5. The impact test, as used, was unsatisfactory for evaluating dynamic bond strength.

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Laboratory Evaluation of Four Rapid-Setting Concrete Patching Materials

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ABSTRACT

Many proprietary patching products are available for the repair of portland cement concrete (PCC) pavement. These materials must cure rapidly to minimize delay and limit safety hazard exposure to both the traveling public and maintenance personnel. However, long-term strength and durability are equally important, although information concerning these properties and direct comparisons between patching alternatives is limited. Compressive strength, tensile strength, direct shear, and energy absorption tests were used to evaluate polymer concrete, magnesium phosphate cement, Roadpatch with steel fibers, and epoxy-bonded PCC. The split-cylinder tensile bond strengths of the patching materials were comparable to those of the base concrete. The shear bond strengths and energy absorption tests indicated that polymer concrete has good cured properties as a composite patch but may be susceptible to weathering or thermal deterioration. Roadpatch also had satisfactory cured strength properties but had better resistance to decreases in direct shear bond strength and tensile strength when exposed to simulated weathering. Roadpatch appeared to exhibit a good overall combination of characteristics that indicate satisfactory short-term and long-term durability. The epoxy-bonded PCC alternative demonstrated substantial strengths, but the slow rate of strength gain noted was a major disadvantage for potential field application. Magnesium phosphate concrete does not appear to be an attractive early cure material and it may be susceptible to damage from dynamic loading.

Portland cement concrete (PCC) pavement repair performed in urban areas requires rapid-setting patching materials to minimize the maintenance time. Heavy traffic conditions interacting with maintenance work create delay and safety hazards for both the maintenance crews and the traveling public. Rapid-setting patching materials also make possible the scheduling of patching activities in early morning hours. Thus, a pavement patch can be installed and the pavement section reopened to traffic without causing daytime delays.

Many properly applied rapid-setting patching ma-

terials have satisfactory short-term strength and bonding properties. However, long-term durability is also critical because premature debonding of patches creates further pavement deterioration and expensive repatching.

The major objective of the research reported here is to compare the strength and weathering resistance characteristics of selected rapid-setting PCC pavement patching compounds. A laboratory testing program evaluated material and bonding properties, which are fundamentally related to the durability and performance of spall-type patches. Patching materials currently used for shallow-depth surface repairs of PCC pavement slabs and bridge decks were selected. Previously published research indicated that these products possessed satisfactory material strength and short-term durability.

PATCHING MATERIALS

Polymer Concrete

The polymer concrete consisted of a liquid monomer, a premixed powdered hardener, and fine aggregate. One gallon of monomer was mixed with a 30-lb bag of hardener before the addition of 1 gal of pea gravel.

A coat of polymer primer was applied to base concrete to improve the bond before the polymer concrete was placed. The primer, mixed for application for normal weather conditions, was a two-component resin consisting of 1 qt liquid monomer mixed with 11 g of powdered hardener.

Magnesium Phosphate Cement (MPC)

Following manufacturer recommendations, one 50-lb sack of cement was added to 1 gal of water.

Roadpatch with Steel Fibers

Roadpatch was prepared by adding a liquid (one part Acryl 60 and three parts water) to a blend of powdered component and steel fibers to obtain mortar consistency with a 2- to 3-in. slump. A primer coat consisting of Acryl 60 and powdered component was applied to base concrete before the patching material was placed to improve bond.

Epoxy/PCC

An epoxy adhesive (a mixture of two liquid components in a 1:1 volumetric ratio) was applied to base concrete in a thin coat immediately before placement of rapid-setting PCC. The PCC mix design was one part water, two parts Type I cement, four parts natural sand, and six parts pea gravel by weight. In addition, the curing rate was accelerated by dissolving 1 percent (by cement weight) calcium chloride into the mixing water. The PCC was placed while the epoxy adhesive was still tacky.

Base Concrete

Mixture design and materials were identical to those of the rapid-setting concrete except that the calcium chloride was omitted.

TESTING PROCEDURES

Compressive Strength Testing

Cylinders of patching materials 3 in. in diameter by 6 in. were tested by using ASTM Test Method C 39 as a general guide.

Tensile Strength Testing

ASTM Test Method C496 was the general guide for tensile testing of 3-in. diameter by 6-in. cylindrical specimens. Homogeneous specimens were tested to evaluate tensile strengths of individual patching materials and composite cylinders (Figure 1a) were used to measure bond strength at the interface between base concrete and the patching material. Tensile testing was conducted by using flat steel platens; 8-in. long and 0.25-in. thick plywood strips were placed between the specimen and the platens.

Direct Shear Testing

A composite block specimen (Figure 1b) consisting of a 4-in. width of base concrete and a 2-in. cube of patching material cast on the top was subjected to a horizontal static load applied to the vertical face of the cube. Shear strength of the base concrete was obtained by using monolithically cast block-overlay configurations of the same dimensions.

Impact Testing

The composite block specimen (Figure 1b) was tested to evaluate energy absorption capabilities of the composites of patching material and base concrete. A

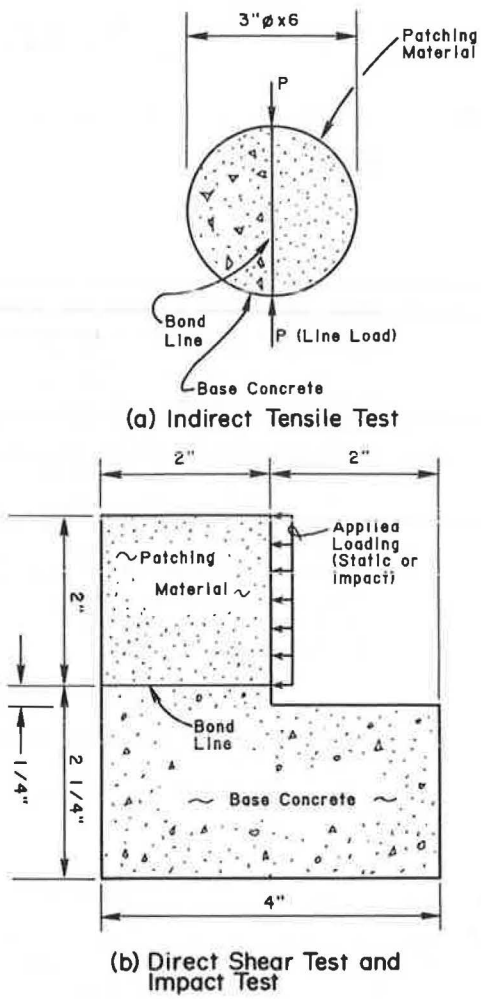

FIGURE 1 Laboratory test specimens.

pendulum impact testing machine was designed so that the pendulum arm was released from an initial horizontal position to swing through an arc and hit the vertical face of the cube at the lowest point of the arc. The energy loss caused by fracturing the bond between cube and base concrete, considered to be the maximum energy absorption capability of the composite of patch material and base concrete, was calculated on the basis of pendulum arc travel.

WEATHERING SIMULATION

One group of laboratory test specimens was placed in random order on metal racks inside a heating-refrigeration unit to simulate field weathering. A minimum 0.5-in. spacing was maintained between specimens and between the specimens and interior walls to provide adequate circulation. Specimens on the top rack were shifted to the bottom rack and other specimens were moved to the rack immediately above at 5-day intervals to prevent preferential temperature changes produced by the air circulation pattern in the unit.

The simulated weathering process is shown in Figure 2. The total time of exposure was 80 days and included two series of 20 daily cycles of freezing and thawing and two series of 20 daily cycles of heating and cooling.

EXPERIMENT DESIGN

Material and bond strengths of all patching materials vary with age and environmental conditions. Three test series described in Table 1 were employed to evaluate the effect of age and simulated weathering exposure.

Rapid-setting patching materials should provide a satisfactory patch in a short period of time. Thus, compressive, tensile, shear, and impact tests should evaluate early strengths and a Group 1 Test Series tested materials 6 hr after specimen preparation. A 6-hr curing period approximates the maximum time a maintenance crew could allow for the curing of typical field-installed patches during an 8-hr work day.

However, epoxy-bonded rapid-setting PCC specimens were tested after 24 hr of curing because a 6-hr curing period was not sufficient time for appreciable strength gains to take place.

Thermal durability of the patching alternatives is an important factor relating to long-term patch performance. Temperature changes may cause deterioration of patching material strength or bond to the patched concrete or both. Weathering resistance was determined by strength measurements following exposure to a series of cyclic temperature changes (Group 3 Test Series). These measurements were compared with corresponding strengths by using non-weathered test specimens in the Group 2 Test Series. Differences between Group 2 and Group 3 Test Series could be attributed to the simulated weathering because curing time was the same. Furthermore, Group 2 strengths can be related to the fully developed properties of the composites of patch material and base concrete.

The strengths shown on the bar graphs represent the means of three duplicate specimens. Coefficients

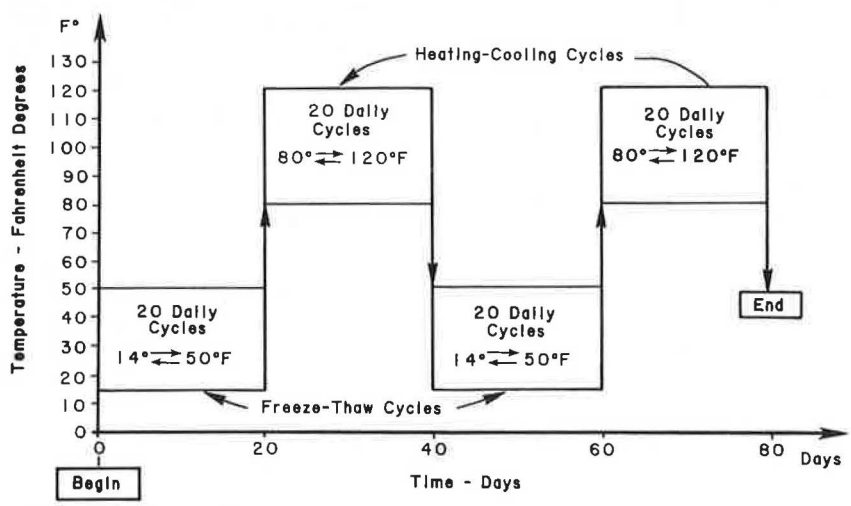

FIGURE 2 Simulated weathering program.

TABLE 1 Experiment Design

Test Series Designation	Age or Exposure of Specimens	Test Series Purpose	Testing Conducted
Group 1	6 hr moist curing in laboratory	Determine early strengths of patching materials and composite patches	Compressive strength, tensile strength, direct shear strength, impact resistance
Group 2	2 days moist curing and 81 additional days in laboratory environment	Determine matured strengths of patching materials and composite patches	Compressive strength, tensile strength, direct shear strength, impact resistance
Group 3	2 days moist curing, 1 day soaking in water, and 80 additional days of cyclic temperature changes	Determine durability potential and thermal degradation of patching materials and composite patches	Compressive strength, tensile strength, direct shear strength, impact resistance

of variation (CV) were also calculated, although the sample size was too small for statistical tests of significance to be utilized with meaning.

COMPRESSIVE STRENGTH RESULTS

As shown in Figure 3, the highest early age (Group 1) mean strength was associated with polymer concrete, followed by Roadpatch and MPC. The data for polymer concrete and Roadpatch had CVs less than 10 percent and the means appear to represent accurate values. The MPC CV exceeded 30 percent, and it appears that the mean compressive strength is overestimated by this limited data set. However, the early age compressive strengths of all three materials are adequate for making quick patch repairs. It should also be noted that the 24-hr average compressive strength of the rapid-setting PCC was 2,080 psi, which was lower than those measured at 6 hr for the proprietary patching products.

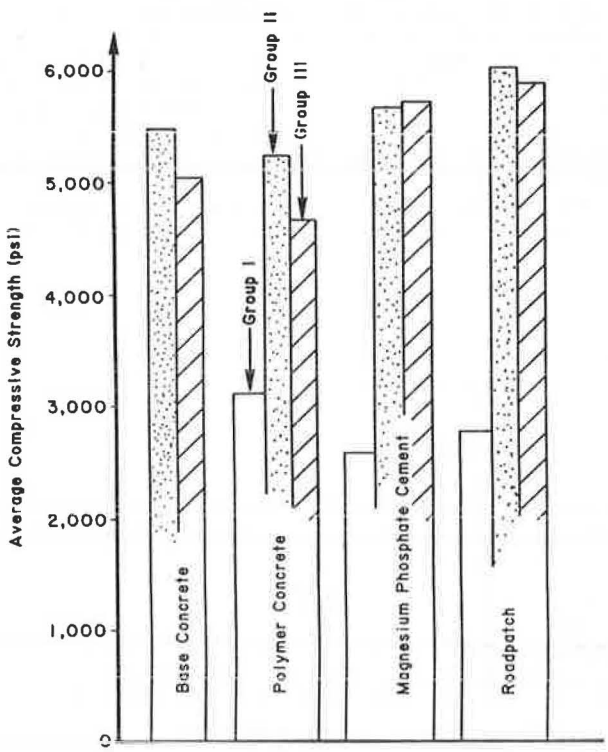

FIGURE 3 Compressive strength results.

Group 2 compressive strengths had minimal variation with CVs less than 20 percent for all materials. The final cured strengths of the patching products were approximately equal to the compressive strength of the base concrete.

A comparison of Group 1 and Group 2 strengths indicates that the patching materials continued to gain strength. This additional strength gain is an assurance that the compressive strengths of the patching materials are adequate for field application.

Group 3 (simulated weathering) results showed little variation (all CVs less than 10 percent). Simulated weathering did not affect the compressive strength of Roadpatch or MPC as much as it did for the base concrete or polymer concrete. Polymer concrete suffered the largest reduction in strength (11 percent). Comparison of Group 2 and Group 3 results suggests that Roadpatch and MPC may provide better weathering and thermal durability.

TENSILE STRENGTH RESULTS

The Group 1 means shown in Figure 4 indicate relatively small differences between patching materials. Homogeneous and composite polymer concrete data showed little variation (CVs less than 5 percent). However, considerable variation (CV greater than 25 percent) was associated with the MPC data. Therefore, the average tensile strength for MPC is not considered as valid as that for the other materials. It should also be noted that the 24-hr average tensile strength of the rapid-setting PCC was 340 psi, which was lower than those measured at 6 hr for the proprietary patching products.

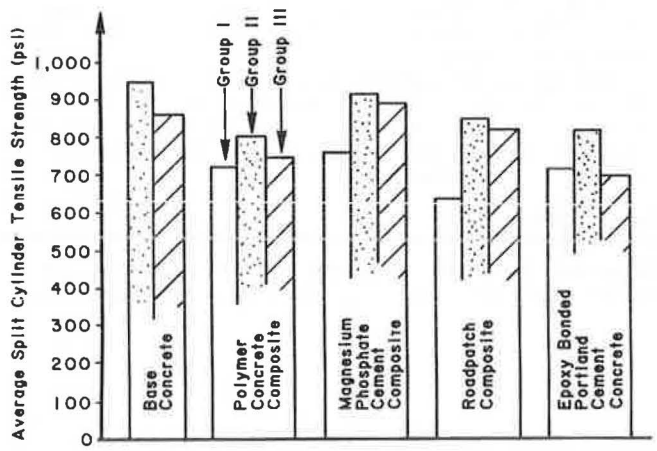

FIGURE 4 Split-cylinder tensile strength results.

The epoxy adhesive provided a strong bond for the concrete half-cylinders. However, the slow curing time of the epoxy renders the epoxy-bonded PCC unattractive for making rapid-patch repairs. The rate of strength gain of the epoxy used for bonding the PCC was very slow and approximately 12 hr was necessary before the epoxy stiffened so that it would not deform when touched. Considering the variance in the test data, it appears that polymer concrete is the better choice of material on the basis of Group 1 testing.

Relatively little variation was present in Group 2 results (all CVs equal to or less than 10 percent). Roadpatch exhibited the greatest tensile strength of the homogeneous test cylinders, which was approximately 30 percent higher than that of the other materials (data not shown in Figure 4). Composite cylinders of patching material and base concrete possessed tensile strengths approximately the same as those of the base concrete.

A comparison of Group 1 and Group 2 strengths indicated a notable increase in tensile strength with time for Roadpatch and a somewhat smaller increase for the other materials. As with the compressive strengths, the increasing tensile strengths are positive indicators that materials selected on the basis of early strength will be adequate in later months.

Comparison of Group 2 and Group 3 strengths indicated a 20 percent reduction in the average tensile strength of the homogeneous polymer concrete (not shown in Figure 4). A small reduction (approximately 7 percent) was also present in the average tensile

bond strength of the polymer concrete composite. As is shown in Figure 4, Roadpatch and MPC specimens exhibited a negligible reduction in bond strength. On the basis of the trends in Group 2 and Group 3 average tensile strengths, it appears that Roadpatch and MPC are better choices for rapid-setting materials.

DIRECT SHEAR RESULTS

Considerable data variation was noted during Group 1 testing, which could have been the result of small specimen size or the difficulty experienced in tracking the load on the block or overlay specimens with load cell or strain indicator instrumentation. Although the results shown in Figure 5 exhibit CVs in excess of 17 percent, a general evaluation of the relative shear bond strengths can be made. A comparison of Figures 4 and 5 indicates that direct shear strengths generally parallel the tensile strengths of the composite cylindrical specimens with the exception of the MPC composite. This material exhibited good tensile bond strength but poor direct shear bond strength.

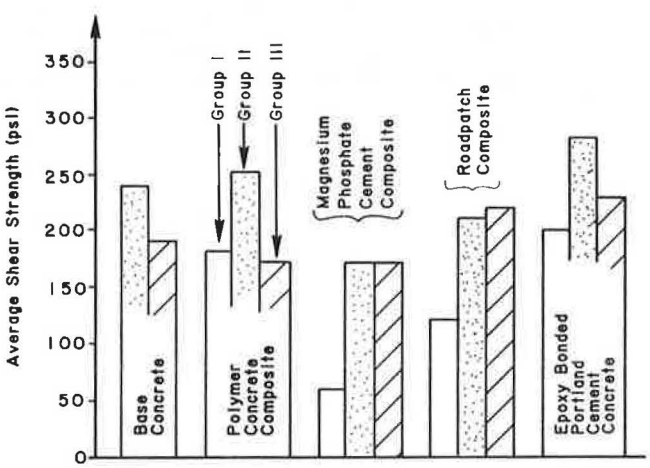

FIGURE 5 Direct shear strength results.

The shear bond strength of the composite epoxy-bonded concrete was very good, but undesirably long hardening time is a disadvantage with this material. On the basis of the differences in Group 1 direct shear results, polymer concrete appears to be the best choice.

A comparison of Group 1 and Group 2 results shows an increase in the average bond strengths with time. The Group 1 bonded composites exhibited average shear strengths in excess of those of the base concrete, although excessive curing time is required. Polymer concrete and Roadpatch test specimens exhibited average shear strengths comparable with that of base concrete.

The comparison of Groups 2 and 3 indicated that polymer concrete experienced a considerable loss (approximately 24 percent) of shear bond strength during the weathering process. The average shear bond strength of Group 2 and Group 3 MPC specimens was less than that of any of the other patching materials. The epoxy-bonded PCC displayed a weathered strength comparable with that of Roadpatch and a strength reduction (Group 2 versus Group 3) comparable with that of polymer concrete. Although significant variation was present in the results (CVs up to 30 percent), the relative performance of the Roadpatch material in the direct shear testing was good. It exhibited no loss in average bond shear strength and the data trend indicates that Roadpatch is the better choice on the basis of this criterion.

IMPACT TEST RESULTS

As is shown in Figure 6 for Group 1 tests, the polymer material had a higher average energy absorption capability than the other patching materials. The CV for these results was less than 8 percent. Roadpatch specimens (CV greater than 18 percent) also demonstrated a significant energy absorption capability. MPC composite specimens possessed low energy absorption capacity. The early age bond strength of MPC appears to be too low to dissipate energy in fracturing either the overlay (patching) material or base concrete. The specimens fractured through the bond line and the overlay broke away intact.

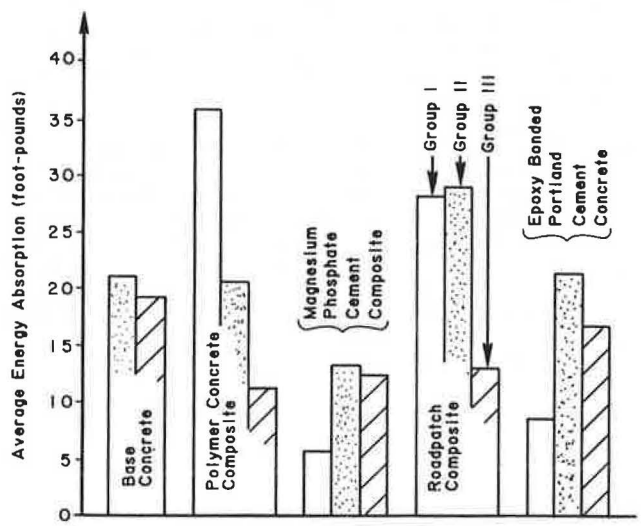

FIGURE 6 Average energy absorption results.

Group 1 epoxy-bonded PCC block and overlay specimens also had a very low energy absorption capability. Although this alternative demonstrated static strengths comparable with those of polymer concrete, low energy absorption capability would be undesirable for satisfactory field performance.

Roadpatch specimens exhibited the greatest average energy absorption capacity in the Group 2 results. MPC has a much smaller energy absorption capacity than any of the other patching materials. Group 3 data indicate that the energy absorption capabilities of polymer concrete and Roadpatch were severely reduced by exposure to the simulated weathering process. Both materials exhibited reductions of approximately 50 percent. Although MPC possessed the least unweathered energy absorption capacity, little deterioration was noted after exposure to simulated weathering.

CONCLUSIONS

The general conclusions concerning the relative performance of the patching materials are based on the trends in the laboratory results. Direct shear and impact test results exhibited significant scatter. Even with these discrepancies, an indication of shear bond strength and energy absorption capability

was evident. Consideration of the overall test results indicates that strength and bonding properties of the patching materials were directly related. Also, the durability of the homogeneous patching materials appears to be a good indication of the durability of their bond to base concrete.

Of the materials tested, polymer concrete exhibited the most ideal setting time. Polymer concrete appears to be the best of the materials tested in terms of early strength, which indicates that it would be suitable for making quick-patch repairs. However, polymer concrete displayed a relatively large loss of energy absorption capacity with age and a loss of strength after exposure to simulated weathering, which indicates a potential problem with long-term durability. Early age strengths and energy absorption capacities suggest that polymer concrete is probably the best choice of the materials tested for making rapid repairs to concrete pavements and bridge decks.

MPC does not appear to be an attractive early cure material. Comparison of early age strengths indicated that MPC had the least strength; it also had a very low energy absorption capacity. This material appears susceptible to damage from dynamic loading. However, an advantage of MPC is its thermal durability.

Early strengths of Roadpatch were relatively good. Test result trends indicated that the final cured strength and energy absorption capacity properties were the best of the rapid-setting materials tested. However, Roadpatch demonstrated a substantial loss of energy absorption capacity after simulated weathering, which may be indicative of a long-term durability problem.

Epoxy-bonded PCC patching materials used in this study are not recommended because the rate of strength gain of the epoxy adhesive and that of PCC were both too slow for completing a field patching repair within 1 working day. However, because the strengths of the test specimens were substantial and the energy absorption capacity and durability properties also were good as compared with those of other material alternatives, additional effort should be made to identify or develop a fast-curing epoxy and PCC mixture design. For situations in which rapid-setting time is not critical, this alternative, as tested in this study, is satisfactory.

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