POLYMER CONCRETE OVERLAY TEST PROGRAM


Interim Report


by

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Conducted by

Oregon State Highway Division
Materials and Research Sections


In Cooperation with

US Department of Transportation
Federal Highway Administration


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# PREFACE

The views and findings expressed in this report are
those of the authors  and do not express the official views
of the Oregon State Highway Division nor the Federal Highway
Administration.  This report should not be construed as an
endorsement nor rejection of any product used in the polymer
concrete development.

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16. Abstract

This report describes work done on various combinations of monomers and polymer concrete mixes and identifies the mixes showing the greatest potential for use in bridge deck overlays. Presented are test results showing physical properties of various polymer concrete mixes, such as compressive strength, split tensile strength, modulus of elasticity, thermal coefficient of expansion, and shrinkage coefficient. The effects of polymer content, work time, and temperature on various properties are also discussed.

The development of two polymer concrete systems with excellent membrane potential are described along with the details of bonding characteristics of several systems.

Finally, a polymer concrete mix with suitable properties for deck and pavement patching is detailed.

Due to the positive results of the laboratory work on the polymer concrete overlay systems, an experimental field installation is recommended.

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A number of studies have been conducted during the past few years in which concretes have been modified through the use of monomers which were subsequently polymerized. Most of this development involved the impregnation and polymerization of cured portland cement concrete, a treatment resulting in several remarkable improvements in properties. (1, 2, 3).

The favorable effects of using polymers in portland cement concrete led to an interest in developing polymer concrete, a mixture in which the polymer provides the total binder for the aggregates. Interest in this development was fostered to a major extent by the need for an impermeable, high-strength, quick setting material for structural overlays on bridge decks. The major problems to be corrected with overlays include the protection against corrosion of reinforcing steel due to moisture and deicing chlorides, vibrations due to frequent and heavy axle loads, and excessive deflections due to insufficient deck thickness. The extended closure required during the curing of portland cement concrete can cause intolerable congestion and delay to traffic. The polymer concretes can develop adequate strengths within a few hours to carry normal traffic if the material can be mixed and placed quickly. As the material is modified to extend the time for mixing and placing, the cure time is also extended; perhaps requiring 24 hours to gain adequate strength.

The subject of this report is the developmental work done by the Oregon State Highway Division under the sponsorship of the Federal Highway Administration. Principal aspects of the study involved working with aggregate gradations to minimize the voids and with several combinations of monomers, catalysts and promoters to achieve physical characteristics suitable for field placement service.

Compressive strengths of polymer concrete mixes and shear bond strength between overlay and substrate concrete have received particular emphasis in the study, but other characteristics were evaluated as well. Data were obtained on split tensile strength, permeability, shrinkage, thermal expansion, modulus of elasticity, workability, gel time of monomers, and effect of placement delay or work time availability.

One binder studied was a monomer blend containing 95 percent methyl methacrylate (MMA) and 5 percent trimethylol propane trimethacrylate (TMPTMA) with a benzoyl peroxide catalyst and dimethylaniline promoter. Polymer concrete mixtures that used this MMA monomer had excellent compressive strengths when cast in 3-in.-by-6-in. cylinders. When used as an overlay, however, the Oregon tests found excessive evaporation of the surface monomer left a texture that would be expected to abrade under traffic. Protection against this evaporation and thickening of the polymer to get a thicker film on aggregates seems necessary for satisfactory service from MMA mixes. Other investigators have reported satisfactory overlay mixes using MMA monomer where they have provided protection against evaporation through the use of a plastic sheet.

The binder that has been used most extensively in the Oregon developmental work is a polyester-styrene (PES) blend containing 23 percent styrene, 38.5 percent GR511, and 38.5 percent GR941. The GR511 is a flexible polyester and GR941 is a rigid polyester; both are products of the Marco Division of the W. R. Grace Company. Some mixtures utilized slightly different proportions, but all contained the same ingredients. Generally, the PES mixes have been polymerized by using equal amounts of methyl ethyl ketone peroxide as a catalyst and cobalt napthenate as a promoter. The amount of catalyst and promoter has been varied within the range of 2.5 percent of each to 0.3 percent of each by weight

of monomer. The higher percentages of catalyst and promoter yielded polymer concretes having excellent properties providing the mixtures could be placed and finished within 10 minutes. To extend the time available for placement, reduced percentages of catalyst and promoter were utilized with limited success. Subsequently, an inhibitor was utilized which effectively delays gel time with only minor reduction in early strength.

It was the intent of the investigation to evaluate any polymer binder that appeared promising for polymer concrete. The only proprietary product of this type that was located during the project is marketed as "Radgrout"; a product of Radiation Technology Incorporated of Rockaway, New Jersey. Results of tests are reported for polymer concrete mixes in which Radgrout served as a binder.

A silane coupling agent has been added to the monomers in most of the trial mixes for the purpose of gaining a chemical bond between the polymer and the aggregate in addition to the physical bond. The additive provides a molecular link between the silica in the aggregate and the polymer.

The monomers used in the studies have low viscosities and there is a tendency for them to drain from the aggregate at the surface before polymerization occurs. To stabilize the material, some use was made of Bentone to increase the initial viscosity and prevent this drainage. In other cases, portland cement was used as a filler in the aggregate and it served to prevent excessive drainage of the binder. It also increases the surface area to be coated with accompanying increased binder quantity requirements.

Due to the relatively high cost of monomers, developmental work has been approached with a view toward minimizing the amount of binder required in the polymer concrete mixtures. Emphasis was placed on developing aggregate

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gradations that would minimize the voids to be filled by the polymer binder. For mixes placed promptly after mixing, about 8.5 percent polyester-styrene by weight of aggregate provided a polymer concrete having generally satisfactory properties. Methyl methacrylate blends required about 10 percent binder by weight of aggregate to make a satisfactory mix for cylinders cast promptly after mixing. Recent tests indicate it may be necessary to increase the amount of polymer in each system to provide impermeable, abrasion-resistant material. Another advantage of using the slightly higher polymer content is that workability of the concrete mass is increased. The recent acquisition of an inhibitor that would extend the PES work time to 1-1/2 hours was considered a major accomplishment. Results show cylinders made in the laboratory with 1-1/2 hours of placement time had an average ultimate compressive strength of 7,400 psi in 28 hours. More work must be done, however, to determine the effect of inhibitor on gel time at various temperatures.

Most of the trial batches were mixed by hand using a large bowl and spoons. A Hobart mixer was used on some of the small batches mixed earlier in the study. A procedure for handling and mixing the chemicals, which was prepared for personnel totally unfamiliar with polymer chemistry, is included in Appendix A. Information on the proportions used and the purpose of the various test batches is tabulated in Appendix B.

Additional details of the characteristics and properties of various polymer concrete mixtures are presented in the discussions of the different tests which follow. Throughout this report the monomer content is expressed as a percentage by weight of the aggregate and not of the total mix, in keeping with the Hveem method of asphalt concrete design.

## Aggregate Gradation Study

In order to develop the most economical polymer concrete mix, a study was conducted to obtain an aggregate gradation that would minimize the amount of polymer required as a binder. In comparison with asphalt cement or portland cement binders, the polymer concrete costs are sensitive to the amount of polymer required.

Approximately 60 tests were made on 1/2-in.-minus natural gravels to arrive at a gradation giving minimum voids in dry-rodded samples. Three fine-grained fillers; portland cement, cottrell flour and pozzolan, were included in some of the tests. Portland cement was selected as a filler material for the polymer concrete development because of its uniform grain size and also because it was more easily obtainable. The effectiveness of cement in reducing voids in the dry-rodded aggregate appears in Table 1. Although the minimum void content was found at 14 percent cement, 6 percent cement was selected for the standard mix proportion (gradation VIII-c) since additional filler contributed significantly to the surface area to be coated with only a minor increase in density.

Some work was done with crushed aggregates to determine the optimum gradation for maximum density. However, because of the harshness of the crushed material in working with the small samples, only the natural gravels were used in the polymer concrete mixtures.

A study was also made on gap-graded aggregates, again in an attempt to reduce the void volume. Minimum voids of 18 percent were obtained, a trifle lower than for uniformly graded aggregate with cement filler, but not low

## TABLE 1

### MAXIMUM DENSITY TRIALS
### UNIFORM GRADATION
### NATURAL GRAVEL, NATURAL SAND, PORTLAND CEMENT

|  | VII-d | VIII-a | VIII-b | VIII-c | VIII-d | VIII-e | VIII-f | VIII-g | VIII-h | VIII-i | VIII-j |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % Retained 1/2 in. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| % Retained 3/8 in. | 13.5 | 13.23 | 12.96 | 12.69 | 12.42 | 12.15 | 11.88 | 11.61 | 11.34 | 11.07 | 10.8 |
| % Retained 1/4 in. | 16.5 | 16.17 | 15.84 | 15.51 | 15.18 | 14.85 | 14.52 | 14.19 | 13.86 | 13.53 | 13.2 |
| % Retained #4 | 20.0 | 19.6 | 19.20 | 18.80 | 18.4 | 18.0 | 17.8 | 17.2 | 16.8 | 16.4 | 16.0 |
| % Pass #4 (Sand) | 50.0 | 49.0 | 48.0 | 47.0 | 46.0 | 45.0 | 44.0 | 43.0 | 42.0 | 41.0 | 40.0 |
| % Cement | 0.0 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 | 12.0 | 14.0 | 16.0 | 18.0 | 20.0 |
| % Voids | 22.01 | 21.64 | 20.46 | 19.37 | 19.03 | 18.67 | 18.47 | 18.36 | 18.52 | 19.27 | 20.60 |

enough to make it economically desirable to separate and reblend the material. More work is planned with the aggregate gradation.

## Workability Tests

In order to measure the workability of various polymer concrete mixes, sets of six 2-in. cubes were molded. Evaluation of the stiffness during mixing and placing and the difficulty in finishing were recorded at 5 minute intervals. The cubes were then allowed to cure for 24 hours and tested for comparative compressive strength. Tests were conducted at room temperature (72F - 75F) and also at reduced temperatures of 56F and 60F.

The amount of time required to mix, place, and finish (work time) had a significant effect on the ultimate strength and the ability to finish the polymer concrete smoothly. As placement delay was increased, the mix became stiff and the compressive strength decreased (see Figures 1, 2, 3). The modulus of elasticity test indicates a 30 minute work time is too great for the proportions used in the mix tested.

The ease of mixing and placing was generally increased as the amount of liquid binder was increased. Mixes with a polymer content of 10 percent or more had a tendency to bleed during finishing, leaving an excessive amount of liquid at the surface. Once polymerized, the excess liquid formed a smooth glassy surface. Crushed stone could, however, be embedded into this surface if it were necessary to provide an anti-skid surface in the field.

Work time has been extended with the introduction of hydroquinone as an inhibitor. The time available for placing the mixes has been extended to 1-1/2 hours in the laboratory at 75F.

Temperature also had an effect on workability. At lower temperatures uninhibited mixes had a greater mobility up to a 20 minute work time. After 20 minutes, however, the mixes stiffened quite rapidly and at 40 minutes there was little difference between finishing at 56F or at 75F. Studies are being planned to find the effect of inhibitor on work time and compressive strength at various temperature levels.

## Compression Tests

Early results from compression tests conducted on cylinders and cubes indicate that the strength of a polymer concrete is dependent on factors such as the amount of polymer used as the binder; work time in mixing, placing, and finishing; and the temperature at which it is mixed, placed, and cured. Later tests with an inhibitor showed the total allowable work time could be extended to 1-1/2 hours without apparent loss of compressive strength. Aggregate gradation VIII-c, shown in Table 1, was used in the mixes for all tests reported.

To compare strengths at different polymer contents, compressive tests were conducted on samples containing 8-1/2 percent and 10 percent polymer (by weight of aggregate). Cylinders tested at 7 days had a compressive strength of 10,300 psi for the 10 percent mix, while a compressive strength of 8,100 psi was obtained for the 8-1/2 percent mix. These samples had work times under 10 minutes.

Tests were also made to study the effect on compressive strength when work time was extended. Ultimate compressive strengths of over 5,000 psi for uninhibited specimens were consistently recorded with 8-1/2 percent PES mixes

-8-
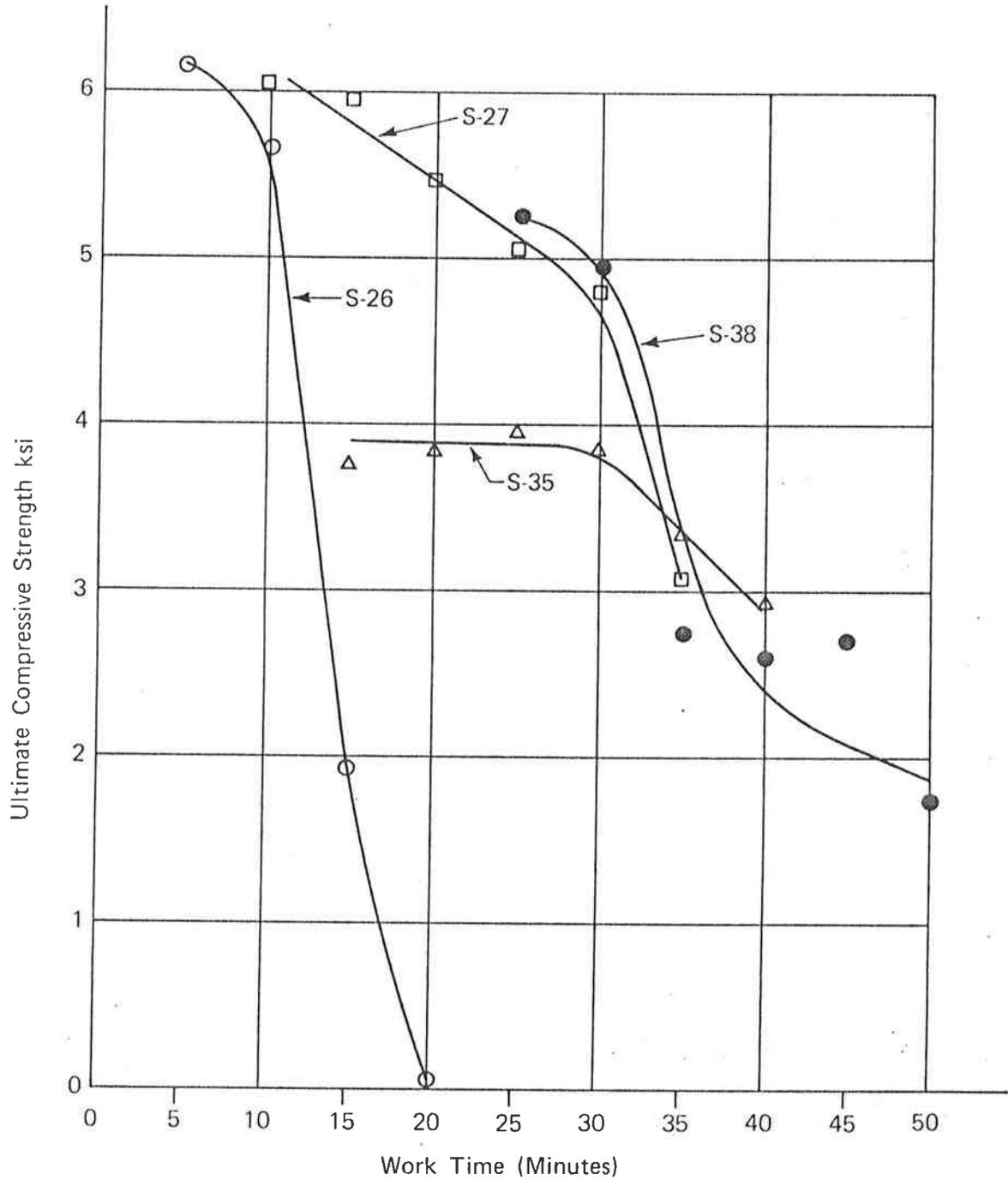
Figure 1. Ultimate compressive strength vs. placement delay.
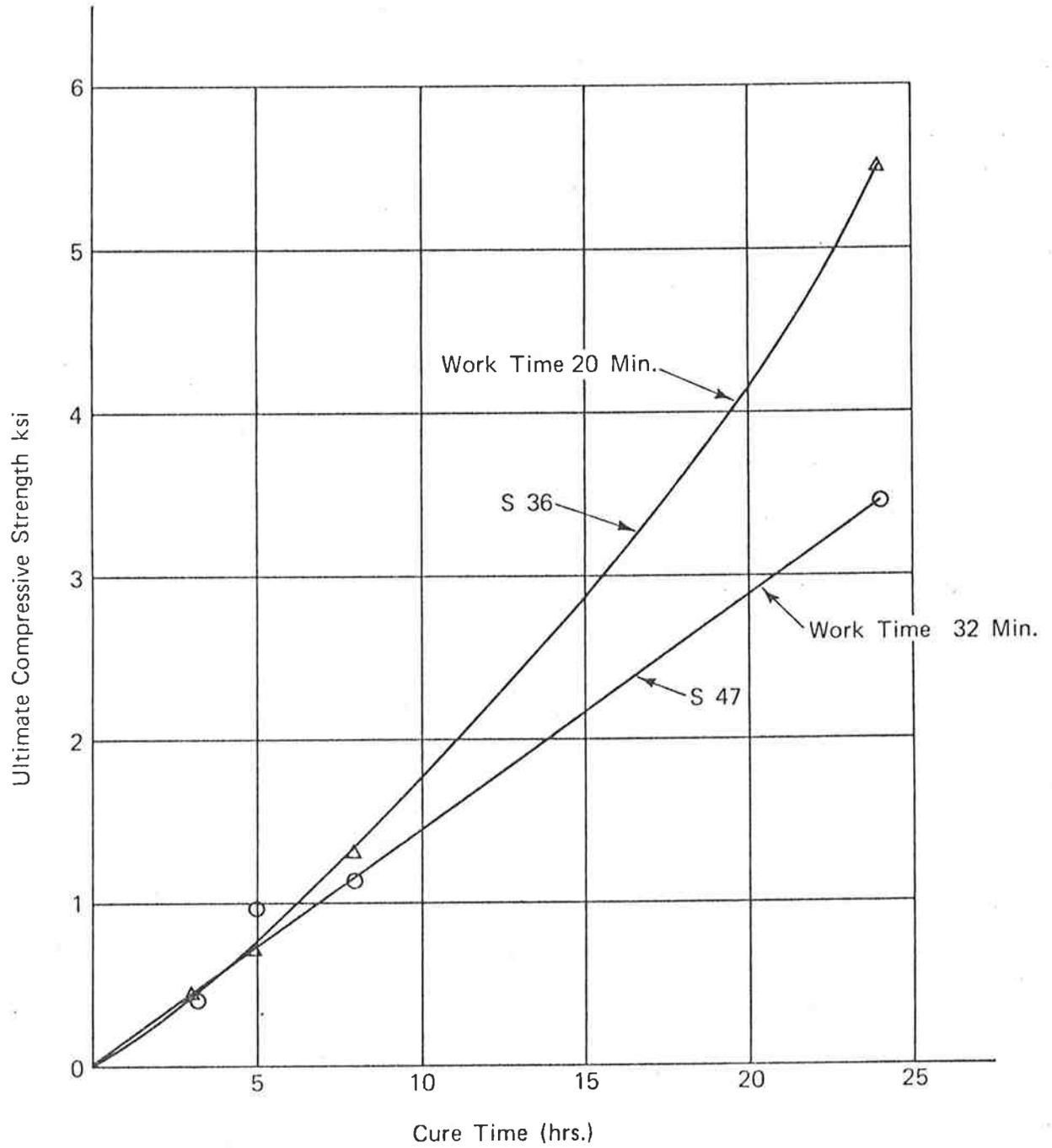
Figure 2. Ultimate strength, cure time and work time compared.

2" Cubes

8½% PES

24 hr. Cure

───── 1.5% Catalyst
& Promoter

─ ─ ─ ─ 0.5% Catalyst
& Promoter

S 27
@ 72F

S 55
@ 75F

S 54
@ 56F

S 50
@ 60F

Ultimate Compressive Strength ksi

Work Time (Minutes)

-11-
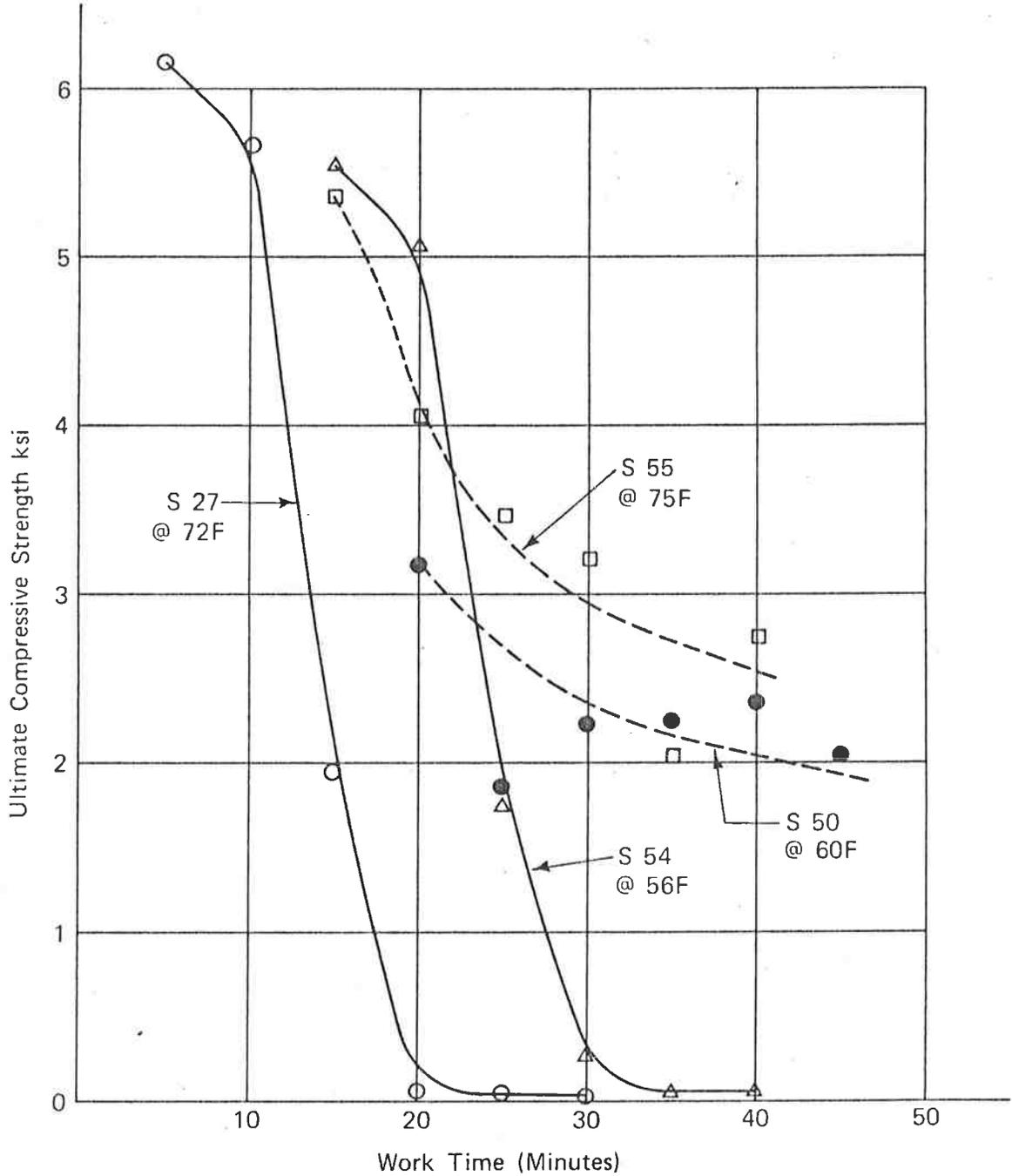
Figure 3. Effect of catalyst-promoter and mixing temperatures on ultimate strength vs. work time.

when the work time was under 10 minutes and the polymer concrete was allowed to cure for 24 hours. As the work time was extended to 25 minutes, however, compressive strengths dropped to 3,000 psi. Work was done with a mix containing an inhibitor to extend the allowable work time of the polymer concrete. A mix containing 10 percent resin was mixed and placed in cylinders at 30, 60, and 90 minutes. Based on the weight of the resin, the mix had 2 percent catalyst, 1 percent promoter, 2 percent silane and 450 ppm of hydroquinone inhibitor. After a 24 hour cure at room temperature these cylinders showed ultimate compressive strengths of 7,820 psi, 8,490 psi, and 7,980 psi respectively, indicating a successful extension of work time.

The effect of ambient temperature during mixing, placing, and curing of uninhibited polymer concrete was investigated at two temperature levels; room temperature, and a range of 56F to 60F. All mixes contained 8-1/2 percent polyester-styrene, but two were catalyzed and promoted at 0.5 percent while two were catalyzed and promoted at 1.5 percent. The work time was varied from 5 to 40 minutes while the cure time to test remained constant at 24 hours. Results comparing these variables are shown in Figure 3. Two mixes containing 1.5 percent catalyst and promoter were initially examined. The mix that was cast and cured at 72F (Mix S27) had a compressive strength of 5,700 psi with a work time of 10 minutes, and only 100 psi with a work time of 20 minutes. The specimens that were cast and cured at 56F (Mix S54) had a compressive strength of 5,000 psi with a 20 minute work time and 200 psi with a 30 minute work time.

The results from the 0.5 percent catalyzed and promoted specimen tests were somewhat different. A sample that was cast and cured at 75F (Mix S55) had a compressive strength of 4,000 psi with a work time of 20 minutes, and 3,000

psi with a 30 minute work time. Another mix, (Mix S50) also catalyzed and promoted at 0.5 percent, but cast and cured at 60F, had a compressive strength of 3,100 psi with a 20 minute work and a 2,200 psi compressive strength when placed in 30 minutes.

These results indicate that an uninhibited mix containing 1.5 percent catalyst and promoter sets up too rapidly to be used as a batch-mixed overlay even at lower temperatures. From test results seen to date, small amounts of work time can be gained by varying the amount of catalyst and promoter, at the expense of compressive strength. The use of the inhibitor, however, can provide work time to 1-1/2 hours with no apparent decrease in strength. More work is planned to study the correct proportion of catalyst, promoter and inhibitor to be used at various temperature levels.

A polyester-styrene mix containing 10 percent binder with 1.5 percent catalyst and 1.5 percent promoter was examined in the laboratory as a patching material. Allowing a work time of 5 minutes, strengths above 3,000 psi were recorded in 3 hours at room temperature. A 5 hour cure time produced compressive strengths of over 6,000 psi. These values, shown in Figure 4, indicate this particular mix is well suited for patching in warm weather with a minimum work time. Two patches have been placed in the field containing a small amount of inhibitor to slightly prolong gel time. The mixing, placing, and finishing of each polymer concrete patch was accomplished in 15 minutes. Eighteen minutes after finishing, traffic was allowed over the patches. Cylinders that were cast from these mixes had compressive strengths of over 7,000 psi in 5 hours. For components and proportions for this mix see the Implementation Package contained in this report.

10% PES (Patch Material)
1½% Catalyst
1½% Promoter
5 Min. Work Time
Temp. 74°
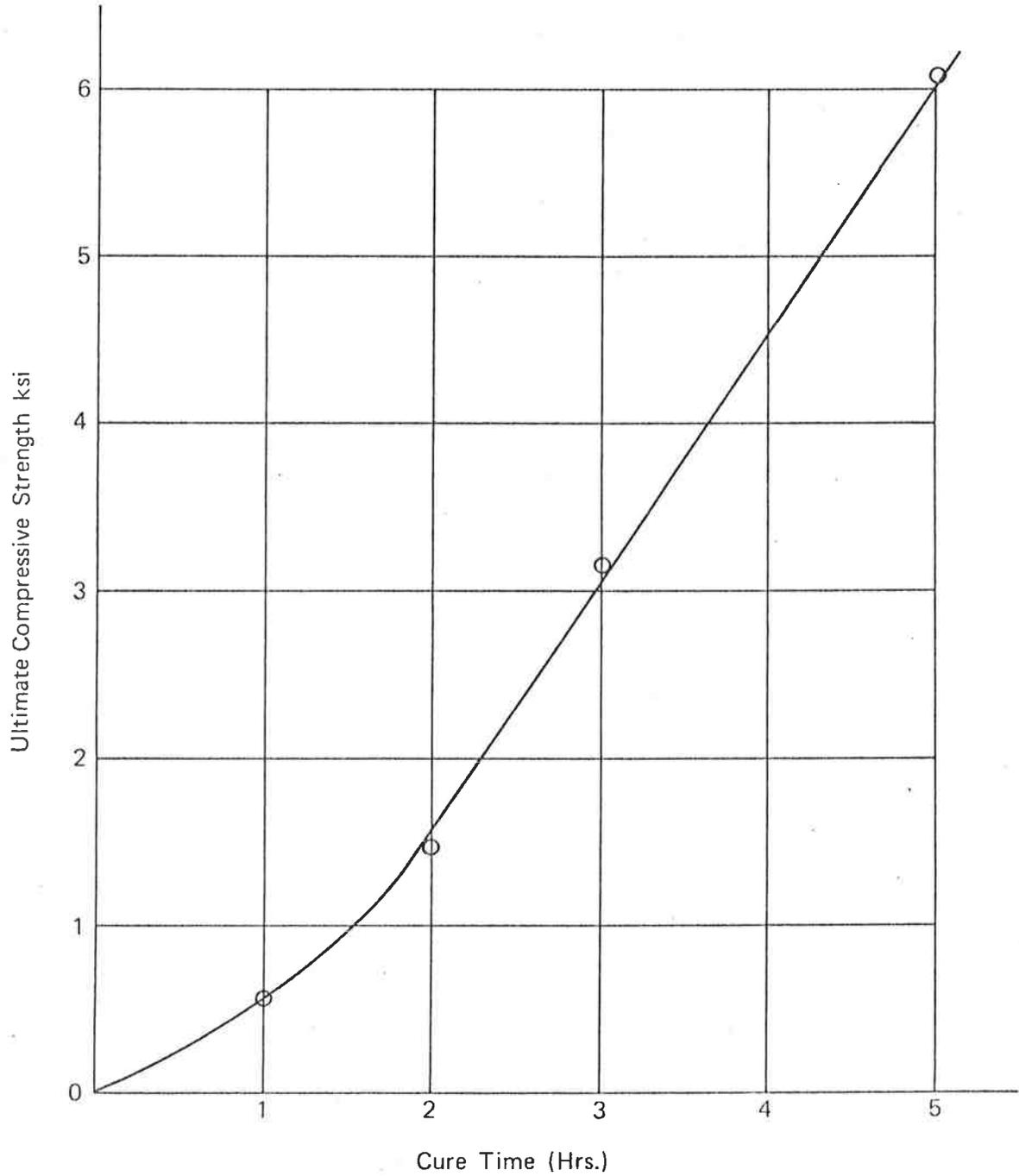
Figure 4.  Ultimate strength vs. cure time for PES patching material.

## Bond Tests

The successful application of an overlay depends on its ability to adhere to an existing concrete surface. The criteria established for the polymer concrete overlays was to have a minimum bond shear strength with the substrate of 200 psi when tested in shear by applying a force parallel to the interface. (4, 5)

During this study, polymer concretes with three different binders were tested. Included were methyl methacrylate, a polyester-styrene blend, and a proprietary mix called Radgrout. These mixes were placed on 6-in.-by-6-in.-by-21-in. portland cement concrete beams that had been previously cast and cured. After allowing a 24 hour cure time for the polymer concrete mix, 4-in. diameter cores were taken through the beams and the bond shear strength immediately determined. Complete results of the bond tests are shown in Table 2.

During the early testing period, the polymer content was varied within the range of 8 to 14 percent in different mixes, and overlays were placed on surfaces that had been prepared by wire brushing only. Initially, no tack coat was used because it was expected an adequate amount of polymer would drain from the overlay to provide bond at the interface. This procedure did not provide consistently high bond strengths between the substrate concrete and the overlay.

The procedure was modified by sandblasting the surface and by utilizing various monomer tack coats, both promoted and unpromoted. Results of tests show the use of a promoted tack coat on a sandblasted surface produced consistently high bond values. With this procedure, failures in the bond shear test were typically in the substrate concrete and not at the interface, thus assuring adequate bond. Average bond values in excess of 400 psi were obtained. Tack

TABLE 2

BOND TEST RESULTS

| TEST NO. | POLYMER MIX Type | % | SURFACE PREP. | TACK COAT | CURE TIME | BOND STRENGTH PSI CORE NUMBER | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 |
| M-7B | M | 12 | Wire Brush | None | 24 hr. | 16 | SO | SO | SO |
| S14B | PES | 12 | Wire Brush | None | 48 hr. | 357 | 143 | 76 | SO |
| S-15B | PES | 10 | Wire Brush | None | 24 hr. | 505 | 444 | 517 | 388 |
| S-16BC | PES | 10 | Wire Brush | None | 96 hr. | 215 | 181 | SO | SO |
| S-17B | PES | 10 | Wire Brush | None | 7 hr. | 142 | SO | SO | SO |
| S-18B | PES | 9 | Wire Brush | 15 Mils Unpromoted | 24 hr. | 72 | SO | SO | SO |
| S-19B | PES | 8 | Wire Brush | 50 Mils Unpromoted | 24 hr. | 454 | 267 | --- | --- |
| S-20B | PES | 8-1/2 | Wire Brush | 50 Mils Promoted | 24 hr. | 321 | 326 | --- | --- |
| S-21B | PES | 8-1/2 | Wire Brush | 20 Mils Unpromoted | 24 hr. | SO | SO | --- | --- |
| S-25B | PES | 8-1/2 | Wire Brush | 35 Mils Promoted | 24 hr. | 551$^+$ | 409$^+$ | 456$^+$ | 461$^+$ |
| S-28B | PES | 8-1/2 | Sandblasted | 15 Mils Promoted | 24 hr. | 519$^+$ | 452$^+$ | 347$^+$ | 556$^+$ |

Legend: M = Methyl methacrylate
PES = Polyester-styrene

SO = Spun off during coring
+ Indicates failure in core and not at interface

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TABLE 2
(Continued)

| TEST NO. | POLYMER MIX Type | % | SURFACE PREP. | TACK COAT | CURE TIME | BOND STRENGTH PSI CORE NUMBER | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 |
| S-29B | PES | 8-1/2 | Sandblasted | 35 Mils Promoted | 24 hr. | 503+ | 534+ | --- | --- |
| S-30B | PES | 8-1/2 | Sandblasted | 50 Mils Promoted | 24 hr. | 258+ | 239+ | 454+ | 375+ |
| S-31B | PES | 8-1/2 | Sandblasted | 15 Mils Unpromoted | 24 hr. | 402 | 659 | 557 | 724 |
| S-32B | PES | 8-1/2 | Sandblasted | 35 Mils Unpromoted | 24 hr. | 258 | 162 | --- | --- |
| S-33B | PES | 8-1/2 | Sandblasted | 50 Mils Unpromoted | 24 hr. | 185 | 446 | 463 | 237 |
| S-41B | PES | 8-1/w | Sandblasted Wet Surface | 35 Mils Promoted | 24 hr. | 364+ | 455+ | 450+ | 352+ Dir. Ten. |
| S-42B | PES | 8-1/2 | Sandblasted Sandblasted | 15 Mils Promoted | 24 hr. | 643 Oil | 297 Oil | 312+ Dir. Ten. | --- |
| S-45B | PES | 8-1/2 | Sandblasted Acid Solution | 15 Mils Promoted | 24 hr. | SO Oil | SO Oil | 402+ | 404+ |
| S-46B | PES | 8-1/2 | Sandblasted TSP Solution | 15 Mils Promoted | 24 hr. | SO Oil | SO Oil | 582+ | 507+ |
| S-51B | PES | 8-1/2 | Sandblasted Sandblasted | 15 Mils Promoted | 24 hr. | 497+ Oil | 533+ Oil | 540+ | 434+ |

Legend:  PES = Polyester-styrene
Oil = Motor oil placed on end of concrete beam (Cores 1 and 2)
SO = Spun off during coring

+ Indicates failure in core and not at interface
Dir. Ten. = Direct tension test
Sandblasted / Acid Solution = Bm. initially cleaned by sandblasting = Bm. cleaned by acid solution after being contaminated by oil

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TABLE 2
(Continued)

| TEST NO. | POLYMER MIX Type | % | SURFACE PREP. | TACK COAT | CURE TIME | BOND STRENGTH PSI CORE NUMBER | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 |
| RG-3B | RG | 10 | Wire Brush | None | 96 hr. | 70 | 155 | SO | SO |
| RG-4B | RG | 12 | Wire Brush | None | 96 hr. | SO | SO | SO | SO |
| RG-5B | RG | 14 | Wire Brush | None | 96 hr. | SO | SO | SO | SO |
| RG-6B | RG | 10 | Sandblasted | 15 Mils Promoted | 24 hr. | 667 | 538 | 235 Dir. Ten. | 572 |
| RG-7B | RG | 10 | Sandblasted | 35 Mils Promoted | 24 hr. | 570 | 652 | $325^{+}$ Dir. Ten. | 670 |

Legend:  RG = Radgrout
SO = Spun off during coring

+ Indicates failure in core and not at interface
Dir. Ten. = Direct tension test

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coat thicknesses of 15 mils, 35 mils, and 50 mils were used in different tests. The thickness of the tack coat did not appreciably effect the bond strength as the 15, 35, and 50 mil promoted tack coats performed equally well. Tack coat tests were not performed with the methyl methacrylate mixes because it was decided that evaporative and viscosity problems had to be solved for these mixes before they would make a suitable overlay.

To ensure the repeatability of bond values under field conditions, various cleaning methods were tested on oil contaminated beams. The cleaning methods used were: (1) sandblasting; (2) washing with a dilute acid solution; and (3) washing with a tri-sodium-phosphate solution. Sandblasting provided the only satisfactory result.

A test was also made to determine the effects of moisture on bonding. In Test S41, a beam was water soaked until 30 minutes before the application of a 35 mil promoted tack coat and a 1-1/2-in. overlay. Results indicate this amount of moisture has little effect on the bond value with this system.

To confirm the results of the successful bond shear tests, a direct tension force was employed by means of a dynamometer to two polyester-styrene and two Radgrout overlays. Results exceeded 200 psi in tension, indicating a satisfactory bond. Failure in three of the four tests occurred in the base concrete at values over 300 psi.

A Radgrout mix was also tested for shear bond and as in the polyester-styrene mixes, overlays with tack coats performed satisfactorily. Values of over 500 psi in shear bond were recorded.

## Permeability Test

An electrical resistance procedure was used to determine the permeability of the polymer concrete overlays. In this method, the electrical resistance of 1 sq ft of deck surface overlay is measured with respect to reinforcing steel embedded in the portland cement concrete substrate. Reports show a very good or impermeable waterproofing system will always have an average electrical resistance greater than 500,000 ohms per sq ft, while a poor or permeable system would never have an average resistance greater than 100,000 ohms. (6)

Test slabs measuring 1.5 ft square and 4-in. thick, containing two No. 4 bars with 1-1/2-in. of cover, were cast and cured. A 1-1/2-in. polymer concrete overlay containing 8-1/2 percent polyester-styrene (by weight of aggregate) was placed on a slab with a 15 mil tack coat. The overlay was allowed to cure for 48 hours before testing. Within minutes after wetting the surface, the resistivity dropped from infinity to 40,000 ohms. At first it was suspected that the polymer concrete was a conductive material, but further tests indicated it to be non-conductive and permeable.

A tack coat of 50 mil average thickness was then applied to a second slab to determine the value of a thick tack coat alone as a membrane. Again, upon wetting, the resistivity dropped from infinity to 40,000 ohms indicating a porous material.

A system using two separate 15 mil tack coats and a 1-1/2-in. overlay was next investigated. As before, an 8-1/2 percent polyester-styrene mix was used for the overlay. The first tack coat was applied and allowed to cure before the placement of the second tack coat and the overlay. The overlay and

second tack coat were allowed to cure for 48 hours. The system was then subjected to surface soaking by means of a sponge. After 3 hours of testing, the resistivity registered over 10,000,000 ohms indicating an excellent membrane. It is suspected that water penetrated the 1-1/2-in. overlay, but was prevented from reaching the concrete slab because of the two tack coats.

A test was conducted in an attempt to reduce the void content by increasing the polymer content. In this test a 1-1/2-in. overlay containing 10 percent polyester-styrene was placed on a slab with a single 15 mil tack coat. As before, a 48 hour cure time was allowed before commencing the permeability test. The overlay was then soaked continuously for 2 hours with water containing "Calgon", a wetting agent. The resistivity measurements indicated a resistance of over 10,000,000 ohms, denoting an impermeable membrane.

The results from these latter trials indicate that a polymer concrete overlay can be designed for use as a membrane to prevent the penetration of chlorine ions into existing concrete decks.

## Split Tensile Test

Three cylinders that had previously been subjected to five cycles of a freeze-thaw test in air were tested for split tensile strength. These cylinders were an 8-1/2 percent polyester-styrene mix (Mix S27) with 1.5 percent catalyst and promoter and a work time of 5 minutes. Results indicate that this polymer combination had a tensile strength exceeding 1,500 psi, a value over three times that of conventional structural concrete. Further tests are planned to correlate the effect of increased work time, decreased percentage of catalyst and promoter, and the relationship of tensile strength to compressive strength.

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## Freeze-Thaw Resistance Test

Six 2-in. cubes of 8-1/2 percent polyester styrene (Mix S34) were cast and allowed to cure for 24 hours. The cubes were then frozen in air at -10F and thawed in water at 68F. Two complete cycles were accomplished each day, with the freezer portion of one cycle extending overnight. At the end of sixty cycles, a loss in weight of 1 percent was recorded. The cubes appeared to be losing fine-sand particles when rubbed with the hand. Some segregation occurs in casting the small cubes, and it is believed this contributes to the freeze-thaw loss. Also, the many edges on a cube and the difficulty in obtaining compaction reduce resistance to loss in such a test. Because of the undesirable features associated with the 2-in. cubes, cylinders will be used in future freeze-thaw resistance tests.

## Modulus of Elasticity Test

Two samples of 8-1/2 percent polyester-styrene concrete were cast in 6-in.-by-12-in. cylinders. Work time was varied to study its effect on elasticity. The first mix was placed and finished in 12 minutes and then tested at 24, 90, and 168 hours. The modulus of elasticity increased from $1.8 \times 10^6$ psi in 24 hours to $2.6 \times 10^6$ psi in 168 hours when loaded to a maximum stress of 3,000 psi (Figure 5). The second sample was mixed, but the placing and finishing were delayed for 30 minutes total work time. This sample was then tested at 24 and 72 hours. The 24 hour test had to be curtailed at a stress level of 1,400 psi because of excessive strain. During the 72 hour test, the cylinder failed at 1,730 psi with a corresponding E value of $0.4 \times 10^6$ psi. It is apparent from the results of this second sample that polymerization was initiated before
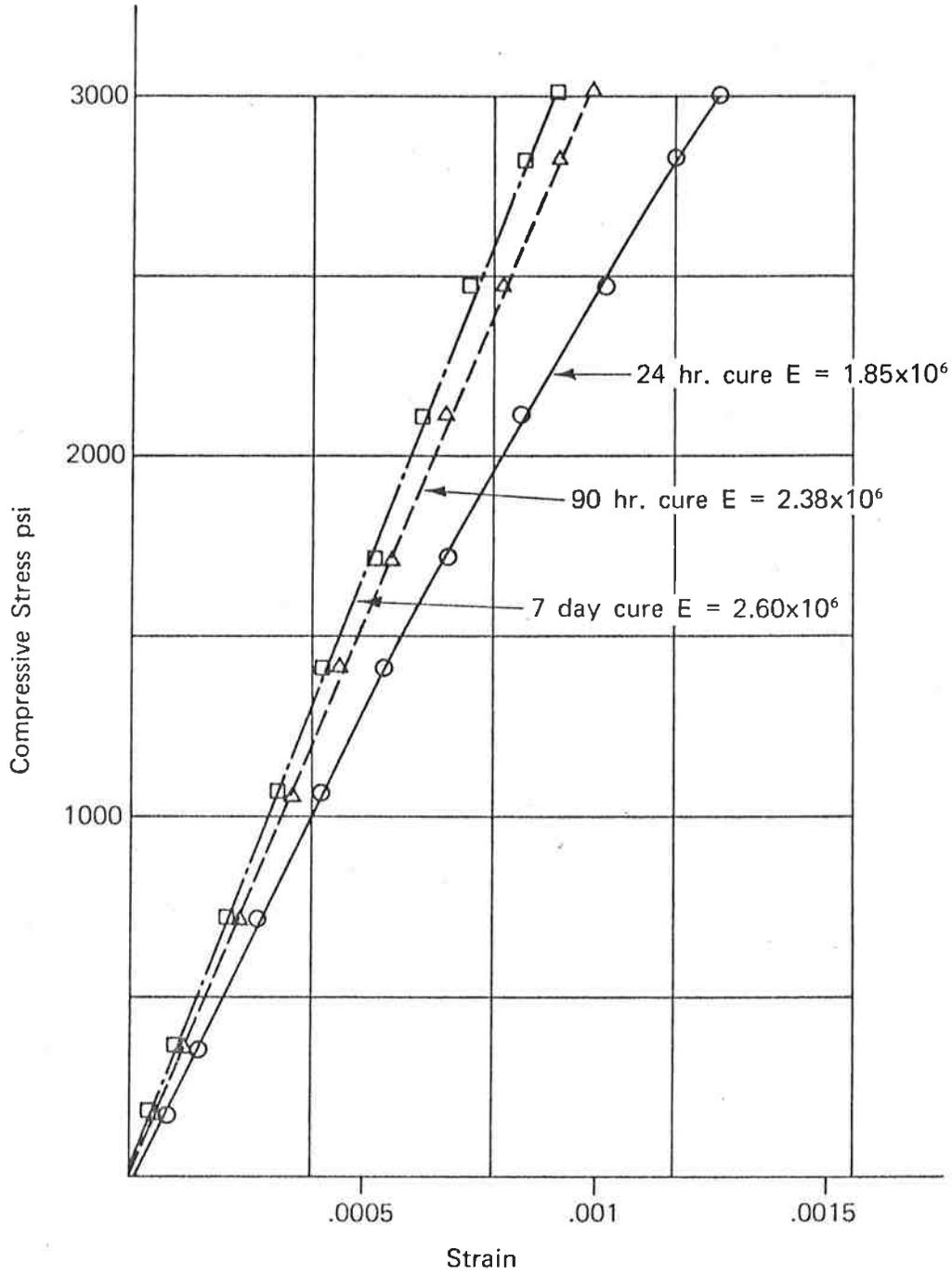
Figure 5. Modulus of elasticity at different cure times.

the material was placed in the cylinder mold.  The large reduction of the modulus

of elasticity and the early failure of the cylinder clearly indicate the need

of an inhibitor to extend work time.

### Thermal Coefficient Test

Three 3-in.-by-6-in. cylinders (Mix S27) of 8-1/2 percent polyester-
styrene concrete were cast and cured for 7 days at room temperature.  Measure-
ments of length were made at room temperature, 140F, and -10F.  Results show
this mixture to have a non-linear coefficient of thermal expansion.  From room
temperature to -10F, the average value for the three cylinders was $7.8 \times 10^{-6}$
in./in./F while from room temperature to +140F the average coefficient was
$9.8 \times 10^{-6}$ in./in./F.

Readings at intermediate temperatures are required to clearly define
the true temperature coefficient curve, but this was not done during this test.
Further investigation is planned to determine the thermal coefficient at inter-
mediate temperatures and also to determine the effect of increased polymer
content on the thermal coefficient.

Although somewhat higher than the thermal coefficients normally
associated with portland cement concrete, the difference is not expected to
cause trouble with overlays.

### Shrinkage Test

Shrinkage studies were made on four mixtures utilizing a polyester-
styrene binder.  Initially, samples were cast containing 8-1/2 percent and 10
percent of polymer, with 1.5 percent catalyst and promoter.  Measurements began
after 3 hours and continued for 14 days while the samples remained in their

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molds. Of the three cylinders cast for each mix, one was placed permanently

in a measuring apparatus while the others were measured and removed after

each reading. At the end of 14 days, the samples were removed from their

molds and measured for an additional 14 days. While in the molds, the shrink-

age was quite low and had apparently stabilized after 5 or 6 days. During the

first 24 hours after removal from the molds, however, a dramatic additional

shrinkage occurred for both mixes. This was followed by a shrinkage at a dimin-

ishing rate for several more days. Results show the amount of shrinkage is

affected by the amount of binder used. The total shrinkage strain after 28 days

was 0.00121 for the 10 percent mix and 0.00093 for the 8-1/2 percent mix.

Two additional samples were cast, each containing 8-1/2 percent of

polymer binder, but with varying amounts of catalyst and promoter. These

samples were removed from their molds in 3 hours, and at that time shrinkage

measurements began. Average measurements indicate a strain of 0.00038 in 1

day, 0.00051 in 5 days and 0.00055 in 18 days for the 1.5 percent catalyzed

and promoted; while the average of measurements of the 0.5 percent catalyzed

and promoted mix produced strains of 0.00085 in 1 day, 0.0010 in 5 days, and

0.0011 in 18 days. It appears that approximately 70 percent of the shrinkage

occurs during the first 24 hours (Figure 6).

It seems likely that the great difference in the measured shrinkage

between the samples having 0.5 percent catalyst and promoter and those having

1.5 percent is influenced by the amount of polymerization that occurred within

the first 3 hours for each mix. Shrinkage that occurs during the time the

polymer is still somewhat plastic is not likely to be troublesome in an overlay

application. It is probable the cylinders having the lower level of catalyst
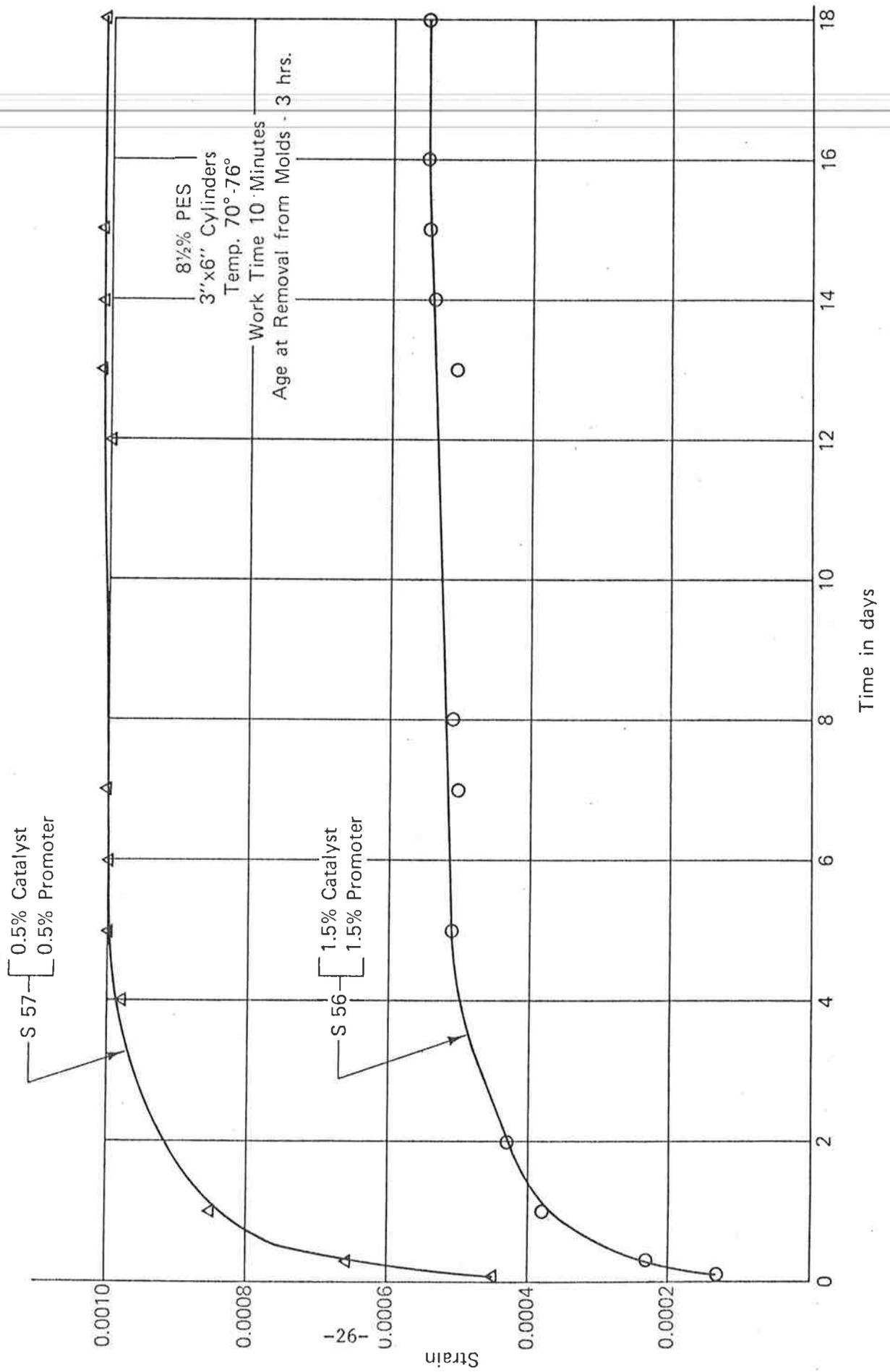
Figure 6. Shrinkage of PES mixes.

and promoter were still in a slightly plastic state at the time the measure-
ments of shrinkage were started. Because of the obvious difficulty of measuring
shrinkage of a mix in its initial plastic stage in a cylindrical mold, other
methods of test are being investigated.

## Proprietary Polymer Concrete Study

The only proprietary polymer concrete binder examined was Radgrout,
a product marketed for rapid patching of highway surface defects. The exact
formulation of this product was not made available to the investigators.
Radgrout is, however, a two-component polymeric compound that is mixed with
sand and gravel to produce a quick-setting polymer concrete. One component
contains the polymer with a promoting agent, while the other component is the
catalyst. The manufacturer specifies the system to be catalyzed at 2.2 percent.
The manufacturer suggests several appropriate aggregate-binder ratios. These
ratios are by volume and vary from a fine mix consisting of one-part sand to
one-part Radgrout liquid, to a coarse mix consisting of two-parts sand and two-
parts 3/8-in. gravel to one-part Radgrout liquid.

The aggregate gradation used with the Radgrout binder was gradation
VIII-c, shown in Table 1. This gradation was used in all polymer concrete
tests and was comprised of 1/2-in.-minus material. The performance of the Radgrout
mix was satisfactory in bond strength when placed on a concrete beam, but only
when the existing concrete surface was sandblasted and a tack coat used. A
mix containing 10 percent Radgrout liquid (by weight of aggregate), when placed
with a tack coat on a sandblasted surface, exhibited bond strengths of over
500 psi. When a 14 percent Radgrout mix was placed without a tack coat on a

-27-

surface that was prepared by wire brushing only, the overlay spun-off during coring.

A 10 percent Radgrout mix was selected for a compressive strength study. A compressive strength of 1,515 psi was recorded for a 3-in.-by-6-in. cylinder with a 3 hour cure at room temperatures, using a 5 minute work time. The compressive strength for the same mix, but with a 24 hour cure was 8,810 psi. A rapid drop in the compressive strength was noted when the work time was increased beyond 10 minutes (Figure 7). It appears that 15 minutes is the maximum work time available to ensure a suitable compressive strength. Further tests of durability and permeability are planned.

## IMPLEMENTATION PACKAGE

The developmental work on polymer concrete during recent months included the satisfactory placement of several small patches in concrete pavements and bridge decks. The quick setting nature of the material makes its use in patching a very worthwhile application. To make the use of polymer concrete as a patching material conveniently available to others, the following implementation instructions have been prepared. Refinements will undoubtedly be appropriate, but the procedure as outlined was found satisfactory.

Directions for patching spalled areas in portland cement concrete bridge decks or pavements using polymer concrete:

1. Check equipment and supplies according to the following lists:

Equipment:

[ ] Air Compressor
[ ] Jackhammer
[ ] Concrete Mixer (paddle type prefered over rotating drum)

Radgrout 10%
3"x6" Cylinders
Vary Work Time
Vary Cure Time
Room Temperature

Ultimate Compressive Strength ksi

24 Hr. Cure

5 Hr. Cure

3 Hr. Cure

Work Time (Minutes)
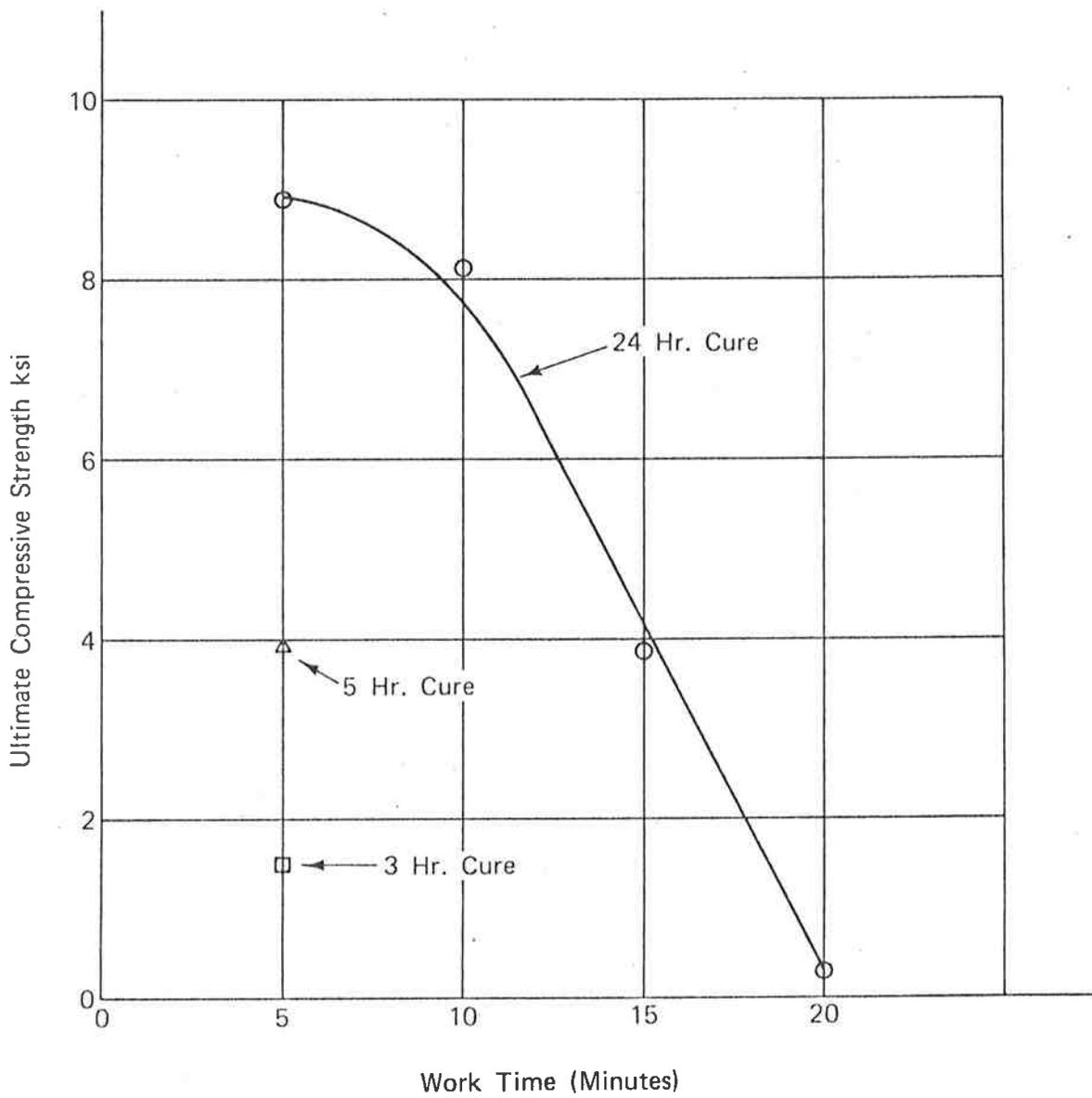
Figure 7. Radgrout strength, work time and cure time compared.

[ ]    Paint Brushes (2)
[ ]    ~~Broom (1)~~
[ ]    Shovels (2)
[ ]    Wheelbarrow
[ ]    Traffic Control Equipment (as required)
[ ]    100-lb Weighing Scale
[ ]    Measuring Tape
[ ]    4-lb Tamper (4-in. sq steel plate with handle)
[ ]    Screeding Device (2-in.-x-4-in. board)

Supplies:

[ ]    Polymer Resin (including catalyst, promoter, inhibitor and silane)
[ ]    Cleaning Solvent (Methylene chloride)
[ ]    Aggregate (coarse, fine)
[ ]    Portland Cement
[ ]    Cleaning Rags
[ ]    Gloves
[ ]    Five-gallon Cans (5)  (mixing and measuring)
[ ]    Thirty-five-gallon Garbage Can (1)  (with plastic liner)
[ ]    Rock Chips (passing the #4 sieve and retained on the #8 sieve)


2.   Patching Procedure:

Step 1    Establish traffic control by warning signs, traffic cones, flagmen, etc. as required.

Step 2    Prepare damaged area by removing loose and unsound concrete by jackhammer.

Step 3    Clean hole with high-pressure air and by brooming.

Step 4    Measure volume to be replaced and calculate the required polymer concrete component quantities.

Step 5    Weigh coarse and fine aggregate separately.  Keep the coarse aggregate separate from the fine aggregate and cement for mixing purposes.

Step 6    Weigh polymer resin.  The polymer resin should be prepared in the laboratory before going into the field.  The exact mixing instructions are found in Appendix A and must be followed. The resins must be transported to the job site in two components; one containing the catalyst and inhibitor and the other containing the promoter.  The two components must not be blended until the coarse aggregate has been placed in the mixer and all other preliminary work has been completed.  The correct amount of resin required for the patch is taken from each component container.  Extra resin should also be provided for a light tack coat for the damaged area to ensure a good bond.  During

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periods of hot weather or when the work is extended over long periods of time, the catalyst should be combined with the monomer in the field, nearer the time at which it is to be used.

Step 7    When using a drum type mixer, place only the coarse aggregate along with the resin into the mixer initially to ensure proper resin coating of the coarse aggregate. Allow 30 seconds of mixing before adding the fine aggregate and cement. The fine aggregate and the cement can be mixed together before being placed in the mixer.

If the paddle type mixer is used, the fine aggregate and resin should be added to the mixer first. As the fine aggregate and resin are mixing, the coarse aggregate should be added to the mixer.

While the concrete mixing is taking place, the polymer tack coat should be applied to the damaged area by paint brush.

Step 8    Mix polymer concrete for approximately 2 minutes.

Step 9    Discharge concrete from mixer and place quickly. If the depth of the hole is 3-in. or less a single lift is acceptable. If the hole is greater than 3-in. two equal lifts are required. The first lift should be well compacted before the second lift is placed.

Step 10   Compacting, screeding, and finishing conclude the patch procedure. If excess fluid comes to the surface during finishing, add fine rock chips and retamp lightly.

Step 11   The patch can be opened to traffic after visual inspection has determined polymerization has occurred.

Step 12   Immediate equipment cleaning is an important step in the patching sequence. Methylene chloride should be added to the mixer immediately after the polymer concrete is discharged. Likewise all tools should be cleaned with methylene chloride after use. Caution must be taken in the disposal of the methylene chloride after cleaning. One method of disposal is to let it evaporate outdoors in an isolated area. A 35-gallon garbage can which has been lined with a disposable plastic liner works well for collecting waste material.

## POLYMER CONCRETE MIX DATA

| | | |
|---|---|---|
| 10.0% | Polymer | by weight of the aggregate |
| 2.0% | Catalyst* | by weight of the polymer |
| 1.0% | Promoter* | by weight of the polymer |
| 2.0% | Silane | by weight of the polymer |
| 200 ppm | Inhibitor* | by weight of the polymer |

This particular polymer blend is suitable for use at a temperature range of 75F-80F.

### POLYMER PROPORTIONS

| | |
|---|---|
| Styrene | 23.0% |
| GR511* | 38.5% |
| GR941* | 38.5% |

### AGGREGATE GRADATION

| | |
|---|---|
| % Retained 1/2" | 0.0 % |
| % Retained 3/8" | 12.69% |
| % Retained 1/4" | 15.51% |
| % Retained #4 | 18.80% |
| % Pass #4 (sand) | 47.0 % |
| % Cement | 6.0 % |
| Total | 100.0 % |

### SAMPLE MIX PROPORTIONS

| | | |
|---|---|---|
| 100.0 | lbs | Aggregate |
| 10.0 | lbs | Polymer |
| 0.2 | lbs | Methyl ethyl ketone peroxide (catalyst) |
| 0.1 | lbs | Cobalt napthenate (promoter) |
| 0.2 | lbs | Silane |
| 0.002 | lbs | Hydroquinone (inhibitor) |

In view of the very small amount of inhibitor to be used, it is recommended that the hydroquinone be made into a dilute alcohol/hydroquinone solution by dissolving 5 grams of hydroquinone in 95 grams of anhydrous methyl alcohol. Then 18.14 grams of solution would provide the 0.002 lbs of hydroquinone listed above.

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\* Catalyst  – Methyl ethyl ketone peroxide
  Promoter  – Cobalt napthenate
  Inhibitor – Hydroquinone

GR511 – Flexible polyester manufactured
       by Marco Division of W. R. Grace Co.
GR941 – Rigid polyester manufactured by
       Marco Division of W. R. Grace Co.

The research objective to develop a polymer concrete mix suitable for use as a bridge deck overlay material has been mostly attained. The requirement to develop an impermeable treatment has been satisfied in the laboratory with resistance readings greater than 10,000,000 ohms. A 1-1/2-in. polymer concrete overlay containing 8-1/2 percent resin was placed on a slab which had received a single 15 mil polymer tack coat. Resistivity measurements indicated this system to be permeable. A second attempt using a similar overlay, but using two separate 15 mil polymer tack coats proved successful. Resistivity readings taken after 3 hours of soaking registered over 10,000,000 ohms. Another 1-1/2-in. polymer concrete overlay containing 10 percent resin was placed on a slab which had received a single 15 mil polymer tack coat. This system proved equally successful with resistance measurements of over 10,000,000 ohms being recorded after a 2 hour soaking period. It has also been demonstrated that a polymer concrete overlay can be successfully bonded to existing concrete. This requires the use of a polymer tack coat on a surface that has been prepared by sand-blasting. When this was done, bond shear values exceeded 400 psi.

The compressive strength of polymer concrete mixes was found to be dependent on such factors as polymer content, amount of promoter and catalyst, work time, and ambient temperature during mixing and placing. An uninhibited mix containing 10 percent polyester-styrene binder (by weight of aggregate) had a compressive strength of 10,300 psi in 7 days, while a mix containing 8.5 percent polymer content had a value of 8,100 psi in 7 days. These samples had a 10 minute placement time.

Materials that were mixed without an inhibitor and placed in molds within 10 minutes and allowed to cure for 24 hours showed consistent compressive strengths exceeding 5,000 psi. In extending the placement time to 25 minutes, however, compressive strengths were reduced to slightly over 3,000 psi for mixes with reduced amounts of catalyst and promoter. The workability of the mixes was also reduced as the placement time was extended.

The effects of catalyst, promoter, and ambient temperature on ultimate strength and placement time can be seen in Figure 3. It should be noted that these samples all contained 8.5 percent polyester-styrene as the binder.

Work time can be increased, sometimes at the sacrifice of some ultimate strength, by reducing the promoter and catalyst in an uninhibited mix from 1.5 percent to 0.5 percent. For a mix containing 1.5 percent catalyst and promoter, work time can be increased by approximately 10 minutes with no significant loss of ultimate strength by reducing the mixing temperature from 75F to 56F.

Contrary to the experience with the 1.5 percent promoter and catalyst mix, the 0.5 percent promoter and catalyst mix appears to provide reduced work time when the mixing temperature is reduced from 75F to 60F. This is probably due to lack of thorough polymerization from the combined effect of the reduced temperature. Studies using hydroquinone as an inhibitor showed that placement time could be extended to 90 minutes without adversely affecting compressive strength. A 10 percent PES mix with 450 ppm inhibitor placed in cylinders at 30, 60, and 90 minutes was found to have 24 hour strengths of 7,820 psi, 8,490 psi, and 7,980 psi, respectively.

Results of the thermal coefficient of expansion test indicated a non-linear coefficient when readings were made at -10F, room temperature, and

-34-

at 140F. An average coefficient of $7.8 \times 10^{-6}$ in./in./F was calculated for the measurements made at room temperature to -10F, while an average coefficient of $9.8 \times 10^{-6}$ in./in./F was calculated from the measurements made at room temperature to 140F. Although the coefficients of thermal expansion are higher than usually associated with portland cement concrete, no problems are anticipated with overlay bond.

Radgrout, a proprietary polymer concrete binder used for patching, was also tested for possible use in an overlay system. Using the same aggregate gradation as the non-proprietary mixes, a 10 percent Radgrout mix was tested for compressive strength. A value of 1,515 psi was recorded in 3 hours, for a work time of 5 minutes, when cured at room temperature. The compressive strength for the same mix increased to 8,810 psi when allowed to cure for 24 hours. Other tests indicate a rapid drop in compressive strength when work time was extended beyond 10 minutes and it appears that 15 minutes is the maximum placement time available to ensure a suitable strength.

The Radgrout system also indicated excellent bond strength when placed on an existing concrete surface, but only when the surface was sand-blasted and a tack coat of Radgrout was used.

Finally, work was done to develop a non-proprietary polymer concrete patching material. A mix containing 10 percent polyester-styrene binder with 1.5 percent catalyst and 1.5 percent promoter was examined early in this project. With a placement time of 5 minutes, compressive strengths above 3,000 psi were recorded in 3 hours and over 6,000 psi in 5 hours (Figure 4). This was accomplished at room temperature. Another mix containing a slightly different amount of catalyst and promoter and utilizing an inhibitor was

successfully placed in the field. After an 18 minute cure, the polymer concrete had set sufficiently to allow the resumption of traffic. The specifications for this mix are described in the Implementation Package section of this report.

## RECOMMENDATIONS

1.  Further laboratory study and small scale field developmental work should continue to evaluate polymer concrete properties such as fatigue strength and durability.

2.  Work should continue on monomer types and monomer blends along with amounts and types of catalyst, promoter, and inhibitors, to enhance various properties.

3.  Utilization should be made of the Implementation Package containing a polymer concrete patching material formula.

4.  Finally, because of the successful laboratory results to date, a field installation of polymer concrete overlay on a short structure carrying moderate traffic is recommended.

# A P P E N D I X   A

## FORMULATION OF POLYMER CONCRETE MIXES

The following is the approach used in preparing the test batches of polymer concrete.  Various abbreviations will be used in these instructions, and include:

MMA
  Methyl methacrylate:  a monomer.

TMPTMA
  Trimethylol propane trimethacrylate:  a monomer.

A174
  Organo-silane ester:  a silane bonding material marketed by Union Carbide.

B27
  Bentone 27:  a material used for thickening, marketed by NL Industries.

BOP
  Benzoyl peroxide:  a catalyst used with MMA.

AIBN
  2,2'-azobis [2-methylpropionitrile]:  a catalyst used in conjunction with BOP to give a more complete early cure.

DMA
  Dimethylaniline:  a promoter.

DMT
  N,N-dimethyl-p-toluidine:  a promoter.

PES
  Polyester-styrene:  the mixed monomer system.

GR511
  A flexible polyester marketed by the Marco Division of W. R. Grace Company.

GR941
  A rigid polyester marketed by the Marco Division of W. R. Grace Company.

Co N
  Cobalt napthenate:  a promoter.

MEKP
  Methyl ethyl ketone peroxide (60 percent MEKP in dimethyl phthalate) the catalyst used with the PES system.

RG

"Radgrout", a polyester patching material marketed by Radiation Technology, Inc.

HQ

Hydroquinone: an inhibitor.

Two distinct systems have been investigated: (1) the MMA-TMPTMA monomer blend; and (2) the PES monomer blend. Some general comments should be made prior to discussing the mixing procedure.

I.   The mixing of these materials requires combining a strong oxidant and a strong reductant (the catalyst and promoter) to obtain the final polymerized material. These materials can react violently or explode when mixed, so extreme care must be exercised in the handling of the two components.

II.  Most of the materials are flammable, and can burn easily.

III. Several of these ingredients can penetrate the skin and cause illness. The DMA and DMT can cause tumors. AIBN is a cyanide bearing compound, and when inhaled can cause cyanide poisoning.

For all the above reasons, good ventilation is a necessity, and cigarette smoking must be prohibited while the materials are being used.

The formulas given will be a basic version. Variations can be added, depending upon the field conditions, the time of set desired, the rate of hardening desired and the amount of reaction heat which the adjacent materials can tolerate.

A typical MMA-TMPTMA system would contain: (All percentages are based on weight, using the total monomer as 100%.)

|  |  |  |  |
|---|---|---|---|
| MMA | 95% | BOP | 1.5% |
| TMPTMA | 5% | DMA | 1.5% |
|  | 100% |  |  |

A typical PES system would contain the following, based on monomer weight:

|  |  |  |  |
|---|---|---|---|
| Styrene | 23.0% | Co N | 1.5% |
| GR511 | 38.5% | MEKP | 1.5% |
| GR941 | 38.5% |  |  |
|  | 100.0% |  |  |

## Instructions for Mixing the MMA-TMPTMA System

Note: The <u>exact</u> sequence of addition must be followed.

1. Weigh into a tared container:

   a. MMA
   b. TMPTMA

2. Stir thoroughly to attain an intimate mix.

3. Divide into two approximately equal portions.

4. Add BOP to one portion and mix thoroughly (Component A).

5. Add DMA and silane to other portion and mix thoroughly (Component B).

6. Charge a mixer with a preweighed, graded aggregate.

7. Slowly pour Component A <u>into</u> Component B, mixing continuously. (Reverse order of addition can cause a violent reaction.) Mix thoroughly.

8. Add monomer mix to the aggregate, mix until thoroughly coated.

9. Molds or forms should not be coated with an oil type bond breaker. A hard wax or wax paper is suitable.

10. Place aggregate-monomer mix in forms or molds; rodding, tamping, or vibrating to consolidate. Finish and put aside for further testing.

11. Tools must be cleaned immediately after use, generally using methylene chloride.

For the MMA system, the addition of 1-part AIBN to 1-part BOP for the catalyst, and 1-part DMT to 1-part DMA for the promoter, will give a faster set, and a higher heat cure. Thus, when a sample is to be polymerized at temperatures lower than 50F, the addition of AIBN and DMT should be mandatory. For higher ambient temperatures, the addition of these two materials is optional.

In order to provide increased strengths, the silane material A174 has been added to the monomers in amounts of about 0.5 to 2 percent of their weight.

Another additive, B27, has been added to the MMA system as an agent to increase the rest viscosity of the monomer.

# Instructions for Mixing the PES System

Note: The exact sequence must be followed.

1.  Weigh into a tared container:

    a.  Styrene
    b.  GR511
    c.  GR941

2.  Stir thoroughly to attain an intimate mix.

3.  Divide into two approximately equal portions.

4.  Add MEKP and HQ to one portion and mix thoroughly (Component A).

5.  Add Co N and silane to other portion and mix thoroughly (Component B).

6.  Charge mixer with a preweighed, graded aggregate.

7.  Slowly pour Component A into Component B, mixing continuously. (Reverse order of addition can cause a violent reaction.) Mix thoroughly.

8.  Add monomer mix to the aggregate, mix until thoroughly coated.

9.  Molds or forms should not be coated with an oil type bond breaker. A hard wax or wax paper is suitable.

10. Place aggregate-monomer mix in forms or molds, finish and put aside for further testing.

11. Clean up tools immediately after use, generally using methylene chloride.

For the PES system, the addition of small quantities of hydroquinone has decreased set time and has extended the allowable placement time of the polymer concrete to 1-1/2 hours at 75F. Concentrations of 200 ppm to 450 ppm have been successfully used in the laboratory. The addition of small quantities of DMA also decreases the set time by generating a higher reaction temperature than the basic system. The use of this material is very critical; the addition of an excess amount may cause an instantaneous set. DMA should be used only in the promoter with a concentration of 1-part DMA to 5-parts Co N being the maximum. Unless conditions warrant, this material is best omitted.

The silane A174 is used for increased strength. The addition of B27 in a concentration of approximately 5 percent of the monomer can be used to increase the rest viscosity of the mix.

The use of these additives and the amount of use for each mix depends on many variables such as temperature of the environment and aggregate; the surface on which the material is to be placed; the ultimate use, or the need for speed in completing the job; etc. Their use should be determined by a person experienced in handling these materials.

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

| TEST NO. PES | POLYMER CONTENT (by wt of aggregate) % | MONOMER PROPORTIONS (by wt of total monomer) | | | ADDITIVES PROPORTIONS (by wt of total monomer) | | | | PURPOSE OF TEST |
|---|---|---|---|---|---|---|---|---|---|
| | | Styrene % | GR511 % | GR941 % | Silane Coupling Agent A174 % | Catalyst MEKP % | Promoter Co N % | Binder Thickening Agent Bentone 27 % | |
| S 1 | 10.0 | 16.6 | 41.7 | 41.7 | 0.0 | 1.0 | 1.0 | 5.0 | Workability and Compression |
| S 2 | 12.0 | 16.6 | 41.7 | 41.7 | 0.0 | 1.5 | 1.5 | 5.0 | Workability and Compression |
| S 3 | 14.0 | 16.6 | 41.7 | 41.7 | 0.0 | 2.0 | 2.0 | 5.0 | Workability and Compression |
| S 4 | 14.0 | 16.6 | 41.7 | 41.7 | 0.0 | 2.5 | 2.5 | 5.0 | Workability and Compression |
| S 5 | 14.0 | 23.0 | 38.5 | 38.5 | 0.0 | 2.5 | 2.5 | 3.0 | Workability and Compression |
| S 6 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.5 | 2.5 | 2.0 | Workability and Compression |
| S 7 | 14.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.5 | 2.5 | 0.0 | Workability and Compression |
| S 8 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.5 | 2.5 | 0.0 | Workability and Compression |
| S 9 | 8.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.5 | 2.5 | 0.0 | Workability and Compression |
| S10 | 8.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.5 | 2.5 | 0.0 | Workability and Compression |
| S11 | 8.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.5 | 2.5 | 0.0 | Workability and Compression |
| S12 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.0 | *1.9 | 0.0 | Workability and Compression |
| S13 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 2.0 | **1.95 | 0.0 | Workability and Compression |
| S14 | 12.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Bond |
| S15 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.75 | 1.75 | 0.0 | Bond |
| S16 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Bond |
| S17 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.75 | ***1.72 | 0.0 | Bond |
| S18 | 9.0 | 23.0 | 38.5 | 38.5 | 2.5 | 2.0 | 2.0 | 0.0 | Bond |
| S19 | 8.0 | 23.0 | 38.5 | 38.5 | 2.5 | 2.0 | 2.0 | 0.0 | Bond |
| S20 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Bond |
| S21 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Bond |
| S22 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Thermal Coefficient |
| S23 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Shrinkage |
| S24 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Shrinkage |
| S25 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Bond |
| S26 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0.0 | Workability and Compression |

* Also contained 0.1% DMA in the promoter
** Also contained 0.5% DMA in the promoter
*** Also contained 0.3% DMA in the promoter

Note: Abbreviations are defined in Appendix A.

| TEST NO. | POLYMER CONTENT (by wt of aggregate) | MONOMER PROPORTIONS (by wt of total monomer) | | | ADDITIVE PROPORTIONS (by wt of total monomer) | | | | PURPOSE OF TEST |
|---|---|---|---|---|---|---|---|---|---|
| | | Styrene | GR511 | GR941 | Silane Coupling Agent | Catalyst | Promoter | Binder Thickening Agent | |
| PES | % | % | % | % | Al74 % | MEKP % | Co N % | Bentone 27 % | |
| S27 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Thermal Coefficient |
| S27w | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.75 | 0.75 | 0 | Workability and Compression |
| S28 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Bond |
| S29 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Bond |
| S30 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Bond |
| S31 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Bond |
| S32. | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Bond |
| S33 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Bond |
| S34 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.75 | 0.75 | 0 | Freeze Thaw Resistance |
| S35 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S36 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Compression |
| S37 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Bond |
| S38 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Compression |
| S39 | 8.5 | 23.0 | 38.5 | 38.5 | --- | 0.3 | 0.3 | 0 | Not Run |
| S40 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Compression |
| S41 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Bond |
| S42 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Bond |
| S43 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Permeability |
| S44 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Modulus of Elasticity |
| S45 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Bond |
| S46 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.4 | 0.4 | 0 | Bond |
| S47 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Compression |
| S48 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Modulus of Elasticity |
| S49 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S50 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S51 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Bond |

Note: Abbreviations are defined in Appendix A.

| TEST NO. PES | POLYMER CONTENT (by wt of aggregate) % | MONOMER PROPORTIONS (by wt of total monomer) | | | Silane Coupling Agent Al74 % | ADDITIVE PROPORTIONS (by wt of total monomer) | | | PURPOSE OF TEST |
|---|---|---|---|---|---|---|---|---|---|
| | | Styrene % | GR511 % | GR941 % | | Catalyst MEKP % | Promoter Co N % | Binder Thickening Agent Bentone 27 % | |
| S52 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S53 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.75 | 0.75 | 0 | Workability and Compression |
| S54 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Workability and Compression |
| S55 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S56 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Shrinkage |
| S57 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Shrinkage |
| S58 | --- | --- | --- | --- | --- | --- | --- | - | Failure |
| S59 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Compression |
| S60 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Compression |
| S61 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Absorption and Conductivity |
| S62 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Absorption and Conductivity |
| S63 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Absorption and Conductivity |
| S64 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Permeability |
| S65 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Permeability |
| S66 | 11.5 | 23.0 | 38.5 | 38.5 | 2.0 | 1.5 | 1.5 | 0 | Absorption and Conductivity |
| S67 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S68 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S69 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S70 | 10.0 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| S71 | 8.5 | 23.0 | 38.5 | 38.5 | 2.0 | 0.5 | 0.5 | 0 | Workability and Compression |
| | | | | | | | | Inhibitor Hydroquinone | |
| RM1 | 10.0 | 20.0 | 40.0 | 40.0 | 2.0 | 1.0 | 1.0 | 400 ppm | Workability and Compression |
| RM2 | 10.0 | 20.0 | 40.0 | 40.0 | 2.0 | 2.0 | 1.0 | 400 ppm | Workability and Compression |
| RM3 | 10.0 | 20.0 | 40.0 | 40.0 | 2.0 | 1.0 | 1.0 | 300 ppm | Workability and Compression |
| RM4 | 10.0 | 20.0 | 40.0 | 40.0 | 2.0 | 2.0 | 1.0 | 300 ppm | Workability and Compression |
| RM5 | 10.0 | 20.0 | 40.0 | 40.0 | 2.0 | 2.3 | 1.0 | 450 ppm | Workability and Compression |

Note: Abbreviations are defined in Appendix A.

| TEST NO. | POLYMER CONTENT (by wt of aggregate) % | MONOMER PROPORTIONS (by wt of total monomer) | | Silane Coupling Agent | | Catalyst | Promoter | Binder Thickening Agent | PURPOSE OF TEST |
| | | MMA % | TMPTMA % | A174 % | 6020 Dow % | BOP % | DMA % | Bentone 27 % | |
|---|---|---|---|---|---|---|---|---|---|
| M1 | 10.0 | 95.0 | 5.0 | 0.0 | 1.0 | 1.0 | 1.0 | 13.7 | Workability and Compression |
| M2 | 14.0 | 95.0 | 5.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | Workability and Compression |
| M3 | 10.0 | 95.0 | 5.0 | 0.0 | 0.0 | 1.5 | 1.5 | 7.0 | Workability and Compression |
| M4 | 10.0 | 95.0 | 5.0 | 0.0 | 0.0 | 2.0 | 2.0 | 7.0 | Workability and Compression |
| M5 | 12.0 | 95.0 | 5.0 | 0.0 | 0.0 | *1.25 | #1.25 | 7.0 | Workability and Compression |
| M6 | 14.0 | 95.0 | 5.0 | 0.0 | 0.0 | **1.5 | ##1.5 | 5.0 | Workability and Compression |
| M7 | 12.0 | 95.0 | 5.0 | 1.5 | 0.0 | *1.25 | #1.25 | 0.0 | Bond Test |

\* These tests also contained 1.25% AIBN  
\*\* This test also contained 1.5% AIBN

\# These tests also contained 1.25% AIBN  
\#\# This test also contained 1.5% AIBN

| TEST NO. | POLYMER CONTENT (by wt of aggregate) % | MONOMER PROPORTIONS (by wt of total monomer) Radgrout % | ADDITIVE PROPORTIONS (by wt of total monomer) Catalyst MEKP % | PURPOSE OF TEST |
|---|---|---|---|---|
| RG1 | 100.0 | 100.0 | 1.0 | Gel time & exotherm temp. |
| RG2 | 100.0 | 100.0 | 2.0 | Gel time & exotherm temp. |
| RG3 | 10.0 | 100.0 | 2.2 | Bond |
| RG4 | 12.0 | 100.0 | 2.2 | Bond |
| RG5 | 14.0 | 100.0 | 2.2 | Bond |
| RG6 | 10.0 | 100.0 | 2.2 | Bond |
| RG7 | 10.0 | 100.0 | 2.2 | Bond |
| RG8 | 10.0 | 100.0 | 2.2 | Compression |
| RG9 | 10.0 | 100.0 | 2.2 | Compression |

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