 792	1.7 - 2.2
Coefficient of thermal expansion, $10^{-6}/°C$ a) Hoop direction b) Axial direction	ASTM D 696	9 - 13 18 - 32
Thermal conductivity, WC^{-1} ($Btu \cdot in \cdot h^{-1} ft^{-2} F^{-1}$)	ASTM C 177	0.19 -0.29 (1.3 - 2.0)
Ultimate tensile strength, kPa(10^3 psi) a) Hoop direction b) Axial direction	ASTM D 2290 ASTM D 2105	165 - 344 (24 - 50) 139 - 690 (20 - 100)
Ultimate compression strength, kPa (10^3 psi)	ASTM D 2586	110 (16)***
Tensile modulus, MPa (10^{-6} psi) a) Hoop direction b) Axial direction	ASTM D 2290 and ASTM D 2105	26 - 32 (3.8 - 4.6) 6.9 - 19 (1.0 - 2.7)

Compression modulus, MPa (10^{-6} psi)	ASTM D 2586	up to 18 (up to 2.6)

* These figures should be considered as a guide only, since commercial pipe products can have properties different from those listed in this table.
** The resin is a polyester, epoxy, phenolic or a combination of these resins.
*** Epoxy resin-based products

Table 2. General Properties and Applications of the Principal Reinforced Thermosetting Plastic Pipes.

Type of Pipe	General Properties	Maximum Operating Temperature* °C (°F)	Joining Methods (5,7)	Principal Applications
GRP	Relatively high mechanical strength; good temperature and chemical resistance	105(220)	Joining by adhesives and mechanical seal devices	Pipe applications where good corrosion resistance and high operating temperature are mandatory at lower cost than with epoxy pipe.
GRE	Very good general chemical resistance to acids, alkalis** and solvents; somewhat limited resistance to oxidizing agents.	120(250)	By use of sleeve coupling; use of cold setting epoxy, etc.	Because of higher cost, use is limited to critical applications in chemical processing, especially in pumping of corrosive liquids*** and slurries.

* The maximum operating temperature depends upon chemical conditions of the fluid being handled.
** Pipes based on epoxy resin matrix cured with aromatic anhydrides have no resistance to caustic alkalis.
*** Lined epoxy pipe manufactured with a C-glass-mat-reinforced liner has become very popular in this application.

Glass-fibre-reinforced polyester (GRP) pipe

The matrix resin of GRP pipe consists mainly of a cured polyester but contains also small proportions of various additives[3,4]. Generally, the matrix constitutes about 70 weight per cent of the pipe material, the reinforcement being the other major component.The most popular matrix formulations used in pipes, fittings, pumps, tanks and ducts are based on general purpose polyester, isophthalic modified polyester, polyester of bisphenol A, vinyl ester, and chlorinated polyester resin (for improved fire-retardant characteristics). By suitable selection of the resin matrix, GRP pipe can be made to resist aggressive fluids or soils and to withstand the corrosive action of most industrial chemicals at temperatures up to 105°C (220°F).

The polyester-based pipes are generally less strong mechanically than those made with epoxy resin and their temperature resistance is somewhat lower. Lower cost and good corrosion resistance, however, have made the general-purpose (conventional) polyester resin popular in the manufacture of glass-fibre-reinforced pipe, fittings, pumps and tanks of all sizes[3,4]. Pipes made from conventional polyester range in diameter from 25 mm (1 in.) to 4.9 m (16 ft) or more.

Owing to their good corrosion resistance and relatively high operating temperature, GRP materials are used as pipe work in chemical processes for handling highly corrosive fluids[5]. GRP is increasingly used in place of steel and cast iron for water distribution systems, and in place of concrete for sewage, drainage and effluent disposal systems.

Glass-fibre-reinforced epoxy (GRE) pipe

There are two general types of epoxy resins most commonly used in GRE pipe, namely, bisphenol A-based epoxy resins and the epoxy novolacs. Bisphenol A epoxy resins are much more widely used because of ease in handling and lower cost. The epoxy novolacs, on the other hand, are used where increased temperature and maximum solvent resistance are required. Both types of resins can be cured with a variety of curing agents, and the choice of these has a pronounced effect on the properties of the final pipe products. The two most popular classes of curing agents used in manufacturing epoxy pipe are aromatic amines and aromatic anhydrides.

Pipe made from bisphenol epoxy resins cured with aromatic amines has good resistance to salts, dilute acid solutions and severe caustic and solvent solutions. Pipe produced from epoxy resin cured with aromatic anhydrides is, in contrast, generally more brittle and less chemically resistant, and has no resistance to caustics. Bisphenol epoxy pipes cured with anhydrides have an upper temperature limit of 75°C (165°F), whereas those cured with amines can be used at temperatures up to 120°C (250°F) or higher[5]. Neither type of epoxy resin is resistant to strong inorganic acids or strong oxidizers.

Generally, epoxy pipe is manufactured by the filament-winding process. Most filament-wound pipe based on epoxy resin has a relatively small diameter, ranging from 25 to 400 mm (1 to 16 in.). This is in contrast to pipe made from polyester resin which is generally of larger diameter and is often custom-made. Reinforced epoxy pipes are available as either lined or unlined products.

Unlined epoxy pipe is replacing traditional materials in oil-field flow lines where resistance to the action of crude oil and paraffin buildup as well as an ability to withstand relatively high pressure surges is necessary. As the chemical resistance of this pipe is lower than that of lined pipe products, its other applications are restricted to handling solvents, and solutions containing salt, diluted acids and alkalis.

Because of its good chemical resistance, lined epoxy pipe manufactured with a C-glass-mat-reinforced liner has become very popular in the chemical process industry. For example, this pipe has provided an economical solution to many severe corrosion problems in pulp-mill bleach plants, phosphoric acid production and the food processing industry. In most applications, the reinforced, resin-rich liner is 0.5 to 0.8 mm (0.020 to 0.030 in.) thick. In applications involving severe exposure conditions, a heavier liner is used. One such liner is described in the NBS Voluntary Standard (2.8 mm (0.11 in. in thickness)), National Bureau of Standards, U.S.[6].

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* Additives which prevent excessive flow of resin before cure.