cated in Figure 12 is based on field experience. It has been observed that subsurface fractures of the joint face that may not be visually detected from the pavement surface can extend more than 1 ft into the slab before they intersect the subbase interface (3). It is therefore appropriate to designate minimum limits for pavement removal for this and other procedures for full-depth pavement repairs.

The pavement-removal technique described was also used in this procedure. Following removal of the subbase material, no further preparation of the area was necessary since the cast-in-place concrete could conform to irregularities in the subbase.

Repair Concrete and Joints

The concrete mixtures described earlier for cast-in-place restoration are used in this method of repair. Transverse joints are treated as if they were contraction joints on new construction. Essentially, this means that they are resawed and sealed by using a preformed seal or a good-quality poured sealant that has the appropriate shape factor.

Performance

Repairs of this type number more than 1000 and have been in service for up to five years. In some contracts, most are in excellent shape; in others, up to 50 percent have failed, sometimes in less than six months. Most failures have been attributable to one of the following causes:

1. Use of HAC concrete, which becomes excessively hot and results in shrinkage cracks that later spall;
2. Inadequate consolidation in the undercut area, which triggers early failure of the load transfer so that adjoining slabs become depressed and sometimes fail;
3. Failure to underseal the adjoining pavement so that it fails outside the limits of the repair; and
4. Poor quality control of concrete, particularly with mobile mixers in which water control is by judgment or slump only and is highly variable.

CONCLUSION

In conclusion, it may be stated that Virginia experience has shown that durable repairs to jointed concrete pavements can be achieved if the engineering requirements of the repair and the engineering characteristics of repair materials are properly accommodated in the chosen repair procedure. Accordingly, most failures have been seen to occur when the above factors did not receive due consideration or when quality control of repair activities was lacking. Such failures are enormously expensive because of the costs for traffic control associated with repairs. For this reason, it behooves the highway engineer to ensure that repairs are carefully planned and that the best inspection and quality control possible be provided on repair activities.

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Highway Pavement Repairs by Using Polymer Concrete

ALVIN H. MEYER, B. FRANK McCULLOUGH, AND DAVID W. FOWLER

As traffic, particularly truck traffic, has increased on the primary highway system, the need for rapid repair methods has increased. Polymer concrete (PC) has been used effectively for rapid repair of portland cement concrete pavements, both jointed and continuously reinforced. Basic formulations for PC are presented and both user-formulated and prepackaged systems are described. Methodology for the repair of cracks, joints, spalls, and punchouts is illustrated. The results of several PC repairs are presented. Deflection measurements that illustrate the restoration of structural integrity, which means a prolonged pavement life, are given.

Many high-volume highways in the United States were constructed by using portland cement concrete (PCC) as the pavement surface. Now that traffic and allowable axle loads have increased, many of these facilities are approaching the limits of their design life, which usually means increased maintenance. The need for rapid, permanent types of repairs has led to the development of polymer concrete (PC) as a repair material.

The use of PC is not new to highway repairs. It

Figure 1. Loading arrangement for testing flexural bond strength of PC to PCC.

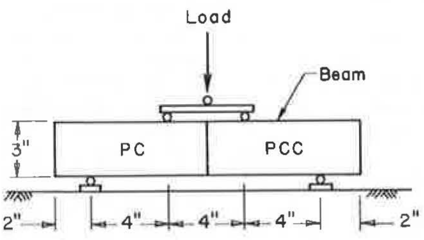
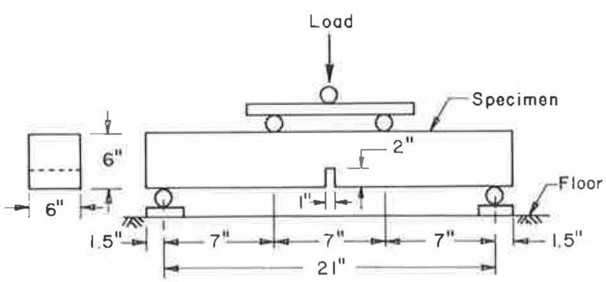


Figure 2. Crack chaser in operation.

Figure 3. Loading arrangement for testing the concrete beams.



has been used for several years as a patching material for highways and bridges. We attempt to summarize the types of repairs that have been made and some of the research that has led to the use of PC for those repairs.

All the PC described in this paper has a base of methylmethacrylate (MMA) for reasons discussed in the next section. Two methods of producing PC are used: prepackaged, which includes all the commercially available systems in which the user mixes the materials in the proportions supplied; and user-formulated, in which the polymer used is formulated by the user to satisfy the conditions of placement.

NOMENCLATURE AND DEFINITIONS

Synthetic polymers constitute a broad class of materials that includes polyesters, nylons, and epoxies that have been chemically transformed into high-molecular-weight chemical structures from simpler units called monomers. Several types of chemical reactions can be used to cause polymerization of monomers into polymers. Each class requires carefully selected formulations of monomers, additives, and reaction conditions to achieve the desired result. A number of these polymer systems have been successfully employed as substitutes for PCC for binding aggregates together to produce PC. Acrylic polymers formed primarily from MMA offer distinct advantages for PC systems for rapid repair of PCC pavements and bridges.

This application of PC places stringent requirements on both the process of polymerization and the properties of the resulting polymer. In addition, the interaction of the polymer with the selected aggregate system to form a good bond is another important requirement, which can be adversely affected by extraneous matter, such as water.

The most important process requirement is the rate of polymerization or the time for curing the monomer into a solid polymer. The resulting polymer must develop adequate mechanical properties to meet the requirements for the composite PC.

The main mechanical property of the polymer that is of interest is the ultimate strength, which is defined as the maximum stress that the material will sustain. For polymers, this characteristic is conventionally measured in tension because most polymer failures occur in this mode. For many purposes, ductility of the polymer is also a critical issue in its applications. For this work, measures of polymer ductility are primarily based on the magnitude of deformation at failure in tension tests. Many of the above-mentioned characteristics are basic to the selection of MMA as the base monomer; however, each characteristic can be significantly affected by the formulation employed in the formation of the polymer.

The remainder of this paper makes extensive use of simple abbreviations of the chemical names of the various ingredients in the formulation of polymers. These abbreviations and the standard chemical names are given below:

Abbreviation	Chemical Name
Monomers	
MMA	Methylmethacrylate
BA	Butylacrylate
EHMA	2-Ethylhexylmethacrylate
IDMA	Isodecylmethacrylate
AA	Acrylic acid
MAA	Methacrylic acid
HPMA	Hydroxypropylmethacrylate
Initiator agents	
BP (also BPO or BzP)	Benzoyl peroxide
DMPT (also DMT)	Dimethylparatoluidine
DMA	Dimethylaniline
Cross-linking agents	
TMPTMA	Trimethylolpropane trimethacrylate
TTEGDA	Tetraethylene glycol diacrylate
Plasticizers	
DOP	Dioctyl phthalate
TCP	Tricresyl phosphate

The polymerization of MMA proceeds by a free-radical process, which requires a source of free radicals. This may be accomplished by a number of methods; however, the most useful for these purposes is the addition of a chemical initiator.

Several types of initiators are known and employed, but peroxides are the most useful for PC applications since their decomposition into free radicals can be catalyzed (accelerated or promoted) by the addition of another suitable chemical. Thus, the initiator system is made up of a peroxide and a promoter, whose type and proportion have dramatic

Figure 4. Repair no. 6.

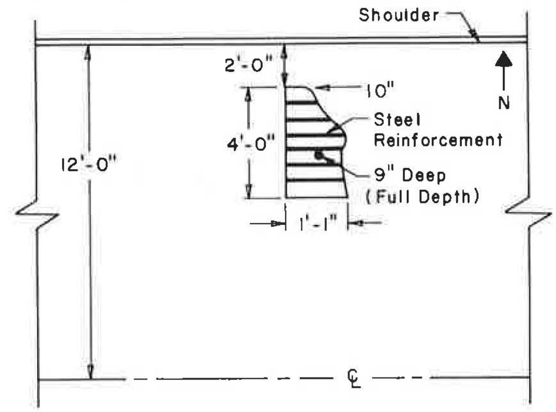
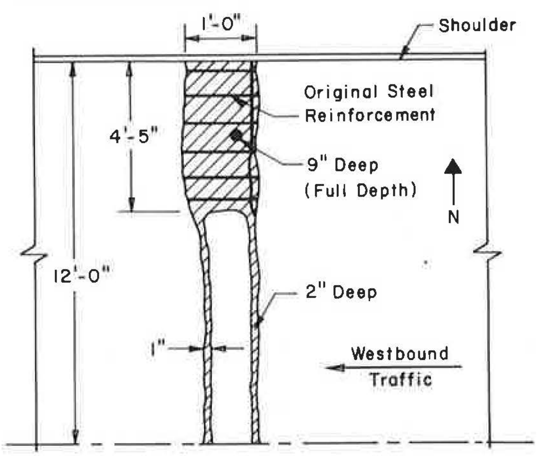


Figure 5. Repair no. 10.



effects on the rate of polymerization or curing and the resulting properties of the polymer. This work has employed BP and DMPT, respectively, as peroxide and promoter. Other choices could have been made or will be made in subsequent work; however, this system has proved sufficiently versatile and effective.

Polymer technology frequently uses mixtures of monomers to form copolymers since this provides an effective means of tailoring the polymerization process and the polymer to meet specific needs. The polymers mentioned thus far are linear in their molecular structure and may be likened to a train (a polymer chain) formed from boxcars, flatcars, etc. (monomers and comonomers).

Chemical monomers that possess multiple functionality can be added to introduce branching and subsequently cross-linking between polymer chains. These materials are known as cross-linking agents and the most typical one employed in PC formulations is TMPTMA. These materials dramatically alter the polymerization rate and polymer properties.

Sometimes nonreactive plasticizers are incorporated into polymer formulations to add ductility to the resulting material. Plasticizers are used in prepackaged PC formulations but have not been employed in the user-formulated formulations used here. A variety of other chemical ingredients may be added to the formulation as needed to alter workability or behavior.

These materials and concepts form an arsenal of tools for problem solving that can be employed in any PC application.

Figure 6. Joint repair no. 4.

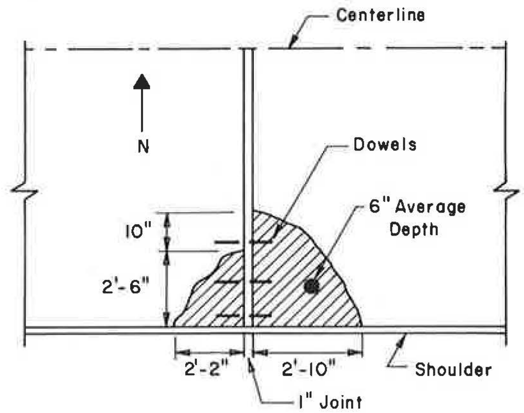
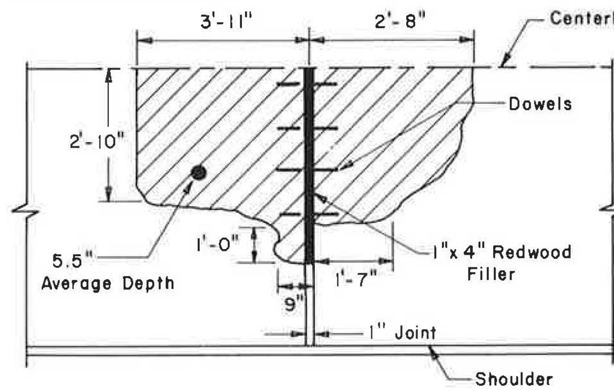


Figure 7. Joint repair no. 7.



PHYSICAL PROPERTIES OF PC

The physical properties of prepackaged and user-formulated PC are very similar. Typical ranges of values are given below:

Physical Property	Range (psi)
Compressive strength	5000-10 000
Modulus of elasticity	2-4 x 10^6
Splitting tensile strength	800-1800
Flexural strength (modulus of rupture)	1500-2500

The flexural bond strength of PC to PCC is equal to the flexural strength of the PCC when the bond surface is clean and dry. To test this property, beams were prepared in which half the length was PCC (Figure 1). In all cases that used recommended procedures to develop bond, the failure occurred in the PCC. When the prepackaged systems are used, a primer coat is necessary to ensure proper bond strength.

The bond strength of PC to steel reinforcement is about three times that developed by PCC. In other words, if 12 bar diameters are required for a PCC application, the same bond strength can be generated with 4 bar diameters when PC is used.

CRACK REPAIR

In many PCC pavement failures, the formation of unwanted cracks precedes the failure. In some instances, if the cracks could be bonded together, the service life of the pavement could be extended.

Figure 8. Deflection between cracks for a sound pavement.

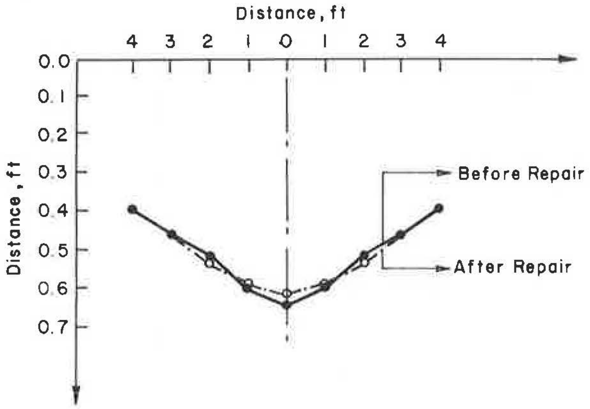
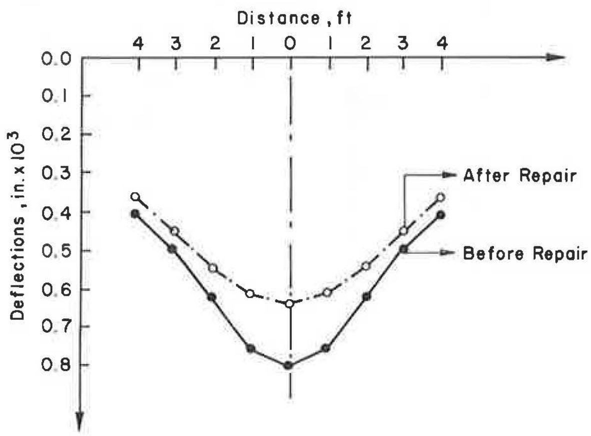


Figure 9. Deflections at upstream edge of repair no. 10.



A test was developed to simulate the crack formed in the concrete pavement by using a crack chaser. A crack chaser is a wheel-mounted piston-driven bit for following cracks in concrete and opening them up uniformly for remedial work. The crack chaser has a special tungsten-carbide-tipped, four-point cross face and side-cutting bits that have a standard diameter of 7/8 in. The standard bit drills holes about 2 in deep and 1 in wide. Figure 2 shows the crack chaser.

Five 6 x 24-in concrete beams were cast that had a groove 2 in deep and 1 in wide at the center. The beams were taken out of the forms after one day, and the sides of the groove were roughened by using a chisel to obtain a rough interface. The beams were moist-cured for one week and then dried in the oven at 250°F for three days.

The beams were broken in half with third-point loading [the groove was on the tension side (Figure 3)], and the loads were recorded. Next, two sheet-metal forms were fixed on the two sides of the groove with latex caulking material. After the caulking had hardened, monomer was poured into the groove to a depth of about 1/4 in to make sure that the crack was filled. The groove was then filled with aggregate and more monomer was added to fully saturate the aggregate. A mixture of 10 parts MMA powder to 90 parts sand was then sprinkled on top. After about 24 h, the sheet metal was removed. The beams were loaded in the same manner and orientation as in the first case.

In all cases, more than 50 percent structural integrity of the beam was restored. Thus, repairing

Figure 10. Deflections at downstream edge of repair no. 10.

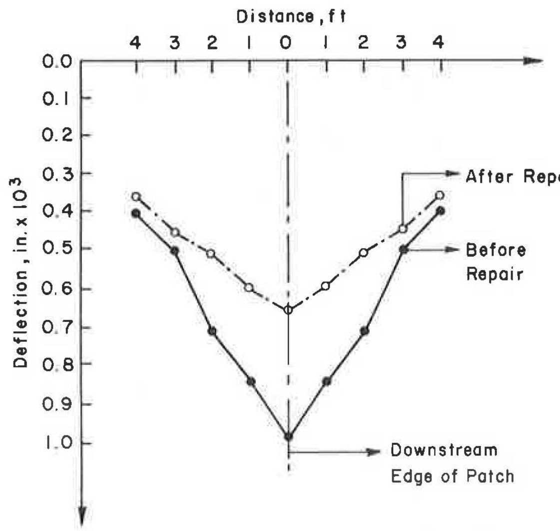
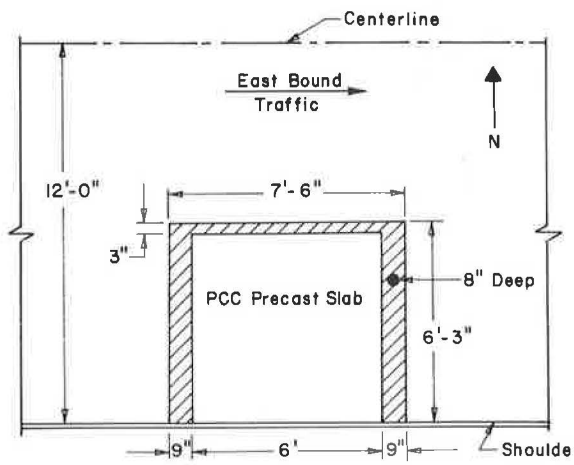


Figure 11. Installation for repair of punchout areas in CRCP.



the crack gave the beam more than 50 percent of the flexural strength of an uncracked beam. In most cases the gain was more than 80 percent.

Repair Procedures for User-Formulated System

Preparation of Repair Area

The repair area should be cleaned of deteriorated or delaminated concrete. The concrete surfaces should be dry and the surface should cool to about 120°F or less prior to making the repair. Joints through which the monomer could leak should be sealed by using caulking compound. If the repair is full depth, the base material usually has sufficient moisture to prevent excessive leakage into the base. If the base appears dry, it can be sprayed with water just before the repair is made. The monomer is lighter than the water, so the water does not come to the surface of the repair.

Making the Repair

The monomers, cross-linking agents, and promoters can be premixed a few hours or a day before use in the field. The initiator is then added when the repair is made.

The monomer can be mixed with the aggregate in one of two ways. The simplest consists of wetting the concrete surface by using the monomer system, placing the mixed, dry aggregate in the repair area, and screeding to a level surface. The monomer is then poured or sprinkled over the aggregate until it is fully saturated. The surface is screeded again to a reasonably smooth finish. Sand can be sprinkled on the surface to provide a smoother surface for trowelling. When added to the surface, MMA powder in the proportion of 10 parts MMA to 90 parts sand tends to form a surface skin in a few minutes, which minimizes evaporation of the monomer. If MMA powder is not used, it is recommended that the repair area be covered with a polyethylene sheet during curing.

If the repair is full depth, it is desirable to place the aggregate to about one-half the depth of the hole, add monomer, add the remaining aggregate, and add the required monomer. In all cases, it is recommended that the aggregates be vibrated or tamped to reduce honeycombing in the PC.

The second method involves mixing the aggregate and monomer in a concrete mixer or a wheelbarrow before the matrix is placed in a hole. The aggregate (coarse and fine) is placed in the mixer or wheelbarrow and an amount of monomer system equal to about 12 percent by weight of the aggregate is added and mixed in for 2 or 3 min. The mix is then placed in the repair hole. Finishing proceeds as in the first method. The mixer or the wheelbarrow and tools can be cleaned by using monomer without the initiator or by washing with water.

It may be necessary to add more monomer to the repair when either of the two methods is used. The aggregate should be kept saturated until curing begins. As the monomer begins to cure, heat is generated. The PC usually cures in 30 min to 1 h. When the repair has cooled enough to permit safely placing one's hand on the surface, the repair is usually ready for traffic.

Safety and Handling

The chemicals used should be handled with reasonable care. Some of them are flammable and toxic, although no more so than gasoline or kerosine. They should be kept in a cool, shaded, well-ventilated area. Some of the chemicals, especially TTEGDA, cause irritation when they come into contact with the skin. Gloves, rubber boots, and goggles are recommended when the materials are used. DMPT and BP should never come into contact with each other in concentrated forms because an explosion may occur. The use of BA should be limited, especially indoors, because of its strong odor.

Field Applications

Numerous repairs have been made in Texas on both continuously reinforced concrete pavement (CRCP) and jointed pavement by using PC. The repairs include spalls, punchouts, joints, and cracks. Both PC systems have been used with essentially the same effectiveness. Figures 4 through 7 are schematics that illustrate the typical types of repairs.

Typically, four to eight repairs are identified in a section of pavement to use the same traffic control for all repairs. Once the repair area has been prepared, PC requires 45 min to 1 h for placement and curing. Once PC has cured, the repair can be opened to traffic.

In addition to usual monitoring of the repairs, deflection measurements were made before and after the repair. The deflections were measured by using the Dynaflect.

Figures 8-10 illustrate typical results of the PC repairs. Figure 8 shows deflections for a sound pavement. Figures 9 and 10 show the change in deflections before and after repair. Comparing the deflections shows that some, if not complete, structural integrity is restored to the pavement. In other words, the life of the pavement is extended. No definitive results are available to indicate the length of the extension.

In addition, PC has been used with precast PCC panels to repair larger punchout areas in CRCP and is being tested for full-depth runway repair. The precast repairs will be reported in a separate paper and hence no details are provided here except Figure 11, which illustrates the type of installation.

SUMMARY

PC can be used to make rapid repairs to areas of highway or runway pavements that show distress. The use of PC can restore some measure of structural integrity to the pavement and prolong pavement life. PC is expensive; it ranges from $250 per cubic yard for some user-formulated materials to $1800 per cubic yard for some prepackaged materials. However, when user-delay costs are included, the use of PC can be justified for most pavements in the primary highway system.

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