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Polymers in concrete: a vision for the 21st century ☆

D.W. Fowler

International Centre for Aggregate Research, The University of Texas at Austin, ECJ 5.200, Austin, TX 78712-1076, USA

Abstract

Polymers in concrete have received considerable attention over the past 25 years. Polymer-impregnated concrete (PIC) was the first concrete polymer composite to receive widespread publicity. PIC has excellent strength and durability properties, but it has few commercial applications. Polymer concrete (PC) became well known in the 1970s and is used for repair, thin overlays for floors and bridges, and for precast components. Polymer-modified concrete (PMC) has been used primarily for repair and overlays. Several limitations have slowed the use of concrete polymer materials. However, there are many current and future uses for these materials that will effectively use their unique properties. Improved, automated repair methods, improvements in materials, replacements for metals, structural applications, and architectural components will prove to be popular uses of concrete-polymer materials.

Keywords: Concrete; Polymers; Concrete-polymer materials; Polymer-impregnated concrete; Polymer concrete; Polymer-modified concrete; Latex-modified concrete; Repair; Overlays; Precast

1. Introduction

Polymers in concrete have received significant publicity over the past 25 years. Many optimistic projections were made as to the future widespread use of polymer-impregnated concrete (PIC), polymer concrete (PC), and polymer-modified concrete (PMC). As the end of the 20th century approaches, a review of the past and future is in order. A discussion of the use of these materials will be presented followed by a projection of the realistic uses of these materials in the future.

2. Historical perspectives

PMC and PC came into use in the 1950s, although the uses were very limited. It was only in the 1970s, after PIC was developed that concrete-polymer materials received significant publicity. American Concrete Institute Committee 548, Polymers in Concrete, was formed and in 1975 the first International Congress on Polymer in Concrete (ICPIC) was held in London. Later RILEM committees were formed to address specific areas in concrete polymer composites. Regular ACI Symposia and ICPIC conferences have helped to make concrete-polymer materials household words in the construction industry.

3. PIC

PIC first became widely known after researchers at Brookhaven National Laboratory and the Bureau of Reclamation in the US performed extensive research on the material in the 1960s, although USSR researchers claimed to have invented it earlier. PIC was produced by impregnating hydrated portland cement concrete with a low viscosity monomer, usually methyl methacrylate, which was subsequently polymerized by radiation or thermal catalytic techniques. PIC typically developed compressive strengths three to four times greater than the concrete from which it was made, had corresponding increases in tensile and flexural strength, and had excellent durability, particularly freezing and thawing and acid resistance, due to its extremely low permeability. Inexplicably, the modulus of elasticity was 50–100% higher than normal concrete even though the modulus of the polymer is no more than 10% of the concrete modulus.

With such outstanding properties, many applications for PIC were forecast, including bridge decks, pipes, and

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E-mail address: dwf@mail.utexas.edu (D.W. Fowler)

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conduits for aggressive fluids, floor tile, building cladding, hazardous waste containment, post-tensioned beams and slabs, and stay-in-place formwork. However, at the present time, apparently only one company in Japan is producing PIC components including stay-in-place forms and channel liners.

4. PC

PC was used as early as 1958 in the US to produce building cladding. PC consists of aggregate with a polymer binder and contains no portland cement or water. Polyester–styrene, acrylics and epoxies have been the most widely used monomers/resins, but vinyl ester, furan, and urethane, have also been used. Sulphur is also considered to be a polymer and sulphur concrete has been used for applications requiring high acid resistance.

In addition to the use of PC for precast cladding, it was most widely used initially and today for cultured marble for counter tops, lavatories, and other sanitary ware. Considerable effort was made to develop and use PC as a repair material for concrete. Its rapid curing, excellent bond to concrete and steel reinforcement, and excellent strength and durability make it a very attractive repair material. As a mortar it can be placed in thicknesses less than 10 mm. However, it has not become as widely used in repair as originally predicted due to cost, lack of familiarity by contractors, and competition from other repair materials such as rapid-setting portland cement formulations. Generally PC has been batched in concrete mixers and placed and finished like concrete. With a ''high tech'' material like PC, it seems clear that different construction procedures are needed to take advantage of the unique properties of PC. Some failures have occurred because of incompatibility between PC and the concrete substrate as a result of the difference in coefficients of thermal expansion coupled with a high PC modulus. Thermal changes can produce high shear and tensile stresses at the interface near boundaries which may cause the repair to delaminate.

PC overlays or screeds have also become widely used because of the ability to use thin layers, fast curing, very low permeability, and ability to use decorative and architectural finishes. Overlays are used for bridge surfaces and floors in sports arenas and stadiums, laboratories, hospitals, factories, and entrances of stores. The use of overlays for floors has met expectations, but they have lagged in the use on bridges.

Precast PC has been used to produce a wide range of products, including drains, underground boxes, manholes, building cladding, acid tanks and cells, hazardous waste containment, tunnel lining, highway median barriers, shells for repairing machinery foundations, floor tile, stay-in-place curb and tunnel forms, sleepers, architectural moldings, and machine tools and bases. Precast represents an excellent use of the material due to its rapid curing, ability to form complex shapes, and excellent vibration damping. PC was at first used as a concrete replacement, but later was used to replace other materials including metals, e.g., cast iron for machine bases and tools. The high strength and stiffness-to-weight ratio, high damping properties, moldability and low thermal conductivity make PC particularly attractive for these applications.

5. PMC

PMC using latexes has been in use since the 1950s. PMC consists of portland cement concrete with a polymer modifier such as acrylic or styrene–butadiene latex (SBR), polyvinyl acetate, and ethylene vinyl acetate. From a construction standpoint PMC has the desirable attribute of being very similar to conventional portland cement concrete technology. The amount of polymer is usually in the range of 10–20% of the portland cement binder. There are only a few polymers suitable for adding to concrete; most polymers would produce poor quality PMC.

SBR has been widely used for floor and bridge overlays, although the minimum thickness is usually about 30 mm. The advantages are excellent bond strength to concrete, higher flexural strength, and lower permeability. Wet curing is usually required for 24–48 h to permit the concrete to gain strength prior to permitting the latex film to form. Acrylic latex has been used to produce mortars which can be sprayed or troweled on architectural finishes. It is also useful for bonding ceramic tile to floors. Acrylic PMC has the ability to be colorfast which makes it an attractive material for architectural finishes.

PMC can be enhanced by the use of fibres to yield improved tensile strength and reduced cracking. Spray-on applications have been very cost effective for vertical surfaces. The cost of PMC is less than that of PC since less polymer is required.

6. Bonding agents

A fourth use of polymers is to seal cracks in concrete. Cracking is perhaps the most well known and most common distress in concrete. Repairing cracks has been a difficult problem. Epoxy injection was developed to provide a structural repair, but has the disadvantage of being very expensive and slow. The development of high molecular weight methacrylate (HMWM) in the early 1980s for sealing cracks was a major development. The

HMWM can be mopped, brushed, broomed, or sprayed onto a surface and the monomer fills cracks with surface widths of 0.2 mm or more. The HMWM wets the crack exceptionally well, and if cracks are clean over 90% of the crack depth is normally filled. The cost of labor is low compared to epoxy injection.

7. Limitations

Polymers in concrete have made tremendous strides over the past 30–40 years. Are these materials a passing fad, or do they represent a significant, important materials technology?

First, it should be understood that one of the primary limitations of concrete-polymer materials is cost. The cost of polymers can range from 10 to 100 times that of portland cement, and even considering that the specific gravity of cement is about $2\frac{1}{2}$ times that of polymer, the cost per unit volume of polymer composites is still considerably higher than portland cement concrete. Due to this higher cost, the volume of concrete polymer per unit area needs to be minimized which makes its use for high volume applications, e.g., pavements, foundations, sidewalks, and hydraulic structures impractical except in very unusual cases where durability renders concrete unusable.

Another limitation is its inability to withstand high temperatures, particularly fires, and therefore the materials cannot be used as the structure for buildings housing people.

A third limitation is the odor and/or toxicity and/or flammability of many of the monomers and resins during construction or fabrication. While these limitations only exist for the relatively short time until curing occurs, the use of these materials can create problems of safety and/or worker discomfort which must be taken into account during construction.

8. The vision for the future

Where will polymers in concrete be successful for the future? Some insight can be found from looking at past history; current and projected developments can also give a view of the future. A brief summary of potential developments follows.

8.1. Materials

- Governmental regulations will require more stringent restrictions on styrene and other volatiles.
- More specialty monomers and resins will become available. Low shrinkage polyester–styrene resins have recently become available. Hybrid resins, which incorporate the advantages of two or more resins, will be developed.
- A void-free batching methodology has been developed which incorporates a gas to replace air. The gas is eventually incorporated into the polymer, resulting in a dense, pore-free polymer concrete.
- Prepackaged latex-modified systems are available in which only water is added. This concept may be applicable to other polymer systems.
- Conductive polymer systems are under investigation for innovative applications.

8.2. Repairs

Repairs will continue to be an important use of polymers in concrete. PC and PMC will be used in innovative ways.

- Repair systems will be developed which will utilize equipment to take advantage of the fast curing properties and to accommodate the special needs, including volatility and flammability. For repair of concrete pavements and airport runways, a mechanized train will be developed which can prepare the damaged area, batch, place, and finish the repair materials in the most economical manner.
- Fibreglass cloth will be placed over deteriorated bridges and floors and polymer mortar used to provide the finished surface.
- Precast flexible sheets will be bonded to floors and pavements with a thin coating of resin or mortar to permit fast repair of surfaces to provide desired surface finishes, e.g., skid resistant or smooth.
- Spray-on systems will be utilized in repair of shallow spalls and applications of surface finishes. Some latex-modified mortars have been used as spray-on systems for architectural finishes for years.
- Preplaced, graded aggregates will be injected with monomer or resin systems to eliminate batching of aggregates and resins.
- Precast concrete components with PC or LMC surfaces will be used for repair of pavements, floors, walls, and hydraulic structures which require high abrasion and freezing and thawing resistance.

8.3. Precast components

Precast PC is one of the fastest growing applications of polymers in concrete. PC is expected to serve as a replacement for portland cement concrete, metals, wood and even structural plastics.

- Complex architectural shapes to take advantage of the ability to mold, texture and color of PC will be commonly used. Examples include ornate, complex facade panels, column covers, domes, statuary, and fountains.

- Thin PC panels attached to light gage steel wall studs to serve as building cladding are on the horizon. Such systems have long been used for thin glass fiber-reinforced concrete cladding. The steel studs serve initially as stiffening ribs and later as wall studs for insulation and interior wallboard.
- Components for transportation infrastructure represent great potential. The high strength, durability, impact resistance and damping make PC an ideal material for precast tunnel liners, median barriers, railroad crossing panels, sleepers, and bridge panels. An innovative sleeper has been under development for several years that appears to have great promise.
- Metal replacement applications will continue to grow. The high strength-to-weight ratio, low thermal conductivity, high damping, and moldability will make PC a strong competitor for many current applications using metals. A good example is in machine tools, where PC has been found to be very competitive with cast iron.
- Structural components will become more widely used. Structural design guidelines are being developed by ACI 548. It is likely that many more applications will be forthcoming where structural capacity is required. Underground boxes, manhole covers to carry highway traffic, precast bridge deck panels, and building cladding can be constructed to satisfy building codes.
- Precast PC shells for repairing equipment bases will be a very cost-effective option. Equipment can be removed, the base cleaned, the precast shell placed over the base, and the void will be filled with a PC grout, resulting in a fast repair which minimizes the down time of the equipment.

9. Conclusions

PIC, PC, and PMC have received considerable attention over the past 25 years. These materials have been used for repair of concrete, overlays, and precast components. Limitations include cost, odor, toxicity, and flammability. New and improved materials, applications, and uses are projected.