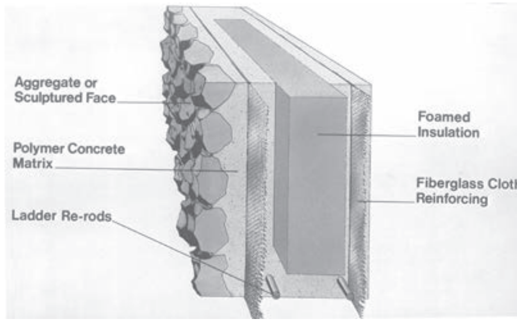

Figure 4. Insulated panel detail

Figure 5. Photo of a block floor

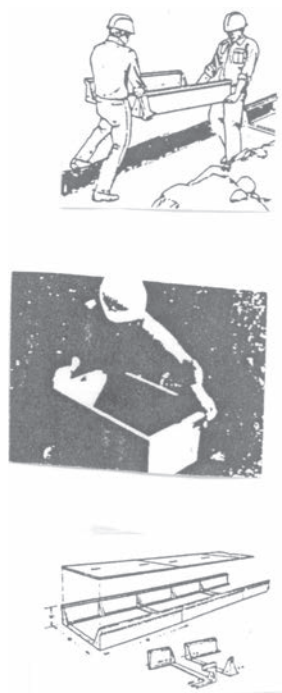

Figure 6. PC boxes

Figure 7. Visi-curb photo

Figure 8. Barrier photo

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Polymers in Concrete: Where Have We Been and Where Are We Going?

by D. W. Fowler

Synopsis: Concrete-polymer materials that include polymer-impregnated concrete (PIC), polymer concrete (PC) and polymer-modified concrete (PMC), have been developed within the past 50 years. PIC, which started out with great promise, has essentially disappeared from the scene. PC has been widely used for repairs, floor and bridge overlays, and precast components, but has not achieved the volume of use that had been projected. PMC has been widely used for overlays and repairs, including spray-on applications. There are many potential applications for the future related to materials processing and applications, which will ensure these materials will continue to be important in the construction field.

Keywords: applications; concrete; polymer concrete; polymer-impregnated concrete; polymer-modified concrete; polymers

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INTRODUCTION

Polymers in concrete have witnessed a steady growth in popularity since they first became known in construction in the 1950s. They became much more widely known after polymer-impregnated concrete received considerable attention in the late '60s and early '70s. Polymer concrete became well known for repairs, overlays, and precast components. Polymer-modified concrete, particularly latex-modified concrete, became widely used for concrete repairs, particularly for overlay, and for spray-on coatings for concrete structures. Monomers and epoxy resins were eventually developed for crack repair. Many applications of past uses will be discussed.

Future uses of polymers in concrete will be discussed. New developments in materials and innovative applications will keep concrete polymer materials in the forefront of construction materials in the 21st century.

WHERE HAVE WE BEEN?

Polymer-Impregnated Concrete

Polymer-impregnated concrete (PIC) was one of the most exciting material developments in years when it was announced in the late '60s. PIC involved drying the concrete, evacuating the air from the pores, forcing a low viscosity monomer into the pores under pressure, and curing by means of heat or radiation. The results were very impressive: compressive strengths of 15,000 to 20,000 psi or more; flexural strengths of 1200 to 2000 psi; excellent durability as measured by resistance to freezing and thawing and abrasion; and negligible creep. Many potential applications were predicted: water and sewer pipe; precast beams; flooring; wall panels; and sanitary ware. Partial-depth impregnation was developed with the goal of producing PIC in the field. Omitting the vacuum and pressure, impregnated depths of 0.75 to 1.5 inches could be obtained. The most obvious applications were bridge decks for corrosion protection; floors for abrasion resistance; and hydraulic structures for wear and abrasion resistance (Polymers in Concrete, 1973).

Like the little girl who was all dressed up with no place to go, PIC remains a material with great potential based on considerable research but with essentially no applications. Approximately 20 bridges were treated and performed well (Bartholomew, 1978). A jail with very deteriorated concrete was given new life (Kaeding, 1978). The most significant application was the impregnation of Dworshak Dam in Idaho, the third highest dam in the United States. Cavitation had seriously damaged the walls of one of the outlet tunnels that carried water through the dam. The walls were repaired and, using techniques developed at The University of Texas at Austin, the walls were dried and soaked with monomer that was polymerized *in situ.* The floor of the stilling basin suffered extreme abrasion and wear, resulting in holes over 10 feet deep. After repairs, including 18 inches of steel fiber-reinforced concrete, the floor was impregnated under very difficult conditions-cold, wet weather, and very high hydraulic pressure that forced water up into the slab as it was being dried (Schrader, 1978). Follow-up inspections have shown that both walls and floor have performed extremely well after 25 years of service.

The process, however, was very time consuming, requiring a long drying period with temperatures at the surface reaching 250°F or higher. After drying,. the concrete had to be cooled before applying monomer. The monomer was soaked for several hours in a thin layer of sand applied to the surface. The concrete was heated to about 160°F to cure the monomer. The process generally took 48 hours. Some concern was expressed that microcracks created during drying were not sealed during the polymerization. Another concern was safety--the flammable monomer had to be handled carefully to prevent fires.

Other materials served as formidable competition to PIC. Durable coatings and polymer concrete overlays provided faster, less expensive solutions for protecting concrete walls and bridges. Improved portland cement concrete and precast polymer concrete became the materials of choice for precast components requiring high strength and durability. At the present time, only a few applications of PIC are being reported: PIC stay-in-place concrete forms and troughs in Japan and partial depth impregnation of floors and statuary using plastic sheets which permits a vacuum to be applied and monomer to be soaked into the concrete. But these very limited applications are a far cry from the many innovative applications prophesied in the '70s.

Polymer Concrete

Polymer concrete, PC, is a composite material consisting of aggregate with a polymer binder. Acrylic, epoxy, polyester-styrene, and sulfur are the most common binders. The fast curing, excellent strength and durability, excellent damping properties, and wide range of elastic moduli available have made PC a very versatile material with many applications. Its primary disadvantages are high cost (binder cost ranges from less than $1 per pound to many dollars per pound); sensitivity of properties to temperature; volatility and flammability of monomers and resins; and lack of experience with PC by many users.

PC was first used in the building industry in 1958 for fabricating innovative precast wall panels (Prusinski, 1978). It was used in Europe as a prepackaged repair material in Europe as early as 1961 (Peschke, 1978). But the interest in PIC in the late '60s and early '70s led researchers to explore the use of monomer and resins as a binder for aggregate. PC rapidly proved to be an excellent repair material for concrete. Thin overlays were produced which had the advantage of providing light weight, fast curing, durable, skid resistant surfaces for bridges, floors, and sports stadiums. Repair and overlays have proven to be excellent applications for PC.

Precast PC has been widely used for flooring, utility boxes, manholes, drains, wall panels, and machine bases. Precast PC can be produced quickly, as compared to precast concrete or machined cast iron, has a high strength-to-weight ratio, and can be produced with cast inserts. The excellent damping characteristics of PC make it a very attractive material for machine bases which support high frequency equipment. One manufacturer has developed a PC shell, which is placed over deteriorated concrete bases supporting pumps, compressors, or other equipment. The void between concrete and shell is filled with a durable grout. The repairs can be made quickly, eliminating the need for extensive shut down time.

Some very innovative building components have been produced using PC. Wall panels, furniture, domes, statuary, roofing panels, and flooring have been successfully produced.

PC has shown steady, although unspectacular growth over the years. Cost, and to some extent safety concerns, have kept it from becoming even more widely used.

Polymer-Modified Concrete

Polymer-modified concrete (PMC) is portland cement concrete to which a polymer is added during batching. PMC has proven to be a very popular construction material. Styrene-butadiene, acrylic latex, polyvinyl acetate, and ethylene vinyl acetate have been widely used in the United States and other countries. The primary advantages of these materials over PIC and PC have been their more conventional technology (similar to other admixtures for portland cement concrete) and lower cost. The primary advantages are very good bond to concrete, very good flexural strength, and good resistance to intrusion by chlorides. The compressive strength ranges from lower to higher than for conventional portland cement concrete (PCC).

Strength gain is similar to that of PCC: however, since the polymer film forms quickly some of the latexes require wet curing to begin within 15 minutes after placement and to continue for 24 to 48 hours. General, mobile batching is required because of the short working time.

PMC has been most widely used for repairs: overlays for repairing parking garages and bridge decks, over-the-counter repair materials, spray-on mortars for vertical surfaces, and general concrete repairs. It is also used as bedding grout for floor tile.

PMC has been perhaps the steadiest performer of the concrete-polymer materials. It is likely to continue to grow in popularity and use.

WHERE DO WE GO FROM HERE?

The growth of concrete-polymer materials has not met some of the ambitious projections made in the '70s and '8Os. The industry has matured, similar to that experienced by epoxies in the '70s and '8Os. Research has slowed considerably over the last 15 years. In order to regain the momentum, significant advances in one or more areas will be needed. Some projections for the future include:

Materials

- Lower cost resins for PC from recycled plastics. Currently the cost of recycled resins is not significantly less than for virgin resins. With the increased emphasis on sustainable development, the cost is likely to be reduced. Recycled resins have been shown to produce PC with a wide range of properties, and for most construction materials the impurities associated with recycled plastics are not a problem.
- Smart polymer concrete, which has the ability to respond to stimuli—deflection, temperature, and stress, and to compensate for changes caused by these stimuli. This is a very promising area for development
- Improved high performance polymers. The polymer industry has made tremendous strides in the past 50 years. It is quite likely that new and improved polymers will be developed.
    - Polymers with more stable properties over a wide range of temperatures.
    - A much wider range of polymers that is compatible with fresh concrete to provide improved properties for PMC.
    - Monomer, perhaps in the form of vapors that can be used for producing PIC much more rapidly and simply.
    - Resins that are designed to be recycled.

Processing

- Improved batching processes that will provide for denser, void-free PC. Several processes are now available.
- Improved proportioning methods that result in more efficient aggregate packing with the objective of requiring less resin but providing adequate workability.
- Improved, more rapid processes for impregnating concrete. There is a tremendous need to significantly improve the performance of existing concrete structures, especially those subject to alkali-silica reaction, sulfate attack, freezing and thawing, abrasion, chloride intrusion, and cavitation. PIC offers great potential for accomplishing this goal.

Applications

- Rapid, user friendly, reduced labor systems for more efficiently using concrete-polymer materials for repairs, particularly on pavements and bridge decks, in order to make them cost competitive and safer to install.
- PIC post-tensioned beams and girders. These members can carry several times more load, are highly resistant to chloride intrusion, have negligible creep, and much higher flexural and compressive stresses.
- Replacements for metal castings. The greater strength-to-weight ratio, much easier just-in-time fabrication, reduced or eliminated machining, much improved damping, and improved insulation offer many advantages for a wide range of new applications.
- Composite PC-PCC components. The use of thin overlays of PC over ordinary PCC will result in lower cost, very good durability (chloride intrusion, abrasion, chemical resistance, and freezing and thawing), fire resistance, very good strength due to the sandwich construction, and a choice of aesthetic finishes.
- Thin PC facing panels attached to lightweight steel or aluminum framing members. The framing members serve both as the erection frame and the in-place, non-load-bearing wall framing. The dead load is much less and the durability much greater than for ordinary PCC panels.
- Thin sheets or tiles made of PC or PMC that can be bonded to floors, bridges and other horizontal and vertical surfaces. This process would eliminate the placing and curing of polymer materials and the associated safety problems. The materials would be much more user friendly.
- Complex PC castings used for structural applications. Railroad ties (sleepers) are an excellent example. The optimum shape is much more complex than the block PCC tie currently used. The use of rapid, automated casting processes utilizing robots along with the rapid turn around due to very rapid curing should make PC ties very competitive when life cycle costs are considered due to the excellent durability and strength.