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Machine Application of Polymer Concrete for Highway Repairs

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Synopsis: Polymer concrete has been used for years to repair portland cement concrete. A monomer system is mixed with well-graded aggregate and placed in the repair area. After the monomer cures, a strong durable material is produced which bonds well to portland cement concrete.

Special mixing and placing equipment was developed for a large pavement repair job in Houston. Longitudinal cracks, longitudinal lane-shoulder joint separations, spalls, punch-outs, and other types of damage were repaired.

Keywords: concrete pavements; concrete slabs; costs; cracking (fracturing); equipment; joints (junctions); methyl methacrylate; patching; polymer concrete; precast concrete; repairs; safety.

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INTRODUCTION

Polymer concrete made with methyl methacrylate (MMA) monomer was used to make pavement repairs in Houston. Specialized equipment was developed by the contractor for mixing and placing the monomer and polymer concrete. Repairs included sealing longitudinal cracks, filling spalls, punch-outs, lane-joint separations, and bonding of precast portland cement concrete slabs.

Materials

Monomer -- The monomer system was a blend of the chemicals shown in Table 1. The MMA and TMPTMA were bought in bulk quantities and delivered to a central location near the jobsite where the manufacturer of the DMT blended all three chemicals together in their proper proportions. The monomer was then transferred to a large holding tank until needed.

A total of 46,000 gallons of monomer were used in this project. Of the polymer concrete used, 45 percent was for sealing 137,000 lineal ft. of random longitudinal cracks and spalls. Another 45 percent was used to seal 51,000 lineal ft. of longitudinal lane-joint separations, 9 percent was used to repair punch-outs and blow-ups and one percent was used to place precast concrete slabs

Aggregates -- Due to the width of lane separations needing repair, the maximum coarse aggregate met the following grading requirements:

Retained on 3/4 in. sieve	0%
Retained on 1/2 in. sieve	0 - 10%
Retained on 3/8 in. sieve	30 - 60%
Retained on No. 4 sieve	85 - 100%
Retained on No. 8 sieve	0%

Fine aggregate met the following grading requirements:

Retained on 3/8 in. sieve	0%
Retained on No. 4 sieve	0 - 5%
Retained on No. 8 sieve	0 - 20%
Retained on No. 16 sieve	15 - 50%
Retained on No. 30 sieve	35 - 75%
Retained on No. 50 sieve	70 - 90%
Retained on No. 100 sieve	90 - 100%
Retained on No. 200 sieve	97 - 100%

Aggregate proportions depended on the type of repair. For longitudinal separations, full depth repairs, and precast slabs, the coarse aggregate was mixed with the fine aggregate at a one to one ratio (by weight). Cracks and spalls were repaired using fine aggregate alone.

Because the moisture content of the aggregates (at the time of placement) was limited by specifications to a maximum 0.5 percent by weight, keeping the aggregates dry became a major concern. To meet the 0.5 percent specification for dryness, the coarse and fine aggregates were blended at a 50:50 weight ratio and dried in a kiln at about 245°F. A special bag with a bottom discharge chute, making the material easier to unload, was selected for transporting the aggregate to the job site (Fig. 1). The bags held 2500 lbs of premixed aggregate.

Table 1. Formulation for Monomer System

Chemicals	Function	Percent by Weight
Methyl Methacrylate (MMA)	primary monomer	95
Trimethylolpropane trimethacrylate (TMPTMA)	cross-linking agent	5
N,N-dimethyl-p-toluidine (DMT)	promoter	6*
Benzoyl Peroxide (BzP (40% dispersion)	initiator	2* (pure BzP)

*DMT and BzP adjusted for ambient temperature to result in a pot life of about 20 minutes; five percent of BzP, which was in the form of a 40 percent concentration in dispersion form, was used.

Steel Fibers -- Three percent by weight of steel fibers were added to the polymer concrete to increase the ductility and toughness of the polymer concrete in large mass repairs, such as lane-joint separations and full depth repairs. Loose, uncollated steel fibers with hooked ends having a length of 30 mm and a diameter of 0.5mm were used.

Thickener -- Polymethyl methacrylate (PMMA) powder at the rate of three percent by weight of the total aggregate was added to the polymer concrete to minimize evaporation and drainage of the monomer and to improve the workability.

DEVELOPMENT OF EQUIPMENT

With the limited existence of proven equipment for field applications, one of the major risks and concerns of the contractor in bidding the job was the development of equipment that could make polymer concrete to meet the requirements of the four polymer bid items and, at the same time, produce polymer concrete in a continuous production-like manner. Because of time constraints specified by the SDHPT for completing the project and because of the different volumes of polymer concrete needed to make each repair two different machines were developed. One machine, the smaller mixer, was capable of delivering the monomer system at a maximum output rate of 1 gal/min. for repairing cracks and spalls where dry aggregates were first placed by hand and injected with monomer later (Fig. 2). The other machine, the large unit, could deliver up to 10 gal. of monomer and mix it with all the PC components, thus yielding up to a maximum of 4 cu. ft. of PC/min.

The Large Unit -- This unit was used for repairing longitudinal separations and full depth repairs, and for bonding precast slabs. Components of the large unit included a 1500-gal. monomer supply, a high-volume air compressor, 9 cu. yd. aggregate supply bins, a feeding system for steel fibers, a PMMA powder metering system, a supply and metering system for BzP, and the mixing pumps and mixing augers which delivered the uncured PC into the repair (Fig. 3).

In order to facilitate production, a boom truck was used to transfer the bags of blended aggregate to the storage compartments on the trailer (Fig. 1). The transfer caused only a minimal disruption in production. The aggregate was fed by gravity into a hopper. The self-powered hopper had an auger which provided accurate metering of the blended material (Fig. 5). Using a mixing auger, the modified rig metered and mixed the different materials with the monomers at rates up to 12 cu. yd/hr. The advantage of using this machine was its modular design.

Two air-powered, direct displacement piston pumps, were used to pump and mix the monomers (Fig. 5). The large pump (10 gal/min.) was used to pump and mix the monomer directly into the mixing auger. The smaller pump (3 gal/min.) was used to apply mixed monomer directly on the repair for keeping the already-placed polymer concrete saturated. This was necessary because the low-viscosity monomer often ran off or leaked out of the repairs. Additionally, in case of a malfunction in the large pump during production, the smaller pump could be easily switched over to the mixing auger.

Since the MMA, TMPTMA, and DMT blend coming from the monomer tank was colorless and the initiator, BzP, was also colorless, a blue dye was added to the BzP. When the monomer was injected into the screw auger machine the operator could easily determine by the color if the monomers had been properly mixed.

Because of the high flammability of the monomer, certain safety precautions were taken by equipping the large mixer:

1) A perforated CO_2 pipe lined the inside of the main screw auger. The CO_2 could be turned on quickly by the operation in case of fire

2) A sink and hand-held shower were installed for use as an emergency eye and body wash station

3) Fire extinguishers were placed at various locations around the machine and truck.

Building and rigging a comparably equipped machine would cost about $85,000, excluding the truck and the air compressor.

Small Mixing Machine -- A smaller monomer mixing and dispensing machine was needed for repairing cracks and minor spalls (Fig. 2). Because of the smaller quantities of monomer used, the MMA, TMPTMA, and DMT were blended and stored in 55-gal. drums. The air compressor to run the hydraulic injection system pump was stationed on a flat bed truck along with a silicone pump which was used in conjunction with another construction item. A small hydraulic injection system pump similar to the small pump used on the large machine was used to mix and blend the monomers. This small pump also had mixing guns and modifications similar to the other pumps. The aggregate bin was designed for a one-to-two-day supply of aggregate and was situated at the end of the trailer for easy discharge. Building and rigging the smaller machine cost about $25,000, excluding the truck and air compressor.

REPAIRS

Longitudinal Lane-Joint Separations and Lane-Shoulder Separations -- The joints at the edge of the concrete pavement adjoining an asphalt median or shoulder were required to be cut to a depth of 8 in. and cleaned of all loose material. Furthermore, the pavement joint face had to be cleaned by wire brushing or scraping with hand tools or power tools, sandblasting, or other applicable techniques. Unknown to the contractor and the State Department of Highways and Public Transportation, some of the 8-in. thick continuously reinforced concrete pavement had been slip-formed with a keyway, making it difficult to clean and fill the joint according to the specifications.

It was decided that a rock saw (Fig. 6) could remove the keyway and also serve to saw-cut the asphalt and clean the face of the pavement. An an added benefit, the use of the rock saw reduced labor costs without significantly reducing production. Due to using the rock saw, the separation trench was a uniform 3 in. wide and 8 in. deep (Figure 7).

A problem that was not anticipated was the tremendous amount of water that drained from beneath the pavement into the trench even after many days without rain. Because water prevented the bond between PC and concrete, great care was taken to dry the edge joint, especially the face of the pavement. Some water in the bottom of the joint actually prevented the monomer from leaking out. Compressed air was used to blow the water out of the edge joint.

Large butane heaters were then used to dry the face of the concrete. Because of the problem with water infiltration, the water removal and drying operation had to be performed just ahead of the polymer concrete placement.

The polymer concrete was placed in the trench using the large polymer concrete machine (Fig. 8). The surface was wetted with additional monomer (Fig. 9) and then finished to insure adequate saturation at the surface. The cost of cleaning the joint and placing the polymer concrete in the lane-joint and lane-shoulder separations was approximately $9.05 per lineal foot. Fig. 10 shows the finished joint.

Full-Depth Repairs -- Punch-outs are full-depth failures of the concrete pavement resulting from intersecting transverse and longitudinal cracks (Fig. 11). Blow-ups are defined as cracking and heaving of concrete pavement, usually located at preformed transverse joints, caused by thermal expansion. Ninety percent of all full-depth failures in this job were punch-outs (Fig. 12). Transverse saw-cuts were made on each side of the failure one lane in width. The cuts were 2 in. deep to provide a neat repair edge and to prevent the steel reinforcing from being cut. The concrete within the repair area was then removed with air hammers.

After preparation was completed, the large polymer concrete machine was used to place polymer concrete in the full-depth repair (Fig. 13). As the area was being filled with polymer concrete the second smaller pump was activated to replenish monomer losses due to evaporation and leakage into cracks and voids. Once the surface was saturated it was screeded smooth. The surface was kept saturated with monomer until polymerization occurred. A mixture of concrete sand with three percent (by weight) PMMA powder was sprinkled over the entire repair area to prevent slick spots from occurring after polymerization and to reduce further evaporation. The entire area was allowed to cure two hours before traffic was allowed over the repair.

The cost of material for this type of repair was up to 20 percent less than the cost of some of the other materials: magnesium phosphate, magnesium polyphosphate, and commercially-available two-component polymer concrete. Another advantage of using polymer concrete in this type of repair was that the set time could be adjusted and thus could be placed at any temperature by adjusting the amount of BzP or DMT.

Limits in the specifications allowed other materials to be placed only when the temperature was below 85˚F. The only material used in this project that was less expensive than the polymer concrete was type III portland cement concrete (PCC). However, while polymer concrete needed only two hours or less to cure, the type III PCC needed up to 10 hours to obtain 3000 psi compressive strength, depending on the temperature. In high density traffic areas the higher price of PC can be offset by the higher cost of traffice control caused by the longer curing.

Precast Concrete Repair Slabs -- The use of precast slabs required removing deteriorated sections of continuously reinforced concrete pavement and replacing it with a precast portland cement concrete slab. Polymer concrete was used to fill the joint between the precast slab and the existing concrete pavement. Plans called for the precast slab to be 7-1/2-in. thick. For the remaining 1/2 in. beneath the slab, the contractor had the option of selecting a poured grout bed or pumping fly ash grout underneath the precast slab. Eleven areas were selected for repair by placement of precast slabs. All sites but one were to be 6 ft. long by a full 12 ft. lane wide, however, the dimensions were verified in the field. Because the actual thickness of pavement at each specific location could not be determined, the slabs were precast 7-1/4 in. thick instead of the planned 7-1/2-in. The slabs were precast at a site near the job and cured for seven days. The areas to be repaired ranged in size from 6 ft. by 12 ft. to 20 ft. by 12 ft.

A supporting frame with leveling jacks was fabricated to install the precast slabs. After the saw cuts were made and the old concrete removed, the supporting frame was attached to the lifting points of the precast slab (Fig. 14). A 27-ton motor crane was used to place the slab.

Instead of using the 1/2-in. grout bed under the precast slab as shown on the plans, the contractor elected to use polymer concrete. Reasons for substitution were:

1) With the possibility of the grout setting up before the slab was in its final position, substituting polymer concrete allowed 15 to 20 minutes before polymerization occurred.

2) No additional equipment was required

3) Since grout was not used in the joints between old and new concrete, there was additional savings in time and on formwork and cleanup.

4) An increase in production was obtained.

Specifications called for a sheet of plastic to be placed over the base to prevent leakage, however, the monomer dissolved the plastic film; so, to prevent leakage, the contractor used clay to fill cracks and voids in the corners and at the edges. Once the precast slab was in position and leveled as required, the gaps around the slab were filled with polymer concrete (Fig. 15). After 2 hours of curing, traffic was allowed over the repaired area.

All eleven precast slabs were in place within seven days. By substituting the polymer concrete for the grout under the slab, the repairs were made more quickly.

Longitudinal Cracks -- The specifications for preparing a longitudinal crack (Fig. 16) required making a vertical groove at least 3/4 in. wide by 3/4 in. deep, centered along the existing crack. In cases where the existing crack was wider than 3/4 in. the crack was routed so that the sides were vertical. The groove was prepared using a crack cutter manufactured by McDonald Air Tool Corporation. Other machines were tried but none would make a vertical groove as well as the crack cutter without spalling the edges of the concrete. Other methods included using a random saw cut machine, but the water needed to run the saw cut machine proved to be a major problem. After the prepared crack had been air blasted, a small amount of monomer was poured into the undisturbed portion of the crack (below the prepared crack) until it would accept no more.

For the smaller mixer, the fine aggregate was loaded into a specially-designed hopper for easy discharge into the prepared crack. The crack was filled with the fine aggregate to a level approximately 1/2 in. above the pavement surface and approximately 1/2 in. on both sides of the crack, assuring a tightly sealed crack and a good bond. The monomer mixture was then poured over the aggregate until it was completely saturated. The aggregate was then tamped and screeded level with the adjacent concrete. If required, the crack was then saturated again with monomer before adding a mixture of concrete sand with three percent (by weight) PMMA powder, sprinkled liberally over the crack. The PMMA powder helped to reduce evaporation of the monomer. The crack was then covered with polyethylene and cured for two hours before allowing traffic over the repair.

For many of these repairs, most of the time involved in making the repair was in the preparation. In the case of cracks and spalls, 10 to 12 crack cutters were required to keep the small polymer concrete machine busy.

Early experience on the job indicated that for polymer concrete crack repairs to be durable, the cracks need to be opened to a depth of 1 to 2 inches instead of the 3/4 in. which was specified. A 1 in. to 2 in. depth would provide a greater concrete surface area for bonding to the polymer concrete. For reliable crack repair, monomer must be allowed to totally saturate the area adjacent to the crack at the surface. This requires additional monomer, but it is necessary to provide a good bond.

CONCLUSIONS

Based on the experience during this project, the full-depth repairs of all types and the precase slab repair method were very successful and are cost competitive with most current fast repair stems now being used.

The ability to continuously mix and place polymer concrete with these machines helped the versatile polymer concrete to compare very favorably with any other rapid setting material product. However, in order for polymer concrete to become more acceptable and cost effective in concrete pavement repairs, some improvements are needed:

1) A monomer that is not flammable

2) A monomer that does not have such a noxious odor; and

3) Most important of all, a monomer which is compatible with water.

Application costs could be significantly reduced if labor for preparing the repair area can be decreased and if aggregates would not have to be dried and bagged.

Fig. 1--Nylon bag for transporting aggregate

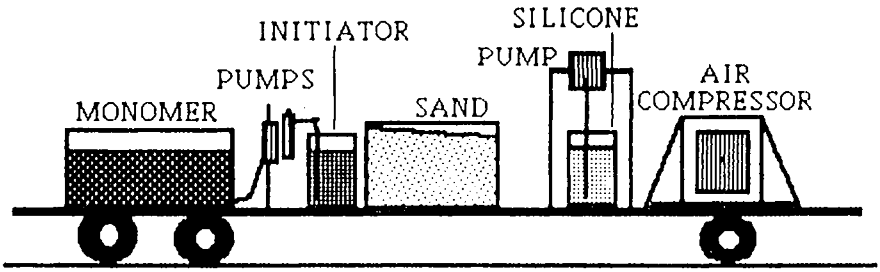

Fig. 2--The small mixer: trailer mounted equipment