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Abstract

Polymer concrete (PC), or resin concrete, consists of a polymer binder which may be a thermoplastic but more frequently is a thermosetting polymer, and a mineral filler such as aggregate, gravel and crushed stone. PC has higher strength, greater resistance to chemicals and corrosive agents, lower water absorption and higher freeze-thaw stability than conventional Portland cement concrete.

Introduction

Polymer concrete (PC) is a composite material in which the binder consists entirely of a synthetic organic polymer. It is variously known as synthetic resin concrete, plastic resin concrete or simply resin concrete. Because the use of a polymer instead of Portland cement represents a substantial increase in cost, polymers should be used only in applications in which the higher cost can be justified by superior properties, low labor cost or low energy requirements during processing and handling. It is therefore important that architects and engineers have some knowledge of the capabilities and limitations of PC materials in order to select the most appropriate and economic product for a specific application. A previous Digest (**CBD 241**)[1] dealt with polymer modified concrete composites such as polymer impregnated concrete and polymer cement concrete. This Digest describes briefly the general nature, properties and applications of the most popular PC materials.

Nature and General Properties

Polymer concrete consists of a mineral filler (for example, an aggregate) and a polymer binder (which may be a thermoplastic[2, 3], but more frequently, it is a thermosetting polymer[2, 4]. When sand is used as a filler, the composite is referred to as a polymer mortar. Other fillers include crushed stone, gravel, limestone, chalk, condensed silica fume (silica flour, silica dust), granite, quartz, clay, expanded glass, and metallic fillers. Generally, any dry, non-absorbent, solid material can be used as a filler.

To produce PC, a monomer or a prepolymer (i.e., a product resulting from the partial polymerization of a monomer), a hardener (cross-linking agent) and a catalyst are mixed with the filler. Other ingredients added to the mix include plasticizers and fire retardants. Sometimes, silane coupling agents are used to increase the bond strength between the polymer matrix and the filler. To achieve the full potential of polymer concrete products for certain applications, various fibre reinforcements are used. These include glass fibre, glass fibre-based mats, fabrics and metal fibres. Setting times and times for development of maximum strength can be readily varied from a few minutes to several hours by adjusting the temperature and the catalyst system. The amount of polymer binder used is generally small and is usually determined by the size of the filler. Normally the polymer content will range from 5 to 15 percent of the total weight, but if the filler is fine, up to 30 percent may be required.

Polymer concrete composites have generally good resistance to attack by chemicals and other corrosive agents, have very low water sorption properties, good resistance to abrasion and marked freeze-thaw stability. Also, the greater strength of polymer concrete in comparison to that of Portland cement concrete permits the use of up to 50 percent less material. This puts polymer concrete on a competitive basis with cement concrete in certain special applications. The chemical resistance and physical properties are generally determined by the nature of the polymer binder to a greater extent than by the type and the amount of filler. In turn, the properties of the matrix polymer are highly dependent on time and the temperature to which it is exposed.

The viscoelastic properties of the polymer binder give rise to high creep values.[5] This is a factor in the restricted use of PC in structural applications. Its deformation response is highly variable depending on formulation; the elastic moduli may range from 20 to about 50 GPa, the tensile failure strain being usually 1%. Shrinkage strains vary with the polymer used (high for polyester and low for epoxy-based binder) and must be taken into account in an application.

A wide variety of monomers and prepolymers are used to produce PC. The polymers most frequently used are based on four types of monomers or prepolymer systems: methyl methacrylate (MMA), polyester prepolymer-styrene, epoxide prepolymer hardener (cross-linking monomer) and furfuryl alcohol. The typical range of properties of PC products made with each of these four polymers is presented in Table I. General characteristics and principal applications are described in Table II.

Table I. Typical Range of Properties of Common PC Products and Portland Cement Concrete[6]

Type of Binder	Density, kg/dm³	Water Sorption %	Compressive Strength, MPa	Tensile Strength, MPa	Flexural Strength, MPa	Modulus of Elasticity, GPa	Poisson Ratio	Thermal Coefficient of Expansion, $10^6 C^{-1}$
Poly(methyl methacrylate)	2.0-2.4	0.05-0.60	70-210	9-11	30-35	35-40	0.22-0.33	10-19
Polyester	2.0-2.4	0.30-1.0	50-150	8-25	15-45	20-40	0.16-0.30	10-30
Epoxy	2.0-2.4	0.02-1.0	50-150	8-25	15-50	20-40	0.30	10-35
Furan polymer	1.6-1.7	0.20	48-64	7-8	-	-	-	38*,61*
Concrete**	1.9-2.5	5-8	13-35	1.5-3.5	2-8	20-30	0.15-0.20	10-12

*Carbon and silica filled mortars, respectively.

**Portland cement concrete.

Table II. General Characteristics* And Applications of Polymer Concrete Products

Type of	General	Typical

Binder Used in PC	Characteristics	Applications
Poly(methyl methacrylate)	Low tendency to absorb water; thus high freeze-thaw resistance; low rate of shrinkage during and after setting; very good chemical resistance and outdoor durability.	Used in the manufacture of stair units, facade plates, sanitary products for curbstones.
Polyester	Relatively strong, good adhesion to other materials, good chemical and freeze-thaw resistance, but have high-setting and post-setting shrinkage.	Because of lower cost, widely used in panels for public and commercial buildings, floor tiles, pipes, stairs, various precast and cast-in applications in construction works.
Epoxy	Strong adhesion to most building materials; low shrinkage; superior chemical resistance; good creep and fatigue resistance; low water sorption.	Epoxy polymer products are relatively costly; they are mainly used in special applications, including use in mortar for industrial flooring, skid-resistant overlays in highways, epoxy plaster for exterior walls and resurfacing of deteriorated structures.
Furan-based polymer	Composite materials with high resistance to chemicals (nost acidic or basic aqueous media), strong resistance to polar organic liquids such as ketones, aromatic hydrocarbons, and chlorinated compounds.	Furan polymer mortars and grouts are used for brick (e.g. carbon brick, red shale brick, etc.) floors and linings that are resistant to chemicals, elevated temperatures and thermal shocks.

*Polymer concretes have greatly improved resistance to chemicals, including hydrochloric acid, alkaline and sulfate solutions, which are present in industrial environments. Polyester polymer concrete is more acid-resistant than the epoxy polymer concrete; it is, however, less resistant to alkalis than epoxy polymer concrete.[8]

Acrylic Polymer Concrete

The most common acrylic polymer is poly (methyl methacrylate) (PMMA), obtained by polymerization of methyl methacrylate (MMA).[3] PC made with this acrylic polymer as a binder is a versatile material, has excellent weathering resistance, good waterproofing properties, good chemical resistance, and relatively low setting shrinkage (0.01 to 0.1%); its coefficient of thermal expansion is equivalent to that of Portland cement concrete (see Table I). Because of its very low tendency to absorb water, acrylic PC has a very high freeze-thaw resistance. The low flash point (11°C) of the MMA monomer is a disadvantage, however as it constitutes a safety problem.

Although the MMA monomer is more expensive than the prepolymer-monomer used in the more popular polyester PC, its unique properties account for its use in a great many diverse applications, including the manufacture of stair units, sanitary products, curbstones, and facade plates. A highly successful development has been its use as a rapid-setting, structural patching material for repairing large holes in bridge decks. The material consists of a highway grade aggregate and a matrix produced by cross-linking MMA with trimethylol propane trimethacrylate (TMPTMA).

Polyester Polymer Concrete

Because of low cost, the most widely used polymer-binders are based on unsaturated polyester polymer. In most applications, the polyester binder is a general purpose, unsaturated polyester prepolymer formulation. These formulations are available in the form of 60 to 80 percent solutions of the prepolymer in copolymerizable monomers such as styrene and styrene-methyl methacrylate. During hardening, the polyester prepolymer and the monomer react through their unsaturated groups (double bonds). The chemical reaction is called cross-linking, the production process associated with it is referred to as curing, and the resulting polymer binder is a thermosetting polymer.[4]

Polyester PC has good mechanical strength, relatively good adhesion to other materials, and good chemical and freeze-thaw resistance. It has, however large setting and post-setting shrinkage (up to ten times greater than Portland cement concrete), a serious disadvantage in certain applications. Polyester PC is used in various precast and cast-in place applications in construction works, public and commercial buildings, floor tiles, sewer pipes and stairs.

Epoxy Polymer Concrete

Epoxy binder like polyester, is a thermosetting polymer[4] The epoxy polymer can be hardened with a variety of curing agents, the most frequently used being polyamines (e.g., tertiary polyamines).[7] The use of polyamine hardeners (curing agents) results in PC products with the highest chemical resistance. Other curing agents are polyamides and polysulfide polymers. Epoxy PC products cured with polyamides have greater flexibility, better heat resistance, and reduced chalking tendency in outdoor exposure, but their solvent and chemical resistance is lower than for similar products cured with polyamines. The use of polysulfide polymers produces epoxy PC with even greater flexibility.

Epoxy PC exhibits high strength adhesion to most materials, low-setting and post-setting shrinkage, high chemical resistance, and good fatigue and creep resistance. Because they are relatively expensive, epoxy polymers have not been used very widely as binders in PC products. Therefore, epoxy PC is used for special applications, in situations in which the higher cost can easily be justified, such as mortar for industrial flooring to provide physical and chemical resistance, skid-resistant overlays (filled with sand, emery, pumice, quartz) in highways, epoxy plaster for exterior walls (e.g., in exposed aggregate panels) and resurfacing material for deteriorated areas (e.g., in flooring). Epoxy PC reinforced with glass, carbon or boron fibres is used in the fabrication of translucent panels, boat hulls and automobile bodies.

Furan Polymer Concrete

Furan polymers are based on furfuryl alcohol, which is derived from agricultural residues such as corn cobs, rice hulls, oat hulls or sugar cane bagasse.[7] The furan prepolymer is usually cross-linked with furfuryl alcohol, furfuraldehyde or formaldehyde to yield thermosetting polymers, highly resistant to most aqueous acidic or basic solutions and strong solvents such as ketones, aromatics, and chlorinated compounds. The furan polymers are used as binders in mortars and grouts to achieve chemically resistant brick floors (e.g., carbon brick and red shale brick) and linings. In addition to exhibiting superior chemical resistance, these floors have excellent resistance to elevated temperatures and extreme thermal shock.

Heat and Fire Resistance

The polymer binders of PC products are organic substances, which are known to have much lower heat resistance than inorganic materials such as stone, cement and metals. Thus, prolonged exposure to elevated temperatures is not recommended, as it causes degradation of the resin and eventual loss of strength. The heat resistance of PC products depends on the type of polymer binder. For polyester and epoxy PC, the safe working temperature limit is about 60°C for continuous exposure, and about 100 to 120°C for brief periods (e. g., during steam cleaning).

Behaviour under fire is very important in applications in which PC materials are used as facing elements or for interior decoration. Although the polymeric component is flammable, PC materials do not burn easily because they have a high mineral filler content. Their behaviour under fire can be further improved at relatively small cost by incorporating fire-retardant additives.

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