EVALUATION OF FIVE COMMERCIAL FAST-SETTING HYDRAULIC PATCHING MORTARS

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

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Research Laboratory Section
Testing and Research Division
Research Projects: 65 NM-140;
65 NM-148; 67 NM-170; 67 NM-173;
67 NM-180
Research Report No. R-715

State of Michigan
Department of State Highways
Lansing, October 1969

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INTRODUCTION

Initiation of Research

The following commercial fast-setting hydraulic patching mortars were presented to the New Materials Committee for consideration and possible adoption for use on Michigan highways: "Speed Crete"[1], "Mirament," "CCC Crete," "Express Repair," and "Instarok." These mortars were introduced at Committee meetings in 1965 and 1967, reviewed, and referred to the Research Laboratory for evaluation.

Proposed Uses for Patching Mortars

Patching mortars are used by the Department to repair spalled concrete bridge decks, particularly in high-traffic areas. In order to more clearly explain the criteria for evaluating these types of mortars, the following description of the properties of an "ideal" patching mortar is presented.

The "Ideal" Patching Mortar

When setting, the ideal patching mortar would develop a strong bond to the original concrete so that it could carry any transferred horizontal shear. It becomes hard enough to develop the high compressive strength required by the composite design, and it develops sufficient tensile strength to cope with the positive-to-negative moment reversals caused by moving loads. It does all of this immediately after placement so that the bridge can be opened to traffic as quickly as possible. The ideal patching mortar, during and after curing, does not shrink since shrinkage forces it to break bond with the concrete substrate. It has a thermal coefficient of expansion equal to the concrete so that the two materials expand and contract together. It is also unaffected by the destructive action of freezing water and de-icing chemicals. Finally, the ideal patching mortar is cheap, easy to mix, easy to place, and requires no special application equipment.

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(1) In addition to this laboratory evaluation, "Speed Crete" was used to patch several bridge decks for field evaluation. Subsequent inspections of these patches were reported by M. G. Brown in Research Report Nos. 618 (December 1966), 646 (August 1967), and 676 (June 1968).

MATERIALS TESTED

Fast-Setting Hydraulic Mortars

These mortars comprise the five listed above that are the subject materials of this report.

Conventional Hydraulic Mortars

The following four conventional hydraulic mortars were included in this report to provide a basis of comparison and evaluation for the subject mortars:

1) Type-I Portland Cement Mortar - Ordinary portland cement mortar has probably been used for more road and bridge patches than any other type.

2) Atlas Lumnite Mortar - Atlas Lumnite is a calcium aluminate cement manufactured by the Universal Atlas Cement Company. Atlas Lumnite is commonly used in industry to secure high-early-strength concrete patches that are resistant to the corrosive effects of certain liquids and gases.

3) Portland Cement Type-I Mortar with SM-100 Admixture - The SM-100 admixture, manufactured by the Dow Chemical Company, is a liquid styrene-butadiene emulsion in water and is claimed to impart superior bonding properties to portland cement mortars. The Department is currently observing the performance of this mortar in several field patches.

4) Portland Cement Type-III Mortar with Embeco Metallic Aggregate - This patching mortar is claimed by its manufacturer to have non-shrink properties. It has been used by the Department for specialized patching in pavements. The Embeco Metallic Aggregate is manufactured by the Master Builders Company.

Epoxy Mortars

The following three epoxy mortars were also included in the report to compare and evaluate them with the other types of mortars.

1) Guardkote 140 Epoxy Mortar - Guardkote 140 is the trade name of a flexible, coal-tar modified epoxy system manufactured by the Shell Oil

Company. It has been used extensively by the Department for patching spalled bridge decks.

2) Guardkote 250 Epoxy Mortar - Guardkote 250 is a flexible, oil-modified epoxy system, also manufactured by Shell. Like Guardkote 140, it has been used extensively by the Department for patching spalled bridge decks.

3) Colma-Dur LV Epoxy Mortar - Colma-Dur LV is a low-viscosity epoxy system made by the Sika Chemical Company. Because of its high strength and flexibility it was included in the report as a control mortar. To the best of our knowledge, this epoxy has not been used by the Department as a patching mortar, but it has been used to seal plastic shrinkage cracks.

TESTING PROGRAM

Test Specimens

The ideal patching mortar described in the Introduction does not exist, but its properties provide a basis for evaluating the properties of existing patching mortars. Proceeding from this concept, the mortar specimens, test intervals, and testing procedures employed for each material were devised as follows:

1) Compressive Strength - Twenty-four 2-in. cubes, conforming to ASTM C109-63, "Compressive Strength of Hydraulic Cement Mortars," were used to evaluate the patching mortar's compressive strengths. These were tested in groups of 3, at 8 and 24 hours, at 3, 7, and 28 days, and after 50, 100, and 200 freeze-thaw cycles following the 28-day test. The freeze-thaw cycles conformed to ASTM C 291-61T, "Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water." A 14-day test was substituted for the eight-hour test for the slower setting comparison mortars.

2) Tensile Strength - To evaluate the tensile strength, 15 briquets were tested in groups of 3, at 8 and 24 hours, and at 3, 7, and 28 days. With these, as well, a 14-day test was substituted for the eight-hour test in the case of slow setting mortars. The briquets conformed to ASTM C190-63, "Tensile Strength of Hydraulic Cement Mortars."

3) Shear Bond Strength - To determine the bond strength in shear, 24 shear bond blocks were tested. These test specimens consisted of a 1-in. mortar cap cast on the 3- by 4-in. sawed face of a 3- by 4- by 3-in. concrete block. The block was clamped on a testing apparatus and loaded until the mortar cap sheared off. These blocks were tested in groups of 3 at the same time intervals and freeze-thaw cycle intervals as the mortar cubes. No ASTM standard currently covers this shear bond test.

4) Shrinkage - To Determine the shrinkage characteristics of the patching mortars, four 1- by 1- by 11-1/4-in. prisms of 10-in. effective gage length were used. These prisms are described in ASTM C151-63, "Autoclave Expansion of Portland Cement." The prisms were weighed and measured at 8 and 24 hours, at 3, 7, 14, and 28 days, and at 3 and 6 months.

After the six-month measurement, the prisms were placed in the moist curing room to measure length and weight recovery. Recovery measurements were made at 1, 3, 7, and 14 days. The majority of the test specimens were cured the first 7 days in sealed polyethylene, and spent the remainder of the time in laboratory air.

Program Limitation

This testing program as stated, is well-suited to hydraulic patching mortars because of their compatibility with a concrete substrate. For this reason, the test results should give a fairly accurate indication of the performance that can be expected in the field. The epoxy patching mortars used for control, however, have a thermal coefficient of expansion that is much different from that of concrete. Temperature changes, therefore, can result in very significant shearing stresses between the epoxy mortar patch and the concrete substrate. To compensate for this physical difference, manufacturers have made their epoxy binders more flexible to better enable them to endure these shearing stresses. The freeze-thaw testing between zero and 40 F gave a limited amount of information concerning the epoxy mortars' performance, but an effective endurance test should run shear bond specimens through repeated cycles of a 100 F temperature change with shear tests after 100, 200, and 300 cycles. Since this report is primarily concerned with the evaluation of fast-setting hydraulic mortars, no special tests peculiar to epoxy mortar were used.

MORTAR PREPARATION

Each mortar specimen was given a one-minute mix time in a Hobart Model N 50 laboratory mixer.

Fast-Set Hydraulic Patching Mortars

Table 1 shows the mix proportions, the entrained air content, and the cost per cubic foot of these mortars. Because their fast-setting nature limited the form-placement time to 10 minutes, the ASTM standard tamping procedure for mortar was discarded in favor of mechanical vibration. This means of consolidation was very rapid and permitted all forms to be struck-off before the mortar set.

TABLE 1
FAST-SET HYDRAULIC PATCHING MORTARS

Component Weights and Cost of One cu ft of Patching Mortar

Mortar	Weight of Packaged Material, lb	Weight of Mix Water, lb	Weight of Pea Gravel, lb	Entrained Air (lin traverse), percent	Cost/cu ft
Speed Crete	101.2	25.3	----	Not Measured	$10.12
Speed Crete w/Pea Gravel	78.4	19.6	39.2	Not Measured	7.91
Mirament	116.8	17.3	----	Not Measured	6.10
CCC Crete	121.7	19.8	----	Not Measured	9.71
Express Repair	102.0	27.3	----	5.6	10.20
Instarok	126.2	15.1(1)	----	6.9	18.90

(1) Gauging liquid

Speed Crete - The Speed Crete mortar was mixed according to manufacturer's recommendations of 6 qt water per 50 lb bag. The bonding surfaces of the shear bond blocks were moistened prior to mortar placement to insure that the concrete would not draw moisture away from the mortar and weaken the bond. The specimens were removed from their forms after six hours and all those not tested at eight hours were placed in the moist room for curing through seven days.

Mirament - The Mirament mortar was mixed according to the manufacturer's recommendation of 3.5 qt water per 50 lb bag, and curing took place in the moist room for seven days.

Speed Crete with Pea Gravel - According to the producer's instructions, the cost per cubic foot of the Speed Crete mortar could be reduced for deeper patches, without diminishing its good performance, by adding 25 lb of pea gravel to a 50 lb bag. Therefore, Speed Crete plus pea gravel were mixed using the same recommended quantity of water. To help improve the bond characteristics, the moistened surface of the shear bond blocks were brushed with a Speed Crete and water slurry immediately prior to the placement of the mortar caps (later testing, however, showed only the eight-hour bond was improved). Since the moist room curing of the plain Speed Crete was not representative of field patching, these specimens were cured for the first seven days in a polyethylene bag.

CCC Crete - The CCC Crete mortar was mixed according to manufacturer's recommendations of four parts CCC Crete to one part water by loose volume, or almost 4 qt water to 50 lb of dry mix. A recommended bonding agent called "Chemtol" was requested a month in advance of testing but was never received, so the shear bond block surfaces were merely wetted before mortar placement. Curing for the first seven days took place in a sealed polyethylene bag to more nearly simulate field conditions. Since the manufacturer stated in his instructions that moisture curing was neither recommended nor desired, a small can of water was set inside the bag to humidify the air and thus reduce moisture loss due to evaporation from the specimens.

Express Repair - A trial mix made according to the producer's recommendations of 5-3/4 qt water to 50 lb of Express Repair produced an unworkable damp lump, but the addition of 14 percent more water (6-1/2 qt) produced a stiff but workable mortar. The shear bond block surfaces were wetted prior to mortar placement and cured for the first seven days in a sealed polyethylene bag. The manufacturer did not recommend moisture curing, so the bag was humified with a small can of water.

Instarok - This mortar was supplied with the usual cement and fine aggregate combined in a dry mix and a special milky colored "gauging" liquid. The manufacturer suggested using enough gauging liquid to produce a mortar of desired consistency; that good bond to concrete could be obtained if the moistened bonding surface were brush-primed with the mortar; that if the mortar were too stiff for brushing, additional gauging liquid should be used as necessary; and that moist curing was neither recommended nor desired. The recommended mix proportions of 2.9 qt gauging liquid to 50 lb Instarok were followed and curing took place in a sealed polyethylene bag with a small can of water.

Conventional Hydraulic Patching Mortars

All of the conventional hydraulic mortars were mixed according to the proportions given in Table 2. The Table also gives the entrained air and the cost per cubic foot of the mortar. To maintain compatibility in form placement, these mortars were vibrated in the same manner as the fast-setting hydraulic mortars; for compatibility in curing, they were cured seven days in a polyethylene bag and 21 days in laboratory air. The polyethylene bag contained a small can of water to supply additional humidity.

Portland Cement Type-I - Approximately one ounce of an air-entraining agent per sack of cement was added to the mortar. Prior to placement, the shear bond blocks were brush-primed with a water-cement slurry to improve their bond strength.

Atlas Lumnite - Prior to placement of the Atlas Lumnite mortar, the shear bond blocks were moistened and brush-primed with a Lumnite slurry. The only admixture used with this mortar was one ounce of an air-entraining agent per sack of cement. The manufacturer recommends that moist curing for 24 hours be provided after the mortar takes its final set. If possible, the moisture should be provided by continuous spraying or sprinkling, since it is needed to replace evaporated moisture from the surface and to carry away the heat of hydration that is generated at a faster rate than that of portland cement. The manufacturer also states that a resin-based curing compound, applied as soon as possible, can be used as an alternate curing method if it seals the entire exposed surface of the mortar.

Portland Cement Type-I with SM-100 Admixture - The SM-100 admixture is a synthetic polymer (styrene-butadiene) emulsion that contains 48 percent solids and 52 percent water by weight. When mixed with a portland cement mortar, it imparts a fluidity characteristic that permits a significant reduction in the required mix water. This reduction in mix water has

TABLE 2
CONVENTIONAL HYDRAULIC PATCHING MORTARS
Mix Proportions, Component Weights, and Cost of One cu ft of Patching Mortar

Mortar	Weight of Sand, lb	Weight of Cement, lb	Aggregate Cement Ratio	Weight of Mix Water, lb	Water Cement Ratio	Weight of Admixture, lb	Entrained Air (lin traverse), percent	Cost/cu ft
Portland Cement Type I	96.6	38.6	2.50	16.2	0.42	----	6.5	$0.88
Atlas Lumnite	96.8	38.8	2.50	16.2	0.42	----	5.7	2.60
Portland Cement Type III w/Embeco	70.9	44.5	2.12	18.6	0.42	23.7	6.6	4.77
Portland Cement Type I w/SM-100	88.9	35.6	2.50	6.0(1)	0.33	5.25 solids +5.70 water 10.95	6.0	3.97

(1) Does not include 5.70 lb of water in the SM-100 admixture.

two beneficial effects; first, it produces a higher strength in the mortar, and second, it reduces the amount of mortar shrinkage after setting. Another characteristic imparted by the polymer emulsion is a reduction in moisture permeability. This causes an initial slow gain in mortar strength, and a slow rate of subsequent absorption after the mortar has dried. The latter characteristic is very beneficial in resisting freeze-thaw damage. This admixture is also reported to substantially increase the tensile and bonding properties.

The mortar was mixed to the proportions recommended by the producer, such that the weight ratio of the SM-100 solids to the cement was 0.15. The producer also stated that enough additional water should be added to the mortar to make it workable. A trial mix made prior to casting the specimens established that a water-to-cement weight ratio of 0.33 was adequate. This included both the water contained in the emulsion and the additional mix water. An air-entraining admixture was added at the rate of 1.1 ounce per sack of cement. Prior to vibrating the mortar, the moistened shear bond blocks were brush-primed with mixed mortar to help improve their bond strength.

The admixture producer recommends damp burlap curing for 24 hours followed by three days of dry curing. An alternate method is to place a heavy coat of calcium chloride over the mortar by fog spraying a 35 percent solution. This is then covered for 24 hours with white-pigmented polyethylene.

Portland Cement Type-III with Embeco Admixture - The manufacturer of Embeco describes it as being a catalyzed metallic aggregate that--when added to grout, mortar, or concrete mixes--counteracts shrinkage and improves other basic qualities. The manufacturer suggests using only non air-entrained cement; possibly because the admixture is generally used for foundation repair and industrial grouting where resistance to weather damage is not a factor. However, since air entrainment is important for bridge deck repair, 0.9 ounces of an air-entraining agent per sack of cement was added to the recommended mix for "repair of concrete." The moistened shear bond blocks were brush-primed with a Type-III portland cement and water slurry prior to placement of the mortar.

Epoxy Patching Mortars

The component properties, mix proportions, and cost per cubic foot of mixed mortar is given in Table 3 for each of the epoxy patching mortars.

When placing the mortar in the molds, it was discovered that the liquid epoxys' transmission of vibrations was so poor that the vibration method was ineffective. Hand tamping in accordance with ASTM C109 and C190 was used instead. The shear bond blocks were primed with the clear epoxy binder immediately prior to placing the mixed mortar.

Guardkote 140 - Eight hours after this mortar was poured, it had set to a semi-solid consistency but was not hard enough to test. The first tests were run at 24 hours. Examination of the caps sheared from the shear bond blocks showed that approximately 85 percent of the area was contributing to the strength since many voids existed at the bonding surface. These voids ranged in size from 1/64 to 1/4 in. in diameter.

Guardkote 250 - The performance of this mortar was very similar to the Guardkote 140 in that it set in the same time, produced low compressive strengths, and developed the same type of void pattern at the bonding surface.

Colma-Dur LV - This product is a penetrating epoxy with a mixed component viscosity similar to honey. Because of its fluidity, it was suspected that the epoxy might permeate the sand and drain out the bottom of the molds; preliminary tests, however, proved it had sufficient adhesion to function well as a binder.

TABLE 3
EPOXY PATCHING MORTARS

Component Properties, Mix Proportions, and Cost of One Cubic Foot of Patching Mortar

Mortar	Weight of Sand, lb	Epoxy Binder						Cost/cu ft
		Part A (resin)			Part B (curing agent)			
		Specific Gravity	Viscosity (poises @ 25 C)	Volume, gal	Specific Gravity	Viscosity (poises @ 25 C)	Volume, gal	
Guard Kote 140	109.5	1.13	16.6	0.952	1.18	4.60	0.952	$7.53
Guard Kote 250	109.5	1.07	62.0	0.952	0.91	0.90	0.952	7.84
Colma-Dur LV	108.5	1.14	3.5	1.262	0.97	0.69	0.629	33.73

TEST RESULTS

Discussion of Graphs

As each patching mortar was tested in compression, tension, shear bond, and shrinkage, the values were recorded and unit strengths were calculated. The entire data are presented in graphical form. Each of Figures 1 through 5 show the following mortar properties: Compression Strength (Fig. 1); Tensile Strength (Fig. 2); Bond Strength in Shear (Fig. 3); Shrinkage Prism Length Variation (Fig. 4); and Shrinkage Prism Weight Variation (Fig. 5). Each figure is divided into four graphs. One graph presents data on the fast-setting hydraulic mortars Speed Crete and Mirament, which were tested simultaneously in the fall of 1966. The second graph contains test data for the remaining fast-setting hydraulic mortars, tested in the winter of 1968. The third graph gives data on the conventional hydraulic control mortars, and the last graph contains test data on the epoxy control mortars. The latter two types were tested in the winter of 1968.

Results of Fast-Setting Hydraulic Patching Mortar Tests

Table 4 gives the composition of each of the fast-setting hydraulic mortars. The analysis was obtained by sieving out the aggregate portion of the mortar and chemically analyzing the cementing portion.

Two graphs in each of Figures 1 through 5 are devoted to these mortars and, in general, show them to be of lower strength than the conventional hydraulic mortars; however, all of them set within 15 minutes after pouring and recorded some strength at the eight-hour test.

Speed Crete - While curing in the moist room, Speed Crete absorbed a significant amount of water which caused a corresponding swelling in specimen weight and dimensions. Following removal from the moist room the specimens were allowed to dry in laboratory air. At 17 days, some of the caps on the shear bond blocks had broken loose and all of them had developed hairline cracks at the bonding surface. This was the initial indication of the mortar's excessive shrinkage which accompanies loss of moisture (Figs. 4 and 5). Complete loss of bond occurred after 50 freeze-thaw cycles. The mortar itself survived 200 freeze-thaw cycles with no apparent physical disintegration.

Mirament - While curing in the moist room, Mirament absorbed a significant amount of water but retained its original dimensions. Following removal from the moist room, however, substantial shrinkage accompanied loss of moisture and--at the 28-day test--most of the developed shear bond strength was lost. Fifty freeze-thaw cycles caused complete loss of bond and produced heavy surface scaling.

Speed Crete with Pea Gravel - The pea gravel aggregate had a restraining effect on the natural shrinkage of Speed Crete mortar. This effect became evident later with the appearance of micro-craze cracks. The shear bond mortar specimens lost most bond strength after 50 freeze-thaw cycles and all bond after 100 freeze-thaw cycles. The remaining specimens survived the 200 cycles with craze cracking as the only evidence of physical disintegration.

TABLE 4
FAST-SET HYDRAULIC PATCHING MORTARS

Approximate Composition as Determined by Sieve and Chemical Analyses
(percent by weight)

	Speed Crete	Minament	CCC Crete	Express Repair	Instarok	
					Mortar	Gauging Liquid
Fraction Retained by #100 Sieve (aggregate)	30	68	55	20	67	----
Silica, Clay, etc., Passing #100 Sieve	7	----	4	9	3	----
Portland Cement Type-I	51	app 16	----	54	----	----
High-Alumina Cement	----	app 16	----	----	----	----
Plaster-of-Paris	12	----	41	17	30	----
Acrylic Copolymer Emulsion Solids	----	----	----	----	----	28
Water	----	----	----	----	----	72

CCC Crete - Initial testing of the mortar yielded encouraging results; however, absorption tests run on the mortar caps of the 28-day shear bond specimens revealed very rapid moisture absorption and then gradual loss of weight. An investigation showed the cementing agent, plaster-of-paris, to be softening in the water. After 50 cycles of freeze-thaw testing, all shear bond specimens had broken bond. Compression cubes were removed a few cycles later when it was noted that they were disintegrating.

Express Repair - As with Speed Crete, Express Repair shrank excessively with loss of moisture (Fig. 4). This shrinkage was evidenced both by the loss of bond strength at the 28-day test and the craze cracking which appeared on the shear bond mortar caps as they dried following the 50 cycle freeze-thaw tests. All shear bond specimen testing was discontinued at the end of 50 freeze-thaw cycles when it was discovered that they had broken bond. The compression cubes, however, survived 200 freeze-thaw cycles with no apparent physical disintegration.

Instarok - After 28 days, absorption tests run on the mortar caps of the shear bond specimens showed a much slower loss of cementing material than had occurred with CCC Crete. The chemical analysis of Instarok indicated that, like CCC Crete, it contained plaster-of-paris as the principal cementing material. However, the gauging liquid contained an emulsified acrylic copolymer that apparently imparted a reduced rate of moisture absorption to the plaster-of-paris. The shrinkage prism measurements shown in Figures 4 and 5 indicate that the initial moisture content of Instarok did not exceed 2.5 percent of the weight of the mortar, due to the fluidity of the acrylic emulsion. It was also noted that the moisture absorbed after 14 days in the moist room did not exceed the original moisture content and that only minor linear dimension changes accompanied moisture content variation.

From the strength vs time graphs in Figures 1, 2, and 3, it was noted that the drying, after removal from the polyethylene bag at seven days, produced a significant increase in the strength of Instarok. This was probably caused by the "setting" of the acrylic copolymer emulsion.

The bond strength of Instarok was greatly reduced after 50 freeze-thaw cycles and completely gone after 100 cycles. The compression cubes completed 200 cycles but not before the plaster-of-paris had been eroded away to a depth of 1/8 in. on all exposed surfaces.

Results of Conventional Hydraulic Patching Mortar Tests

One graph in each of Figures 1 through 5 shows the test results of these mortars. In general, all shear bond failures of 400 psi or more occurred either totally or partially through the concrete block (Fig. 3). This indicated that the mortars' bond to the concrete approached or exceeded the strength of the concrete itself.

Portland Cement Type-I - The limited evaporation from the specimens permitted by the air in the polyethylene bag thwarted the rate of strength rise and permitted the specimens to shrink while still in the initial stages of curing. Thus, the slow curing nature of portland cement Type-I has handicapped its performance under these conditions. Shrinkage further handicapped this mortar; although it was not as great as some of the fast-setting hydraulic mortars, it was large enough to substantially reduce its shear bond strength (Fig. 4). The mortar itself survived 200 cycles of freeze-thaw testing with no apparent damage.

Atlas Lumnite - Since Atlas Lumnite was a rapid curing hydraulic cement, it had gained most of its strength after 22 hours; the time it was removed from its forms. Because of this, the limited evaporation and shrinkage that occurred in the polyethylene bag did not seriously impair its performance. After the mortar was removed from the polyethylene bag it was noted that the cement, which is black in color, would rub off on one's hands; later, however, following some absorption measurements on shear bond caps, the cement apparently had completed its hydration process and would no longer rub off. It performed consistently well throughout the testing program in all stress measurements (Figs. 1 - 3) and it shrank the least of all of the conventional hydraulic mortars (Fig. 4). Atlas Lumnite survived 200 freeze-thaw cycles with no apparent damage.

Portland Cement Type-I with SM-100 Admixture - Figure 1 shows that this mortar, with its emulsified liquid admixture, developed the lowest compressive strength of any of the conventional hydraulic mortars; however, it still competed favorably with the epoxy and fast-setting hydraulic mortars. In the tensile and shear bond strength measurements (Figs. 2 and 3) the admixture also retarded the rate of strength gain, but after the third day it out-performed any of the other conventional hydraulic mortars. The mortar survived 200 freeze-thaw cycles with no apparent damage.

Portland Cement Type-III with Embeco Admixture - This mortar's most impressive performance was its 6,500 psi compressive strength (Fig. 1) and its 385 psi tensile strength (Fig. 2) at 24 hours. Shrinkage measurements shown in Figure 4 show the shrinkage of this mortar to be greater than any of the other conventional hydraulic mortars. The disappointing performance of the admixture in counteracting shrinkage should preclude its future use for highway work, at least using the mix proportions in Table 2, until it can be proven to be more effective. The effect of this shrinkage shows up as reduced shear bond strength in Figure 3. The graph also shows that all shear bond strength was lost after 50 freeze-thaw cycles.

Results of Epoxy Patching Mortar Tests

Many voids, ranging in size from 1/64 to 1/4 in. in diameter, existed at the bonding surface between the mortar cap and the concrete block. It was initially suspected that they were caused by insufficient epoxy binder; however, after some additional investigation it was concluded that air was being trapped between the mortar and the concrete at the time of mortar placement. Because of the epoxy's high surface tension, the trapped air could not escape.

Guardkote 140 - The graphs in Figures 1 and 2 show the compressive strength of Guardkote 140 mortar to be relatively low, but the tensile strength values to be high compared with the hydraulic mortars. The trapped air voids between the mortar cap and the concrete block reduced the effective shear bond surface by approximately 15 percent and caused the test values shown in Figure 3 to be quite inconsistent. The linear shrinkage, as shown in Figure 4, was the lowest of the epoxy mortars and much lower than any of the conventional hydraulic mortars. The guardkote 140 mortar survived 200 freeze-thaw cycles with no apparent damage.

Guardkote 250 - Like Guardkote 140, the Guardkote 250 mortar tested relatively low in compressive strength and high in tensile strength. Similarly, it trapped air at the bonding surface, but tested to more consistent values in shear bond strength than did the Guardkote 140. The shrinkage of the Guardkote 250 mortar was relatively high; almost equaling that of portland cement mortar (Fig. 4). This shrinkage probably resulted from the loss of the oil with which the epoxy was extended. The mortar survived 200 freeze-thaw cycles with no apparent damage.

Colma-Dur LV - Four hours after this mortar was poured, it had set so hard that removing the forms was difficult. The results of the eight-hour tests were very impressive for all specimens. By seven days, however, shrinkage had reduced the shear bond strength to half of the eight-hour value and 200 cycles of freeze-thaw testing further reduced it to a value below that of Guardkote 250 (Fig. 3). The mortar itself survived 200 cycles of freeze-thaw testing with no apparent damage.

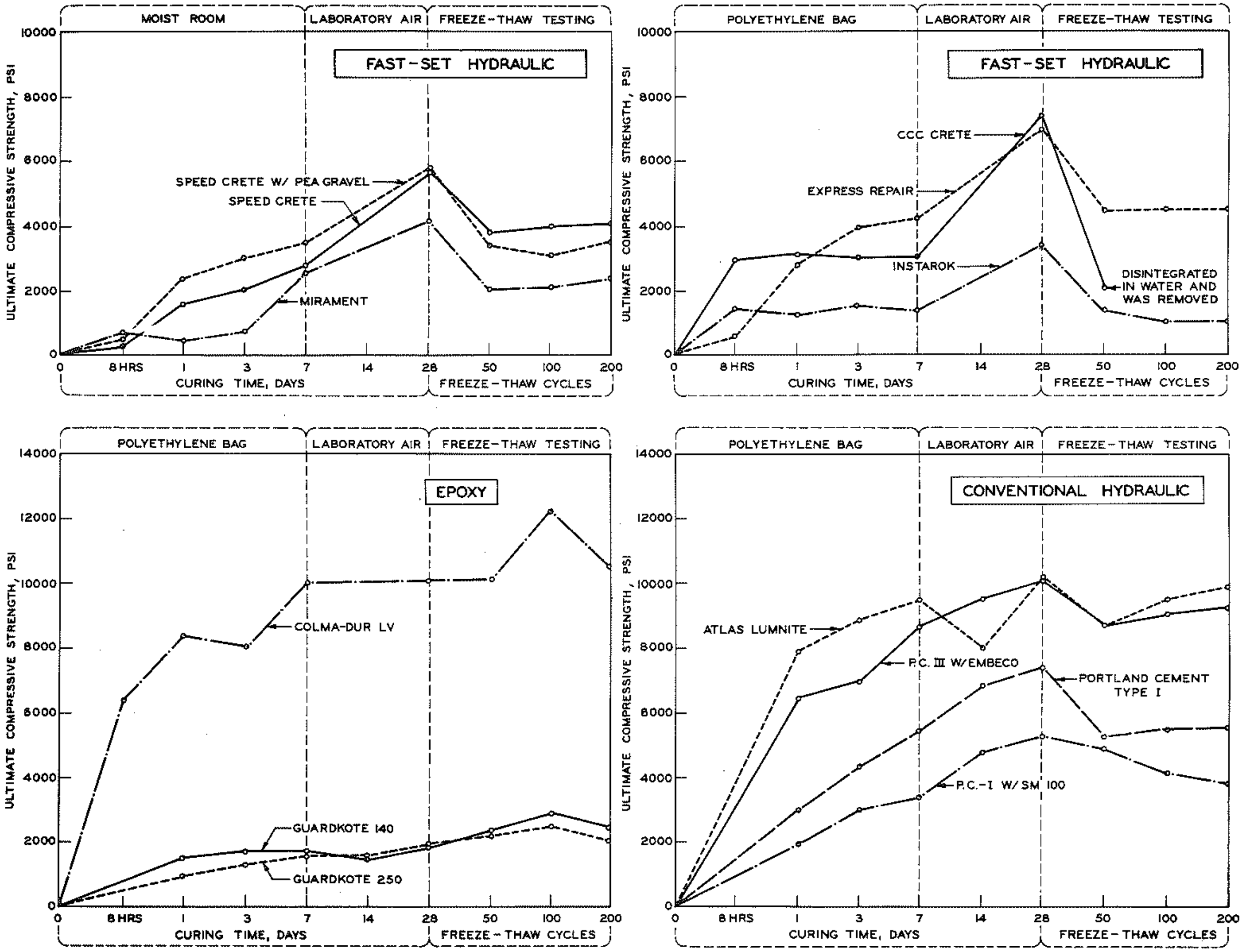

Figure 1. Compressive strength of patching mortars.

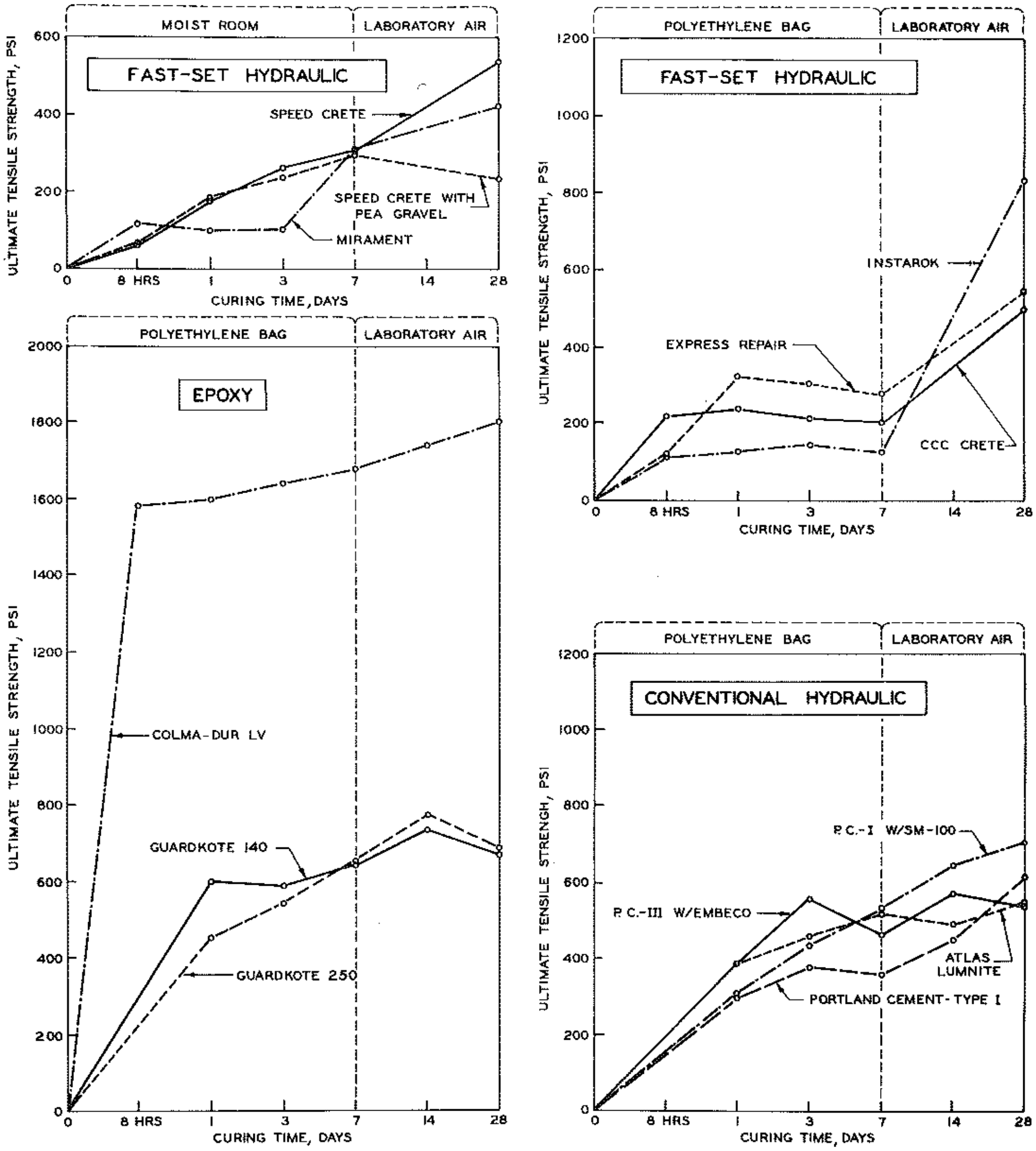

Figure 2. Tensile strength of patching mortars.

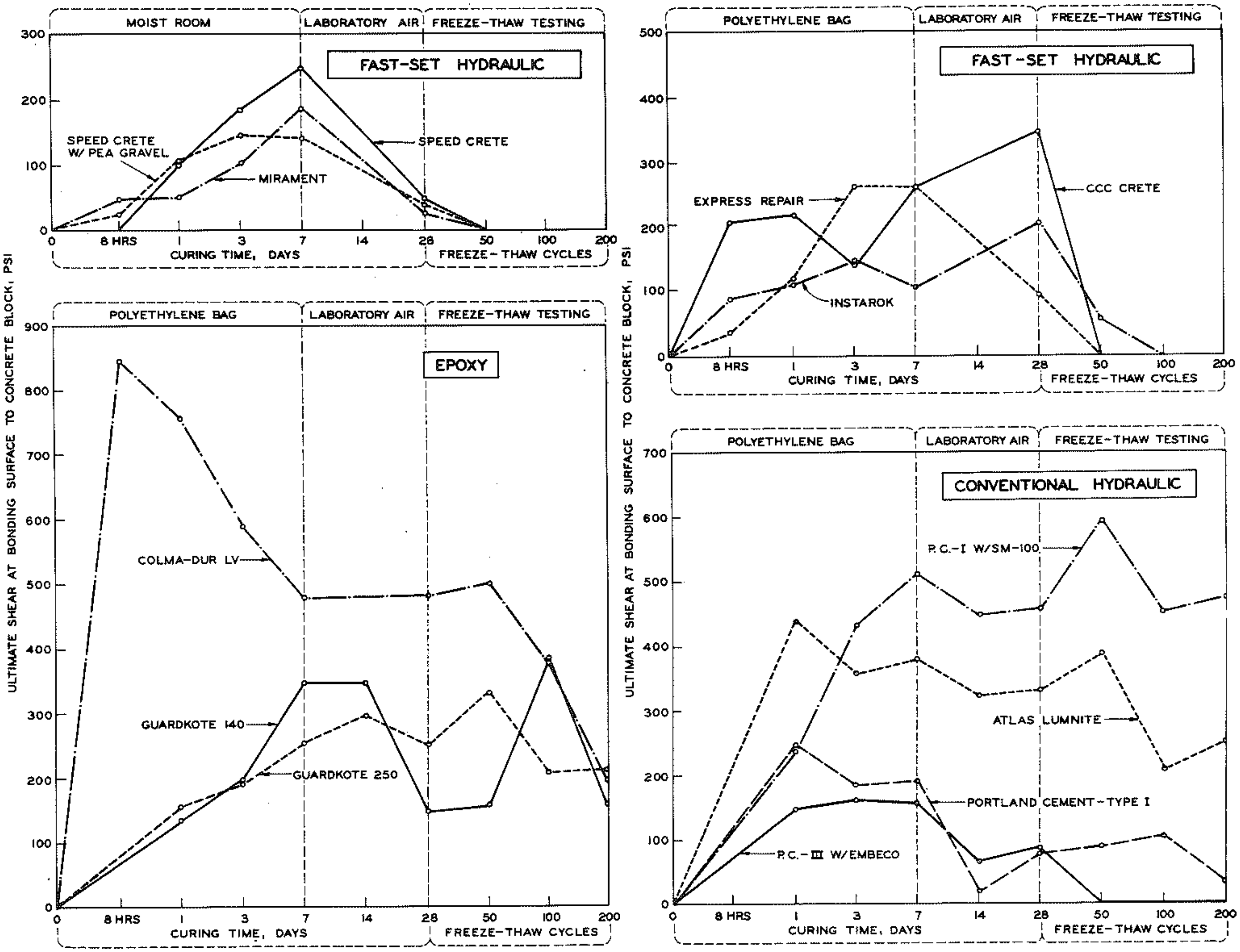

Figure 3. Bond strength in shear of patching mortars.

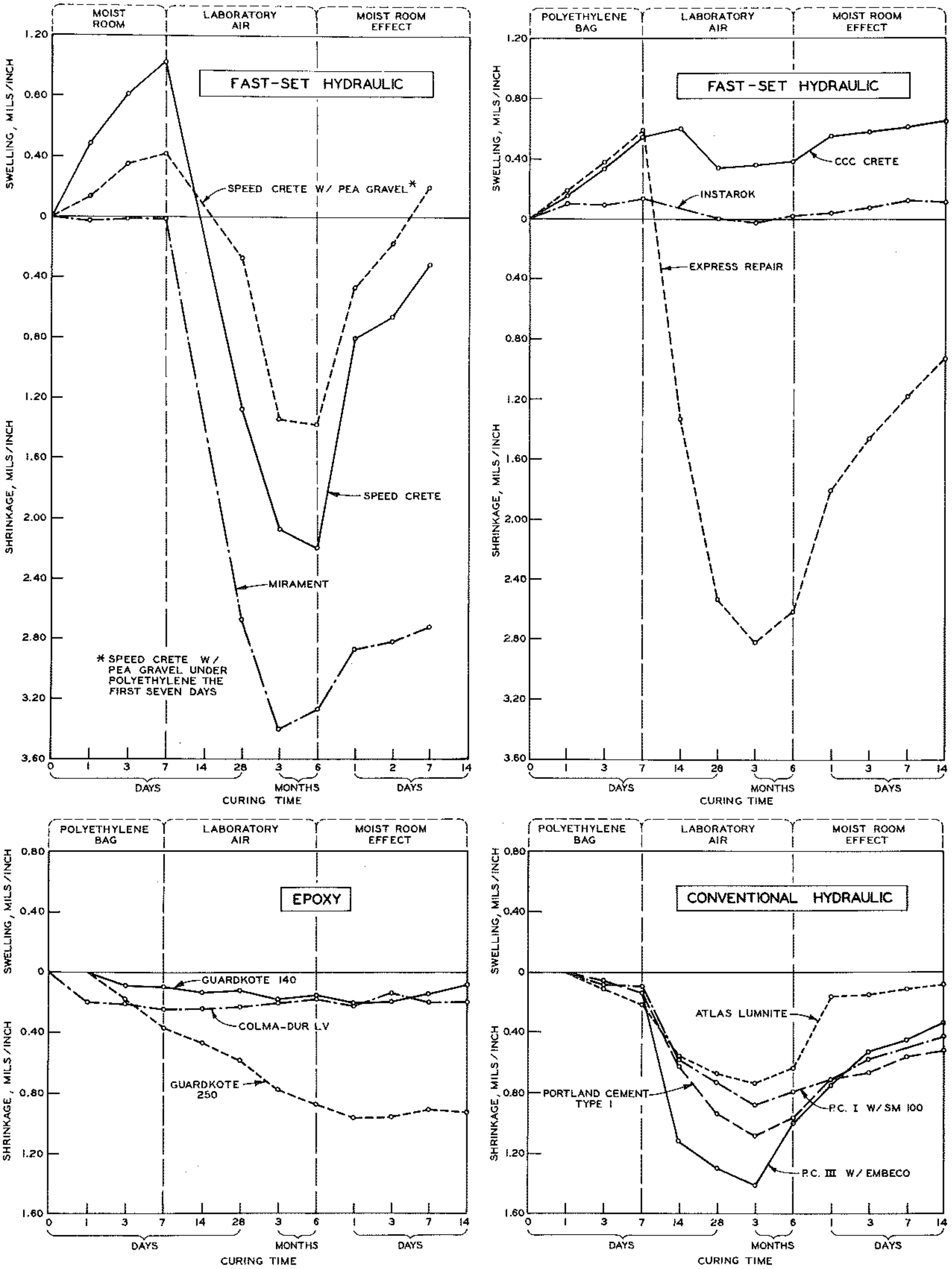

Figure 4. Shrinkage prism length variation of patching mortars.

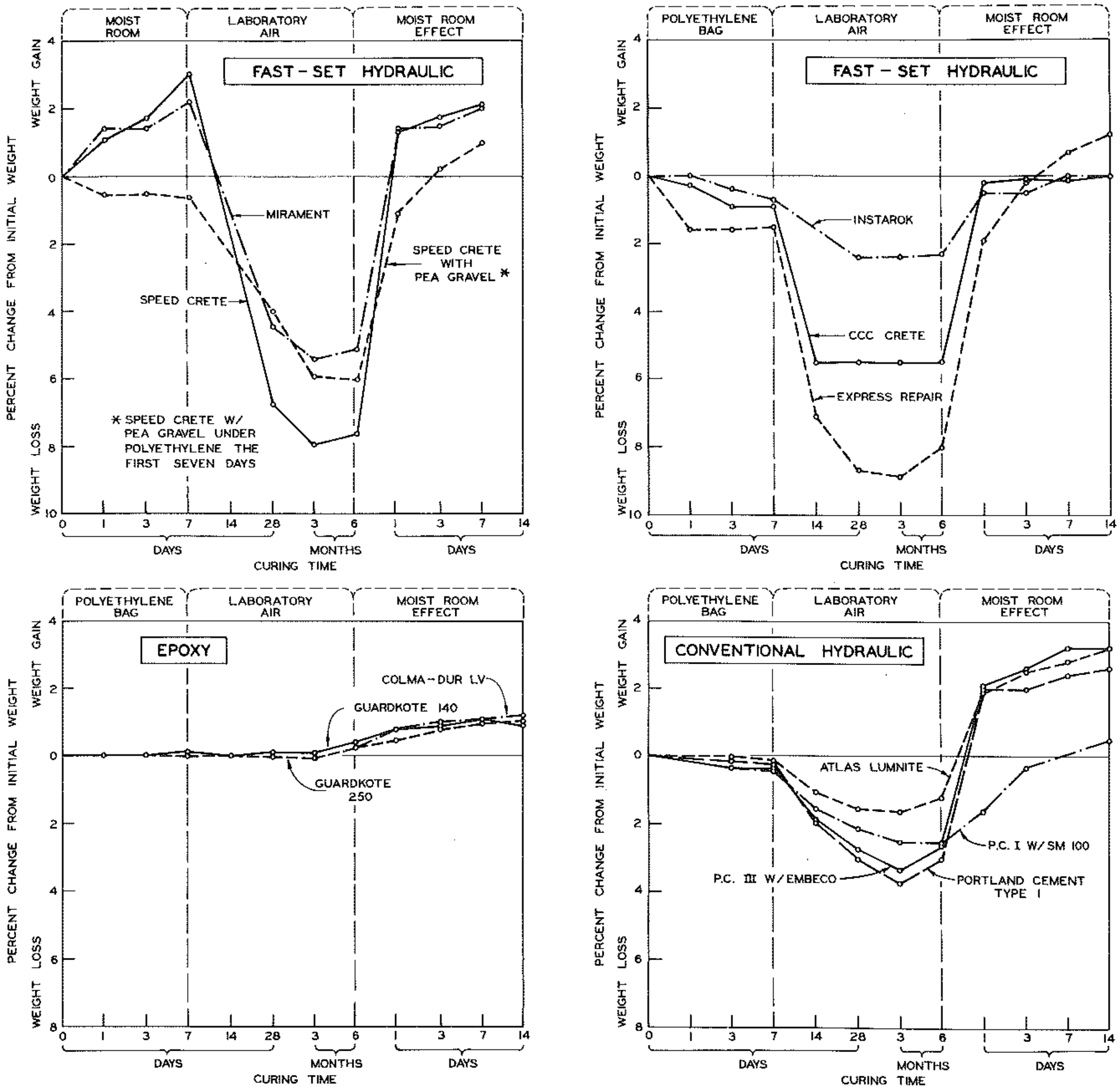

Figure 5. Shrinkage prism weight variation of patching mortars.

EVALUATION OF THE TEST MORTARS

Evaluation System

The system used to evaluate the properties of the various patching mortars was based upon laboratory test data and mortar cost. The properties evaluated are shown in Figure 6 (A through F), along with the rating points assigned them. Included are the mortars' shear bond, compressive, and tensile strengths, shrinkage characteristics, material cost per cubic foot of mixed mortar, and a special rating called "Weather Resistance Factor," which is based on the mortars' resistance to freeze-thaw damage. If the "ideal" patching mortar described earlier was rated in accordance with this system, it would receive a total of 150 points; 100 for performance, 50 for material costs.

Of the 100 points provided for performance, 36 were allotted to shear bond strength because of its critical importance to the effectiveness of the patch. In the rating intervals of the shear bond strength, greatest and equal emphasis were given to the strength developed at eight hours and strengths retained after 100 and 200 freeze-thaw cycles. Lesser emphasis was given to ratings at 24 hours, 28 days, and 50 freeze-thaw cycles.

Twenty of the 100 performance points were allotted to compressive strength. Intervals rated were at 8 and 24 hours, 3 days, and 200 freeze-thaw cycles. Greatest emphasis was given to the strength retention following 200 freeze-thaw cycles.

Shrinkage was allotted 17 points of the performance rating with greatest emphasis placed on the three-month measurement.

Weather resistance factor and tensile strength were allotted 15 and 12 performance points, respectively.

Figure 6 shows that the 50 rating points allotted for material cost have been assigned in a manner such that they are inversely proportioned to the mortars' cost in dollars per cubic foot, as given in Tables 1 through 3.

Table 5 contains a tabulation and total of all of the performance rating points. It shows how each of the 13 mortars performed for each of the rating

A. Shear Bond Strength

Strength Range, psi	Time Interval			Freeze-thaw Cycles		
	8 hr	24 hr	28 day	50	100	200
0-10	0	0	0	0	0	0
10-100	2	0	0	0	0	0
100-200	4	1	1	1	2	2
200-300	6	2	2	2	4	4
300-400	8	3	3	3	6	6
400-500	8	4	4	4	8	8

B. Compression Strength

Strength Range, psi	Time Interval			200 Freeze-thaw Cycles
	8 hr	24 hr	3 day	
0-100	0	0	0	0
100-1000	1	0	0	0
1000-2000	2	1	0	0
2000-3000	3	2	1	3
3000-4000	4	3	2	6
4000-5000	4	4	3	9

C. Shrinkage

Shrinkage Range (mils/inch)	Time Interval		
	7 day	28 day	3 mon.
1.6-1.2	0	0	0
1.2-0.8	0	2	3
0.8-0.4	1	4	6
0.4-0.0	2	6	9
any swelling	2	6	9

D. Tensile Strength

Strength Range, psi	Time Interval		
	8 hr	24 hr	3 day
0-10	0	0	0
10-100	1	0	0
100-200	2	1	1
200-300	3	2	2
300-400	4	3	3
400-500	4	4	4

E. Weather Resistence Factor

Excellent - 15
Good - 10
Fair - 5
Poor - 0

F. Cost Factor

Mixed Mortar Cost ($/cu ft)	
0-2	50
2-4	47
4-6	44
6-8	41
8-10	38
10-12	35
12-14	32
14-16	29
16-18	26
18-20	23
20-22	20
22-24	17
24-26	14
26-28	11
28-30	8
30-32	5
32-34	2
34-36	0

Figure 6. Evaluation System (rating point tables).

intervals given in Figure 6. The data for this table were taken from the graphs in Figures 1 through 4. From the graphs, the magnitude of the test values for each mortar were noted for the intervals being rated; they were then compared with the strength range shown in Figure 6, and the corresponding rating value was selected and entered in Table 5.

The weather resistance factor values shown in Table 5 were selected by observing the vulnerability of the mortar to freeze-thaw damage.

The mortars in Table 5 are divided into two groups; the fast-setting patching mortars and the conventional hydraulic patching mortars. The two Guardkote mortars are included with the former group although they did not develop any strength for the eight-hour test. The mortars in each group are arranged in descending order of their rating point total.

Table 6 combines the performance rating total of Table 5 with the cost factor shown in Figure 6. The combined rating represents a compromise between the mortars' performance and the mortars' material cost. The cost of labor for mixing and placing the mortar is not considered since it is approximately the same for all of the mortars. As in Table 5, the mortars are divided into two groups and arranged in descending order of their rating point total.

The intent of this report was to test and evaluate the fast-setting hydraulic patching mortars. By testing these mortars along with other control mortars, it was hoped that a mortar approaching the "ideal" patching mortar could be found. The evaluation system used is based on the ideal properties of a hydraulic mortar and is not necessarily ideal for evaluating epoxy mortars. However, since only three epoxy mortars were included in the report, they have been evaluated on the same basis as the hydraulic mortars for the sake of simplicity.

Patching Mortar Performance

Fast-Setting Hydraulic Mortars - Table 5 shows that although these mortars were fast-setting, they failed to develop any significant strength at 8 hours and were equally unimpressive at 24 hours, except for CCC Crete. Instarok and CCC Crete, the plaster-of-paris mortars, both resisted shrinkage but were vulnerable to weathering; Speed Crete and Express Repair were very resistant to weathering but shrank excessively; and Mirament had resistance to neither shrinkage nor weathering. Thus, none of these mortars very closely approach the "ideal" patching mortar.

TABLE 5
EVALUATION SYSTEM RATING OF PERFORMANCE

	Mortar	Shear Bond Strength						Compression Strength				Weather Resist. Factor	Tensile Strength			Shrinkage			Rating Point Total
		8 Hr.	24 Hr.	28 Day	F-T Cycles			8 Hr.	24 Hr.	3 Day	200 F-T Cycles		8 Hr.	24 Hr.	3 Day	7 Day	28 Day	3 Mo.	
					50	100	200												
	"Ideal" Patching Mortar	8	4	4	4	8	8	4	4	3	9	15	4	4	4	2	6	9	100
Fast-Setting	Colma-Dur LV	8	4	4	4	6	2	4	4	3	9	15	4	4	4	2	6	9	92
	Guard Kote 140	0	1	1	1	6	2	0	1	0	3	15	0	4	4	2	6	9	55
	Guard Kote 250	0	1	2	3	4	4	0	0	0	0	15	0	4	4	2	4	6	49
	CCC Crete	6	2	3	0	0	0	4	3	2	0	0	3	2	2	2	6	9	44
	Express Repair	2	1	0	0	0	0	1	2	2	9	15	2	3	3	2	0	0	42
	Speed Crete with Pea Gravel	2	1	0	0	0	0	1	2	2	6	15	1	1	2	2	6	0	41
	Instarok	2	1	2	0	0	0	2	1	0	0	10	2	1	1	2	6	9	39
	Speed Crete	0	1	0	0	0	0	1	1	1	9	15	1	1	2	2	0	0	34
	Mirament	2	0	0	0	0	0	1	0	0	3	5	2	1	1	2	0	0	17
Conventional Hydraulic	Atlas Lumnite	0	4	3	3	4	4	0	4	3	9	15	0	3	4	2	4	6	68
	Portland Cement Type I w/SM-100	0	2	4	4	8	8	0	1	1	6	15	0	3	4	2	4	3	65
	Portland Cement Type I	0	2	0	0	2	0	0	3	3	9	15	0	2	3	2	2	3	46
	Portland Cement Type III w/Embeco	0	1	0	0	0	0	0	4	3	9	15	0	3	4	2	0	0	41

Conventional Hydraulic Control Mortars - Table 5 shows that all of these mortars were handicapped by not having any developed strength for the eight-hour test. It also shows that of the four conventional hydraulic mortars, Atlas Lumnite received the highest rating point total for test performance; 68 points of a possible 100. It exceeded or equaled the performance rating of the other three mortars in all tests except shear bond, where it was surpassed by portland cement Type-I with SM-100. The latter mortar's overall performance rating was also good; totaling 65 points out of 100. A slow gain in compressive strength was the only weakness shown by portland cement Type-I with SM-100.

The other two mortars, portland cement Type-I and portland cement Type-III with Embeco, performed well in compression and tension and showed excellent weather resistant characteristics; both, however, shrank substantially upon removal from their sealed curing bags, and lost their bond strength.

Epoxy Control Mortars - Table 5 shows that the performance of Colma-Dur LV closely paralleled that of the "ideal" patching mortar and was vastly superior to both of the Guardkote mortars. It deviated from the "ideal" patching mortar only for the shear bond tests after 100 and 200 freeze-thaw cycles. This weakening was not caused by a mortar break-down but by a thermal shearing action as previously described in the Testing Program section of this report.

The Guardkote mortars, like the conventional hydraulic mortars, were handicapped by not having any developed strength for the 8-hour test. They were further handicapped by their flexibility which precluded the development of any sizeable compressive or shear bond strength. Their tensile strength and resistance to weathering, however, were excellent. Table 5 shows Guardkote 140 to be slightly superior to Guardkote 250. This is primarily because of its lower shrinkage and higher compressive strength characteristics.

TABLE 6
EVALUATION SYSTEM RATING OF PERFORMANCE AND COST

	Mortar	Performance Rating Point Total	Cost Factor	Combined Rating Point Total	Combined Preferential Order of Mortars
	"Ideal" Patching Mortar	100	50	150	
Fast-Setting	Guard Kote 140	55	41	96	3
	Colma-Dur LV	92	2	94	5
	Guard Kote 250	49	41	90	6
	CCC Crete	44	38	82	8
	Speed Crete w/Pea Gravel	41	41	82	9
	Express Repair	42	35	77	10
	Speed Crete	34	35	69	11
	Instarok	39	23	62	12
	Mirament	17	41	58	13
Conventional Hydraulic	Atlas Lumnite	68	47	115	1
	Portland Cement Type I w/SM-100	65	47	112	2
	Portland Cement Type I	46	50	96	4
	Portland Cement Type III w/Embeco	41	44	85	7

CONCLUSIONS

Performance Consideration

If patching mortars are to be operational after eight hours, this report shows that none of the fast-setting hydraulic mortars tested are acceptable. It would appear that epoxy mortars such as Colma-Dur LV, offer the best solution to the fast-setting patching work, i.e. could be placed and opened to traffic in six to eight hours.

Of all the patching mortars tested, our evaluation system has established the three overall best performers. In the order of their preference are the epoxy mortar, Colma-Dur LV, and the conventional hydraulic mortars, Atlas Lumnite and portland cement Type-I with SM-100. Atlas Lumnite requires 24 hours of curing before opening to traffic, and portland cement Type-I with SM-100 should be allowed three days.

Combined Performance and Material Cost Considerations

As earlier noted, the performance rating of the mortars was given a maximum of 100 points, or twice the numerical importance of the cost rating (50 points). The effect of combining these was to temper the performance rating with some degree of economic feasibility. In Table 6, where the performance rating point total of Table 5 was combined with the material cost factor of Figure 6, Colma-Dur LV, the best performing mortar, was severly handicapped by its excessive comparitive cost. The combined preferential order of Table 6 shows that the conventional hydraulic mortars, Atlas Lumnite and portland cement Type-I with SM-100, were rated a close first and second, respectively, with the epoxy mortar Guardkote 140 and portland cement Type-I mortar tied for a distant third and fourth rating. Colma-Dur LV was rated fifth.

RECOMMENDATIONS

Recommendations Based on Laboratory Results

Traffic vibrations occurring while a patching mortar is setting will destroy its bond with the concrete substrate; therefore, to successfully repair any bridge deck with a durable patch it is necessary to remove all traffic from the bridge while the patching mortar sets. From this laboratory work, then, it would appear that in cases where the bridge can be removed from service for 72 hours or longer, portland cement Type-I with SM-100 would provide the most substantial patch. In cases where removal from service is limited to 24 hours, Atlas Lumnite would be the most satisfactory patching mortar, and for service limitation of eight hours, one of the fast-setting epoxy mortars such as Colma-Dur LV would be required.

Required Field Confirmation

Before these laboratory recommendations are incorporated into permanent specifications, field test applications of these recommended patching mortars should be placed and observed to confirm the laboratory results. The Maintenance and Testing and Research Divisions could jointly select three bridge decks that are in need of repair and which can be closed to traffic until the repairs are completed. Two or three of the recommended patching mortars should be placed on each of these decks. Their performance would be periodically observed and reported, and final recommendations based on their successful performance could then be made.