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Polymer Concrete: Guidelines for Structural Applications

Reported by ACI Committee 548



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Polymer Concrete: Guidelines for Structural Applications

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Aly Said

Polymer concrete (PC) can be used in the construction of structural elements with applications, including wall panels withstanding wind and seismic loads, underground vaults resisting lateral earth pressure, vault and utility box covers resisting vehicle loads, and railroad ties resisting static and dynamic rail loads. PC structural elements are used to resist bending moments and axial and shear loads. Creep, fatigue, and service temperature are important aspects for PC structural elements. These guidelines help the defining and understanding of mechanical properties and structural behavior of PC. Industrial standards and design guidelines governing design with PC have been developed and used by the PC industry for the last five decades. These guidelines highlight some of those standards.

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Keywords: beam; creep; equipment foundation; fatigue; fire resistance; fracture; manholes; polymer; polymer concrete; reinforced polymer concrete; utility structures; walls.

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CHAPTER 1—INTRODUCTION

Polymer concrete (PC) has been used in structural applications where strength, stiffness, durability, and ease in molding provide an advantage over other materials. Many types of reinforcement can be used with PC. This guide presents the structural uses of PC.

Polymer concrete is a mixture of aggregates and resins or monomers without portland cement that hardens by polymerization after it is placed. PC was first used commercially in the 1950s in the United States in the production of synthetic marble, followed by the manufacture of architectural facing panels in the late 1950s. Beginning in the 1970s, other structural products began to appear in the market, including floor drains, utility trenches, underground utility vaults and covers, high-voltage insulators, and highway median barrier shells. These products were followed by the introduction of manhole structures and machine tool bases. By the mid-1970s, PC was used as a repair material for portland-cement concrete structures, mainly on highways and bridges. In the United States in the 1980s, chemical companies developed an increasing interest in specific materials and material properties required to produce PC. As a result, many enhancements in the polymers used for PC were developed, and resins tailor-made for PC production became available. This development continues, and important material improvements are often achieved by manufacturers.

Research into the behavior of PC structural elements has been conducted at numerous research labs. Structural research has been conducted on such uses as steel-reinforced beams and panels, ballistic panels (barriers to armed assault on embassies, for instance), electric transmission

poles, structural sandwich elements, building blocks, utility trenches, utility covers, and insulation panels (Fowler 1988).

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_1	=	amplitude of first cycle
A_n	=	amplitude of the n -th cycle
E	=	dynamic modulus, psi (MPa)
f_1	=	frequency of the first mode, Hz
I	=	section moment of inertia, in. ⁴ (mm ⁴)
l	=	specimen length, in. (mm)
n	=	number of amplitude cycles
T_g	=	glass-transition temperature, °F (°C)
W	=	weight of the specimen, lbf (lbf/N)
β	=	l^3/I , in. ⁻¹ (m ⁻¹)
ζ	=	specific damping factor

2.2—Definitions

A/B components—individual parts of a polymer binder system; in epoxy PC, the components typically consist of resin (A) and curing agent/hardener (B); in free radical PC, the components typically consist of resin (A) and initiator (B).

accelerator—chemical used to increase the rate of cure in a free radical system by reacting with the initiator.

catalyst—substance that markedly speeds up the cure of a binder when added in minor quantity.

cross-linking—joining of preformed linear polymer chains to each other to form three-dimensional networks.

cross-linking agent—chemical used to increase the cross-link density of the polymer network.

cure time—the interval after mixing in which a PC system gains adequate strength to support loads, such as foot traffic, vehicular traffic, or both.

curing—the change in properties of a chemical by an increase in molecular weight via polymerization or cross-linking, usually accomplished by the action of heat, catalyst, cross-linking agent, curing agent, or any combination, with or without pressure.

fiberglass—a composite material consisting of glass fibers in resin.

flammable liquid—any liquid having a flash point below 38°C (100°F).

flash point—minimum temperature at which a liquid gives off vapor within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid.

flexibilizer—additive that gives a rigid plastic flexibility.

gel time—time interval after mixing that a liquid material exhibits a significant viscosity increase.

heat deflection temperature—temperature at which a polymer or plastic sample deforms under a specified load.

inhibitor—substance that slows or stops a chemical reaction.

initiator—substance capable of causing the polymerization of a monomer by a chain reaction mechanism; often incorrectly called a catalyst.

methyl methacrylate—low-viscosity methacrylate monomer that is characterized by high volatility.

organic peroxides—sources of free radicals used in polymerization and cross-linking.

polyester—one of a group of resins, mainly produced by reaction of unsaturated dibasic acids with dihydroxy alcohols; commonly dissolved in a vinyl group monomer such as styrene.

premix—a polymer concrete formulation prepared and packaged in advance of use with compatible ingredients preblended together in the correct ratios for the final mixture. For example, aggregates and the catalyst are frequently premixed as one part and the monomers, additives, and promoters as another part of premixed methacrylate systems.

promoters—reducing agent compounds added to the monomer system to cause the decomposition of the peroxide initiators in the system (often called accelerators).

specific heat—heat required to raise the temperature of the unit mass of a given substance by a given amount (usually 1 degree).

surface failure—loss of top surface aggregates from the polymer binder in polymer concrete.

surface seeding—application of aggregate to the freshly applied polymer concrete overlay.

thermal compatibility—ability of a PC to withstand thermally induced stresses and strains without debonding from a substrate.

thermoplastics—material with a linear polymeric structure that can be reshaped repeatedly when heated and will harden when cooled; for example, styrene polymers and copolymers, acrylics (uncross-linked), polycarbonates, nylons, polyethylene, polypropylene, and various polyfluorocarbons.

thermosets—a polymer that will solidify when first cured and cannot be remelted or remolded without destroying its original characteristics; for example, epoxies, unsaturated polyesters, melamines, phenolics and ureas.

tined surface—a surface that is scored or grooved to provide an architectural finish or to facilitate drainage of water.

unsaturated polyester—a prepolymer resin system reacted with a styrene monomer to form thermoset plastic.

working life—time period between the mixing of a PC and the point at which its viscosity has become too high to be workable or too high to bond properly to the substrate.

CHAPTER 3—MATERIALS AND PROPERTIES

3.1—Materials for structural polymer concrete

Polymer concrete (PC), as described in this guide, includes polymer mortars, polymer grouts, and polymer concretes. Example PC formulations are given in Appendix A. Polymer mortars include materials with aggregate sizes smaller than 1/4 in. (6 mm). Polymer grout includes materials with no aggregate. Differences between mortars and grouts depend on the intended use and affect the fabricator's formulation of the material.

3.1.1 Polymers—The monomers, polymers, or a mixture of monomers and polymers in liquid form are mixed with an aggregate system. Polymerization promoters and initiators are also included in the mixture in precise proportion to cross-link or complete the polymerization of the monomers. Several properties of the monomers or polymers are typically used to define the characteristics of the uncured PC. PC is usually classified using the properties of the uncured binder, the cured binder, and the cured PC or mortar. For most applications, the properties of the cured binder will control binder selection.

Thermoset polymers are typically used to form the binder system of structural PC. Unsaturated polyesters are the most popular thermoset used to produce PC. Orthophthalate unsaturated polyester resins are used as binders combined with methyl ethyl ketone peroxide (MEKP) as initiator (Soh et al. 1999; San José and Ramirez Ortiz 1999; Ribeiro et al. 2003; Jo et al. 2008a). Moreover, unsaturated isophthalic polyester resin was observed to produce a hard, rigid polymer that can provide good mechanical properties (Orak 2000). PC binder systems were produced from other thermoset polymers, including low-viscosity vinyl ester resin (Czarnecki and Chmielewska 1999), polystyrene resins (Choi and Ohama 2004; Rai and Singh 2004), and polyurethane (Tokushige et al. 2005). Orthophthalate unsaturated polyester can also be mixed with polyurethane, forming interpenetrating polymer networks to produce lightweight PC (Bignozzi et al. 2001).

Epoxies have been extensively used to form the binder systems to produce PC (Ribeiro et al. 2003; Reis and Ferreira 2004; Barbuta et al. 2010). Epoxies consist of two parts: epoxy resin and epoxy hardener. While the resin contains epoxy reactive groups at the two ends of the polymer chain, the hardener contains free amine hydrogens. A chemical reaction occurs between the two groups to tie polymer chains together and form the solid polymer mass. This chemical reaction is called cross-linking.

The viscosity of the individual or mixed components can be specified to control the coating of the aggregates. Binder resins with low viscosity are more suitable for mixtures with polymer contents lower than 20 percent. Specific chemical resistance and the glass-transition temperature (T_g) are important characteristics for binder selection. A gel time range can be specified to ensure that there is adequate time to place the fresh PC and that the curing will be completed within the time specified for form removal. Additional properties of the uncured binders, such as specific gravity, shelf life, component content, and flash point also may need to be specified (Sprinkel 1991).

Mixing procedures vary with the binder system selected. The combination of monomers, polymers, initiators, promoters, and chemical additives constitutes the binder system. Some binder systems can be formulated as two components, where one component contains the monomers, polymers, promoters, and additives, and the other component is the curing agent or initiator. Another common way to prepare the binder system is to premix the promoters and additives with part of the monomers and polymers and to premix the initiators with the remaining portion. For a specific