EVALUATION OF FOUR ORGANIC RESIN BINDER SYSTEMS

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RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

EVALUATION OF FOUR ORGANIC RESIN BINDER SYSTEMS

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Research Laboratory Section
Testing and Research Division
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68 NM-192; 69 NM-225; 69 NM-229
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Michigan State Highway Commission
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INTRODUCTION

The following epoxy and polyester binders were presented to the Committee on New Materials for consideration and possible adoption for use on Michigan highways: "Cy Bond 2501 Part 2," "Epo Traz," "Steelcote PE-101," and, "Epi Top 100." These materials were introduced at Committee meetings in 1967, 1968, and 1969, reviewed, and referred to the Research Laboratory for evaluation.

These materials have been proposed for use in four different areas of highway construction and maintenance: they act as a binder when mixed with dry sand and form a mortar that can be used for patching spalled and broken concrete on bridge decks and pavements; the same resin mortar can also be used as a surfacing material on orthotropic steel decks; they can be spread on a concrete surface to act as a concrete sealant; and when spread on a concrete surface and covered with broadcasted sand they form a skid-resistant surface. When used for patching, a mortar material should effectively substitute the concrete it replaces by bonding tightly to the substrate concrete with little or no shrinkage, bear its share of the compressive loads which result from the composite design, and protect the substrate concrete and reinforcing steel from deicing chemicals. When used as the wearing course for an orthotropic bridge, it should function effectively in terms of wear-resistance, as well as protecting the steel deck beneath from corrosive surface moistures. In addition to these requirements, the mortar should be easily placed and should cure rapidly in order that the bridge can be quickly returned to service.

MATERIALS TESTED

Subject Materials

1) "Cy Bond 2501 Part 2" (67 NM-171) is a two-part polyester system which is formulated for use as both a sand mortar binder and a surface sealant. Its performance as a sealant will be explored in a future report. It is manufactured by the American Cyanamid Co.

2) "Epo Traz" (68 NM-192) is a two-part epoxy resin system that is formulated for use as both a sand mortar binder and a surface sealant. Again, its performance as a sealant will be covered in a later report. It is produced by the U. S. Plastics Co., and has been used extensively in commercial flooring applications.

3) "Steelcote PE-101" (69 NM-225) is a two-component polysulfide modified epoxy system which was formulated for use as a sand mortar binder. It is manufactured by the Steelcote Manufacturing Co.

4) "Epi-Top 100" (69 NM-229) is a two-component flexible epoxy binder which was developed for use as a sand mortar binder. It is produced by the Celanese Resins Co.

Control Materials

1) "Polylite 31-830" is a two-part polyester system which is formulated for use as a sand mortar binder. Although it has been used in limited highway concrete repair in other states, its performance was unknown here and it was included to provide a comparison material for the Cy Bond polyester material. It is manufactured by Reichhold Chemicals, Inc.

2) "Versamid 140" + "Genepoxy E15" ("Epon 815") is a two-component sand mortar binder whose compatible components come from two sources. Epon 815, a modified epoxy resin, was developed by the Shell Oil Co. Versamid 140, a modified polyamide curing agent is obtained from the Chemical Division of General Mills. When supplied by General Mills, Epon 815 is redesignated "Genepoxy E15."

Upon a recommendation made by the Battelle Memorial Institute, this was included as a control material (1). As this laboratory work was in progress, this material was used on an orthotropic test bridge (Creyts Rd over I 496, west of Lansing) where it currently is serving as a wearing course on the north half of the deck.

3) "Guardkote 250" is a two-component, oil extended epoxy system which was formerly produced by the Chemical Division of the Shell Oil Co. It is used primarily as a sand mortar binder and was widely used throughout Michigan as a bridge deck patching material. It also currently serves as a wearing course on the Creyts Rd bridge (south half).

4) "XE-1030" is a two-component polysulfide modified epoxy system which is used as a sand mortar binder. It was extensively used on Michigan highways for repairing joint spalls. It is manufactured by the Permalastic Products Co.

TESTING PROGRAM

Test Specimens

The test specimens and test intervals used must reveal as completely as possible all of the physical properties of the material that would have a bearing upon its performance as an orthotropic bridge deck surface and as a bridge deck patching mortar. The following mortar specimens, test intervals, and testing procedures were devised to evaluate the materials' suitability for these applications.

1) Compressive Strength - Twenty-four 2-in. cubes, conforming to ASTM C109, were used to evaluate the mortar's compressive strength. These were tested in groups of three, at 1, 3, 7, 14, and 28 days, and after 50, 100, and 200 freeze-thaw cycles following the 28-day test. The freeze-thaw cycles conformed to ASTM C666. An eight-hour test was substituted for the 14-day test for the fast-setting polyester mortars Cy Bond and Poly-lite.

2) Tensile Strength - To evaluate the tensile strength, 15 briquets were tested in groups of three at 1, 3, 7, 14, and 28 days. With these, as well, an eight-hour test was substituted for the 14-day test in the case of the fast-setting polyester mortars. The briquets conformed to ASTM C190.

3) Shear Bond Strength - The shear bond strength was determined for bonding to both concrete and steel; 24 specimens were tested in each group. For concrete bond strength, the test specimens consisted of a 1-in. mortar cap cast to the 2 by 4-in. sawed face of a 3 by 4 by 3-in. concrete block. For steel bond strength, the specimens consisted of a 1-in. mortar cap cast to the sand-blasted back of a 3-in. length of a 3-in. channel section. Both groups of specimens were clamped on a testing apparatus and loaded until the mortar cap sheared off in single shear. Both groups of specimens were tested in groups of three at the same time intervals and freeze-thaw cycles as the mortar cubes. Failure of the specimen often occurred in the concrete. No ASTM standard currently covers this type of shear bond test.

4) Shrinkage - To determine the shrinkage characteristics of the resin 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. The prisms were weighed and measured at 1, 3, 7, 14, and 28 days, and at three and six months. An eight-hour measurement was also included for the fast-setting polyester mortars. After the six-month measurement, the prisms were placed in the moist curing room to measure the length and weight changes caused by water absorption. Measurements were made at 1, 3, 7, and 14 days.

5) Thermal Coefficient of Expansion - To determine the thermal expansion properties of the resin mortars, the same prisms used to determine the shrinkage characteristics were also used to determine the mor-

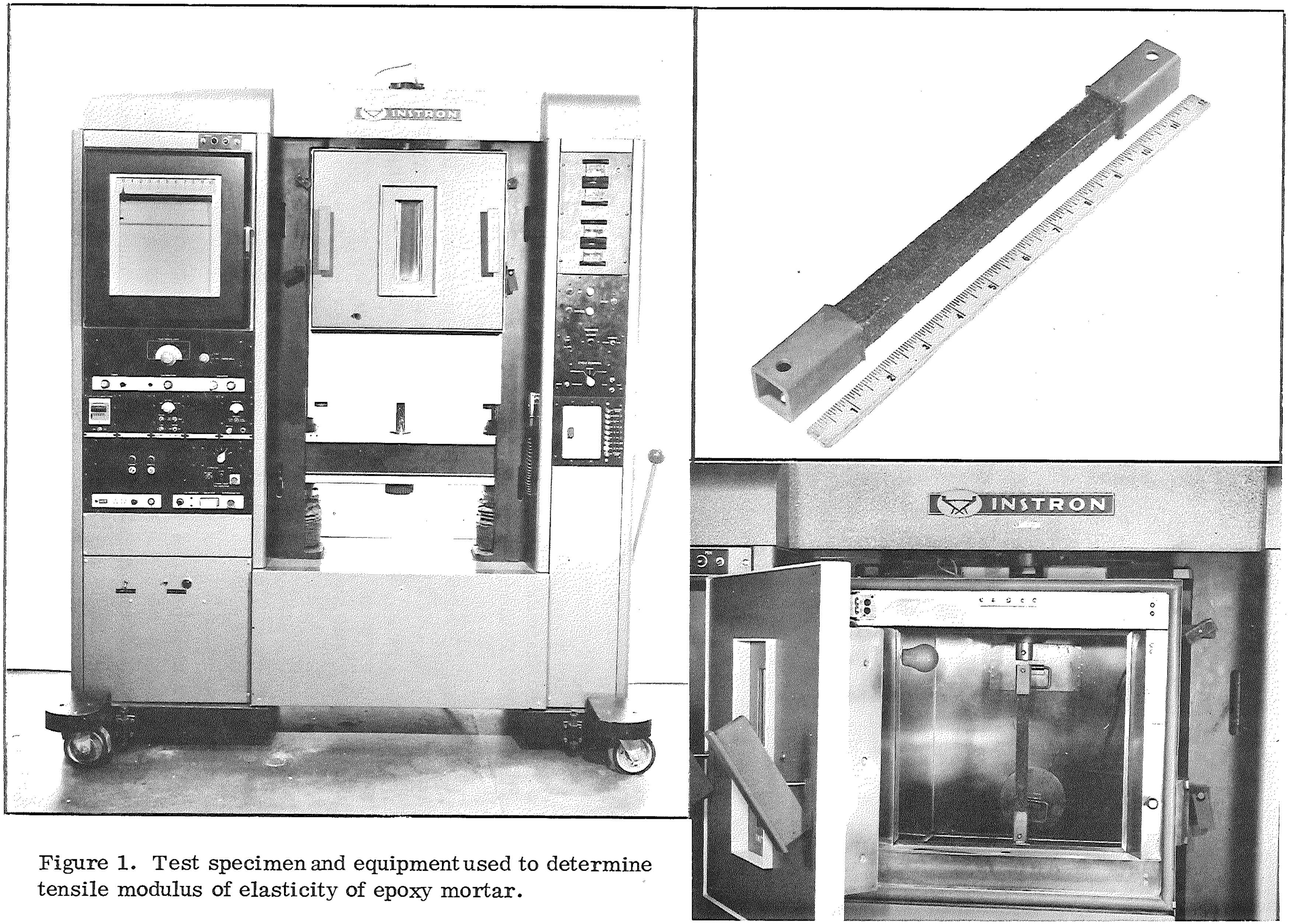


Figure 1. Test specimen and equipment used to determine tensile modulus of elasticity of epoxy mortar.

tar's thermal expansion properties. Measurements were made at the following temperatures, 0, 35, 76, and 120 F. Since the measuring apparatus was kept at room temperature, a stable prism temperature was maintained by insulating them with polyethylene sheeting and handing them out through an access port of the walk-in freezer one at a time. For the 120 F temperature, they were brought up to the required temperature in an insulated box which was placed in a large oven. They were measured as removed, one at a time, through a portal in the insulated box.

6) Tensile Modulus of Elasticity - This physical property was required to calculate the tensile stresses developed during the flexural fatigue testing of the composite beams which were used in this work. To determine the tensile modulus of elasticity, three prisms were cast with a 3/4-in. square cross-section and an 8-in. gage length. The ends of the prisms were embedded in steel tubular loading adaptors which were each 2 in. long. Since the resin mortar's bonding strength to the steel tubular ends greatly exceeded the prism's tensile strength, no problems were encountered with the prism end anchorages. Testing was performed after a seven-day room temperature cure in a standard Instron Model TT-D (20,000-lb capacity) testing machine which recorded the total load and total strain on chart paper. The machine was equipped with an environmental chamber which maintained the required temperature to within 1/10 deg F. Tests were run at 0, 35, room temperature, and 120 F. Figure 1 shows a view of the testing arrangement.

7) Flexural Fatigue Characteristics - To determine the epoxy mortars' flexural fatigue properties when used as an orthotropic bridge deck surface, a fatigue beam was built with a 1/2-in. layer of epoxy mortar bonded to a 1/4 by 2 by 26-in. steel bar. The bar, in turn, was mounted horizontally on a testing machine as a simple beam with cylindrical bearings, 24-in. from center to center (Fig. 2). For each cycle, the cam—through a connecting rod—forced the beam from an undeflected position down to maximum deflection and back again. The testing speed was about seven cycles per second. The epoxy mortar, bonded on the underside of the steel bar, was stressed in tension only. A maximum mid-point deflection of 0.08 in. was used which resulted in a span-over-deflection ratio of 300. The epoxy mortar was instrumented with SR-4 strain gages after a seven-day room temperature cure, at the mid-point, 3/8-point, and 1/4-point of the span length.

Because the Poisson's ratio of the epoxy mortar was not determined, the strain gage readings were of little value in accurately determining the actual surface strains. However, they did provide an insight into the plastic nature of the epoxy mortars. A silver paint conductor stripe was also

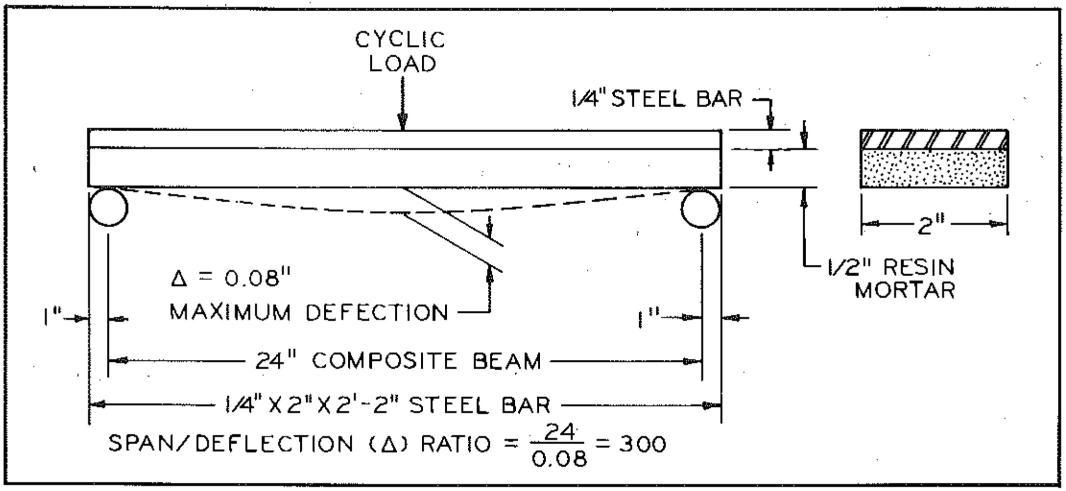


Figure 2. Steel bar and resin mortar composite beam used in fatigue testing.

painted along an edge to shut-off the machine when a crack occurred. It had been planned for the machine to run one million cycles each at the three different temperatures; room temperature, 35, and 0 F. A strain gage recording machine was stationed near the machine and connected through a timer switch such that it would record the strain gage readings for one minute out of each hour (Fig. 3).

Mortar Preparation

Initially, all epoxy mortars were to be mixed such that the volume of epoxy binder exactly equalled the volume of the voids in a well-consolidated 2NS sand (2.2 gal/cu ft). However, when this mix criteria was used, the mixes had a noticeable excess of epoxy binder which seemed to bleed to the surface on the unconfined mortar and drain through and away from the unconfined mortar. When another mix was tried, with a 10 percent reduction in epoxy binder, it eliminated the excess, but still seemed to completely saturate the sand. A microscopic study of the two mortar mix types revealed both to have isolated air voids comprising approximately 14 percent of the total mortar volume, but with one distinct difference: the voids of the richer mix were spherical in shape, while the voids of the leaner mix were irregular.

Further studies of the strengths of the two mortars revealed insignificant differences; the leaner mortar was 5 percent stronger in compression, while the richer mortar was 3 percent stronger in tension. Since so little difference existed, the leaner mix was used in this study to minimize the forming difficulties by eliminating the excess epoxy.

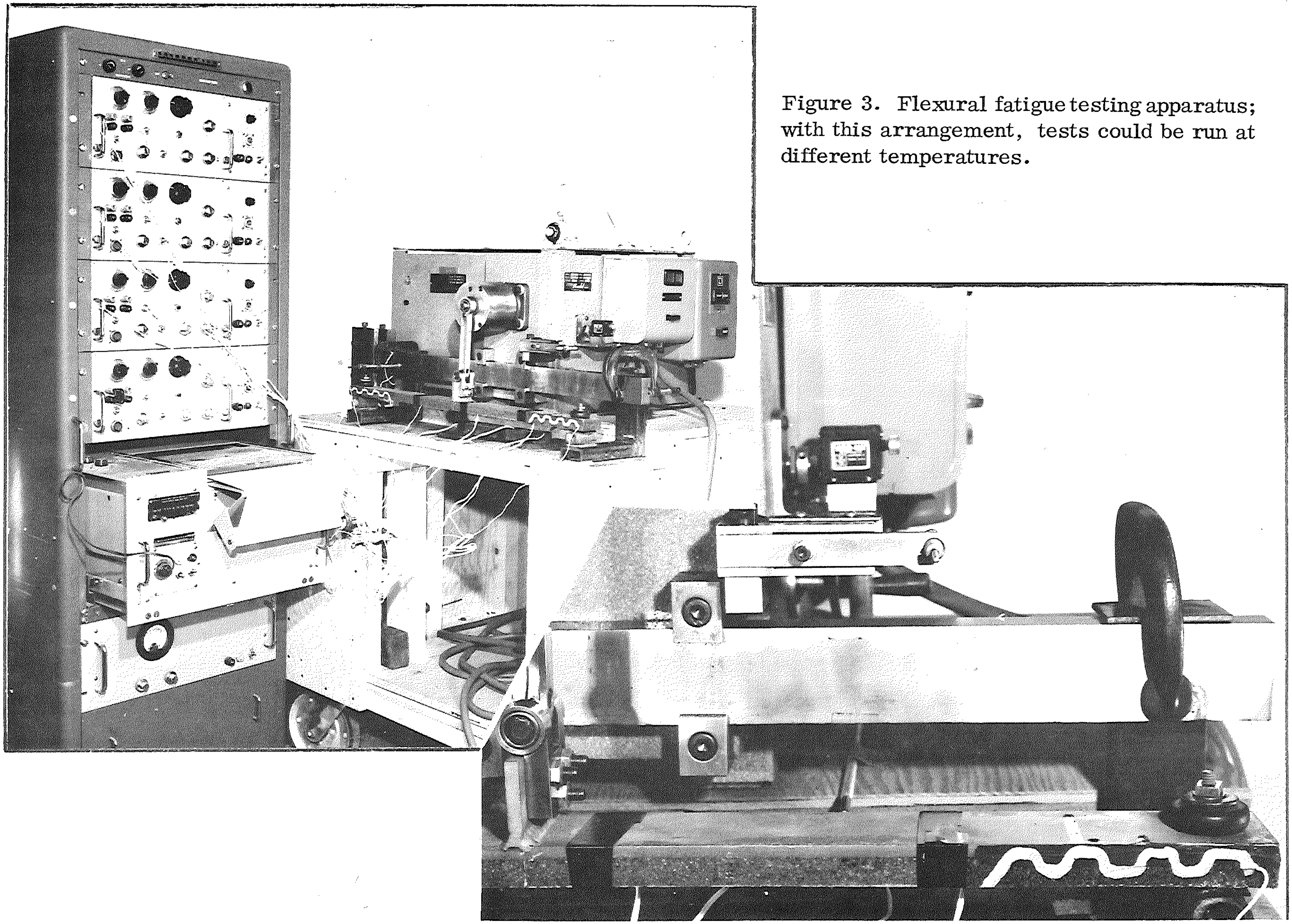


Figure 3. Flexural fatigue testing apparatus; with this arrangement, tests could be run at different temperatures.

TABLE 1
RESIN MORTAR PROPORTIONING
Component Properties and Mix Proportions of One Cubic Foot of Resin Mortar

Resin Mortar	Weight of Sand, lb	Part A (resin)			Part B (curing agent)			MEK Peroxide Catalyst, fl oz	Weight of Portland Cement Filler, lb
		Sp. Gr.	Viscosity, poises at 25 C	Volume, gal	Sp. Gr.	Viscosity, poises at 25 C	Volume, gal		
Cy Bond 2501	107.9	1.12	3.7	1.860	--	--	--	2.3	---
Polylite 31-830	108.0	1.13	6.9	1.860	--	--	--	2.3 (MEK) 0.7 (Cobalt)	---
Epo Traz (1st mat'l)	101.4	1.56	116	1.071	1.58	100	1.071	---	---
Epo Traz (2nd mat'l)	90.4	1.56	120	1.310	1.53	41	1.310	---	---
Versamid 140 and E15	107.5	1.13	(E15) 8.1	0.932	0.96	(V 140) 155	0.932	---	---
Guardkote 250	107.0	1.04	42	0.934	0.88	0.90	0.934	---	---
Steelcote PE-101	106.4	1.18	61	0.950	1.24	11	0.950	---	---
XE-1030	106.7	1.14	34	1.272	1.21	11	0.635	---	---
Epi-Top 100	106.7	1.08	12	1.465	0.98	6	0.424	---	---
Epi-Top 100 + 25 percent p.c.	103.2	1.08	12	1.473	0.98	6	0.427	---	4.190
Epi-Top 100 + 50 percent p.c.	98.0	1.08	12	1.513	0.98	6	0.440	---	8.620
Epi-Top 100 (richer mix)	105.2	1.08	12	1.526	0.98	6	0.440	---	---
Creyts Rd, Versamid 140 and E15	101.1	1.13	(E15) 8.1	1.069	0.96	(V 140) 155	1.069	---	---
Creyts Rd, Guardkote 250	101.0	1.05	52	1.075	0.90	0.5	1.075	---	---

The proportioning used in the various epoxy and polyester mortars, along with their binder components physical properties are given in Table 1. Cured properties of the resin binders only (containing no aggregate) are given in Table 2. All of the subject and control mortars included in this report were given a one-minute mix in a Hobart Model N50 laboratory mixer. The following describes the preparation of each of the mortars.

1) Cy Bond 2501 - This polyester binder was furnished as two materials; a primer material called 'Part 1' and the binder or sealant material, 'Part 2.' Both materials were catalyzed with 0.8 percent methyl-ethyl-ketone peroxide by weight. In accordance with the manufacturer's instructions, the primer was applied to the surfaces of both the concrete and steel shear bond specimens and allowed to set for two hours before the mortar was placed. The mortar was hand tamped into the molds in accordance with ASTM C109.

2) Polylite 31-830 - This polyester binder was accompanied by a two-component epoxy primer. The manufacturer recommended trying the material with and without the primer to see which would produce a better bond to concrete or steel surfaces. The polyester was catalyzed with 0.8 percent methyl-ethyl-ketone peroxide and 0.25 percent of a cobalt solution, both measured by weight. The priming epoxy was mixed and applied to both the steel and concrete shear bond block surfaces about one hour before the mortar was placed. The mortar was hand tamped into all specimen molds.

3) Epo Traz - Because an insufficient amount of this material was originally received, more had to be requested to complete our work. When the latter material was opened it was discovered to be different than the original material. Parts A and B of both materials contained inert mineral filler, but they differed in the amount of filler used. This alteration substantially changed the viscosity of the components and the mortar proportioning had to be changed accordingly to produce a workable mix. An analysis of the latter material disclosed that Part A contained approximately 61 percent filler by weight; approximately 90 percent of this filler was silica, 9 percent was calcium carbonate, and a small but undetermined amount was amorphous carbon or lampblack. Some of this filler might have been fly ash. Part B contained about 60 percent silica by weight.

From the original material the following specimens were molded: cubes, briquets, steel and concrete shear bond blocks, and shrinkage prisms. From the later material, the modulus of elasticity prisms were made along with the composite flexural fatigue beams. Another set of shrinkage prisms was cast from this material.

TABLE 2
CURED RESIN BINDER PROPERTIES
(Without Aggregate)

Resin Binder	Gel Time 100 g, min	Tensile Strength, psi	Elongation in./in., percent	Shear Bond, Concrete, psi	Absorption, 24-hr, Water, percent
Cy Bond 2501	41	5,030	10.0	530	--
Polylite 31-830	39	1,620	47.1	320	--
Epo Traz (1st mat'l)	155	990	8.1	405	--
Epo Traz (2nd mat'l)	260	525	15.8	440	0.33
Versamid 140 and E15	330+	5,290	13.0	830	0.45
Guardkote 250	40	870	51.0	695	--
Steelcote PE-101	67	1,950	33.0	630	--
XE-1030	44	4,360	21.0	1,260	0.14
Epi-Top 100	59	3,135	19.2	910	0.36
Versamid 140 and E15 - Creyts Rd	400	5,640	14.8	880	0.45
Guardkote 250 - Creyts Rd	58	995	40.0	570	0.33

Note: All tests run after 7 day cure at room temperature except Guardkote 250 which was cured 16 hr at room temperature plus 6 hr at 158 F and XE-1030 which was cured 4 days at room temperature.

The surface of the steel and concrete shear bond blocks, the steel bar of the fatigue beam, and the tubular ends of the modulus of elasticity prisms were all primed with the combined epoxy before the mortar was applied. The manufacturer describes this material as being a resilient epoxy.

4) Versamid 140 + Genepoxy E15 - Laboratory work with this material revealed that the Versamid 140 component had a high viscosity; this raised the viscosity of the combined epoxy to approximately that of honey. Because of this higher viscosity, it was necessary to keep the epoxy temperature in the high 70's to assure good workability of the mortar. To avoid mold bonding problems, a wax base release agent was used since silicone grease was ineffective in preventing this mix from sticking to the molds. The bonding surfaces of the shear bond specimens, the fatigue beams, and the modulus of elasticity prisms were all primed with combined epoxy prior to placement of the epoxy mortar.

5) Guardkote 250 - The epoxy used in this work was made up of several Guardkote 250 samples of various lot numbers. The samples used were only those that had been approved and had identical specific gravities and relatively close viscosities. The collective specific gravity and viscosity of the resulting components is given in Table 1. Laboratory tests on the combined epoxy showed that it met all requirements of the MDSHT Supplemental Specification (1-27-66) for epoxy resin binder type B. The bonding surfaces of the shear bond specimens, the fatigue beam, and the modulus of elasticity prisms were all primed with combined epoxy prior to the placement of the epoxy mortar.

6) Steelcote PE-101 - Since only two quarts of this material were sent us, we limited our test specimens to only those which were associated with the fatigue beam stress calculations. Hence, we cast four shrinkage prisms which also determined the material's thermal coefficient of expansion, three tensile modulus of elasticity prisms, and two fatigue beams. The bonding surfaces of the fatigue beams and the modulus of elasticity prisms were primed with combined epoxy prior to placement of epoxy mortar.

7) XE-1030 - Since we had several acceptable samples of this material on hand, representing many different lot numbers, we combined these to make about two gallons of part A and one gallon of part B. The collective epoxy was then tested for viscosity and specific gravity of each part; the gel time, tensile strength, and shear bond strength of the combined epoxy were also tested. These tests showed this composite sample to have excellent properties, exceeding the minimum requirements of the MDSHT 1967 Road and Bridge Specifications for epoxy polysulfide binder. The bonding surfaces of the shear bond specimens, the fatigue beams, and the modulus of elasticity prisms were all primed with combined epoxy prior to placement of the epoxy mortar.

8) Epi-Top 100 - A sufficient quantity of this material was available not only to pour a full series of test specimens with a 'normal' mortar mix, but also to make three additional sets of specimens associated with fatigue testing. The work with the additional specimens was prompted by a question which arose regarding the fatigue characteristics of a 'filled' epoxy mortar, and what benefit, if any, an inert filler might produce in the epoxy binder. Therefore, following the normal mix, portland cement, which was found to be a suitable filler, was mixed with the epoxy binder to produce one grout which contained 25 percent filler by weight, and another grout containing 50 percent filler by weight. These grouts were then combined with sand to form suitable mortar.

The third set of fatigue associated mortar specimens was made up with the 'unfilled' epoxy binder. This mortar contained 10 percent more

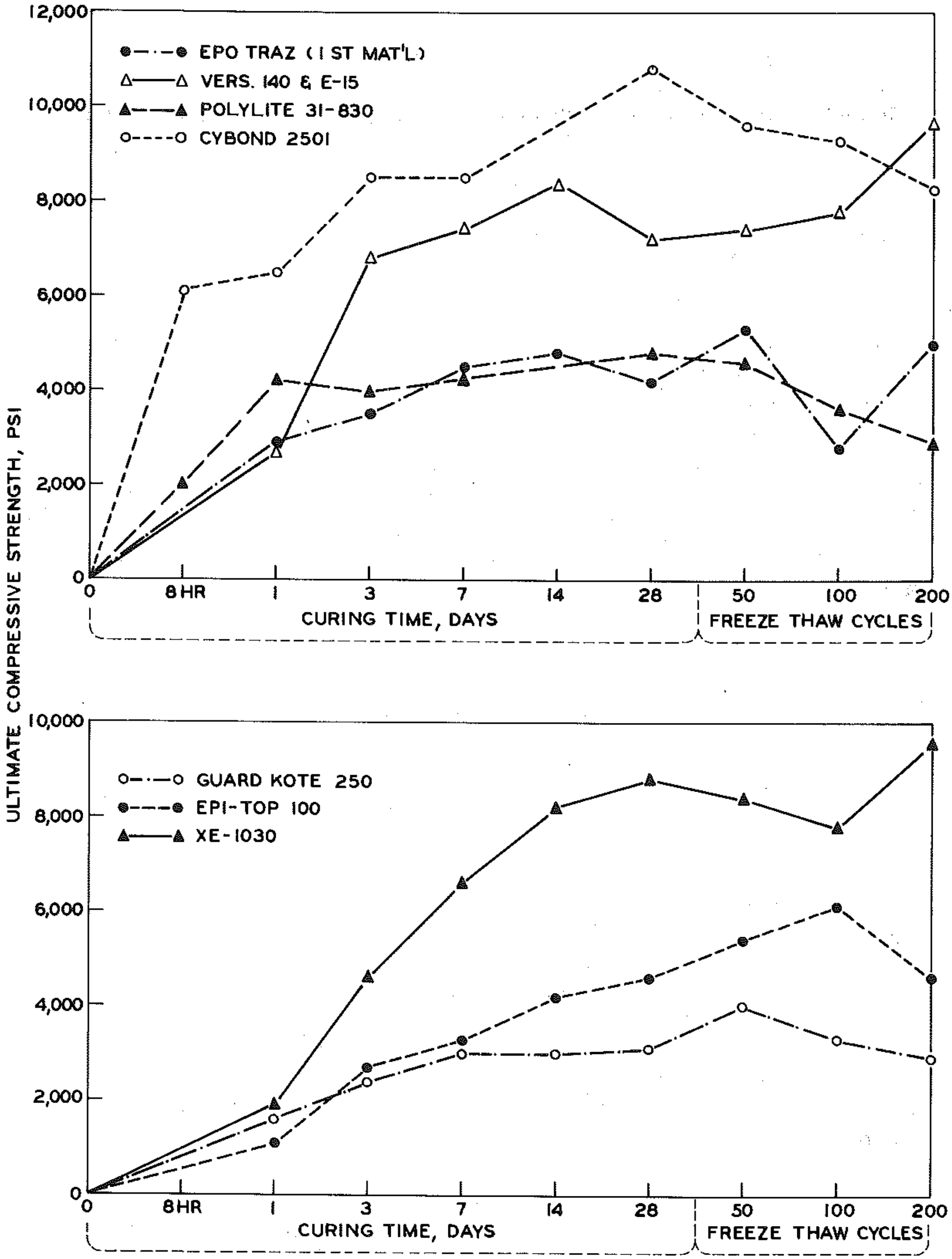


Figure 4. Compressive strength of resin mortars.

epoxy than the normal mix. In the tables and figures, this latter mortar is referred to as the 'richer mix.' In each of the above described cases, the bonding surfaces of the shear bond specimen, the fatigue beam, and the modulus of elasticity prisms were all primed with the epoxy binder or grout prior to placement of the epoxy mortar.

9) Creyts Rd Versamid 140 + Genepoxy E15 - The work with this epoxy was done while the construction of the Creyts Rd bridge deck was in progress. The mortar tested in this work was held as similar as possible to the mortar used on the actual orthotropic bridge deck. The materials used were sampled directly from the project site and the material proportioning was kept identical. The only specimens cast were those that were associated with the fatigue beam stress calculation. The bonding surfaces of the fatigue beam and the modulus of elasticity prisms were all primed with combined epoxy prior to placement of the epoxy mortar.

10) Creyts Rd Guardkote 250 - The same considerations observed for the preceding epoxy were also observed for this material. This work was also done while the construction of the Creyts Rd orthotropic bridge deck was in progress.

TEST RESULTS

As each resin mortar was tested, the values were recorded and unit data calculated. All data are presented in this report in either graphic or tabular form. Graphically presented data are shown in Figures 4 through 9, and include: compressive strength (Fig. 4); tensile strength (Fig. 5); bond strength in shear to concrete (Fig. 6); bond strength in shear to steel (Fig. 7); shrinkage prism length and weight variation (Figs. 8 and 9). The following data are given in Tables 3 through 7; thermal coefficient of expansion (Table 3); tensile modulus of elasticity (Table 4); tensile modulus of elasticity (120 F tests) (Table 5); calculated tensile resin mortar stresses at mid-span of composite beam during fatigue testing (Table 6); and flexural fatigue test results of resin mortar and steel composite beams (Table 7).

Compressive Strength

The following materials were tested in compression: the two polyester resins, Cy Bond 2501 and Polylite 31-830; the epoxy grout Epo Traz (1st material); and the epoxy binders, Versamid 140 + Genepoxy E15, Guardkote 250, Epi-Top 100, and XE-1030. Of these materials, the two polyester resins were the only ones that set fast enough to allow an eight-hour test.

The graphs in Figure 4 show that all the mortar developed over 2,000 psi in 24 hours except Guardkote 250, Epi-Top 100, and XE-1030.

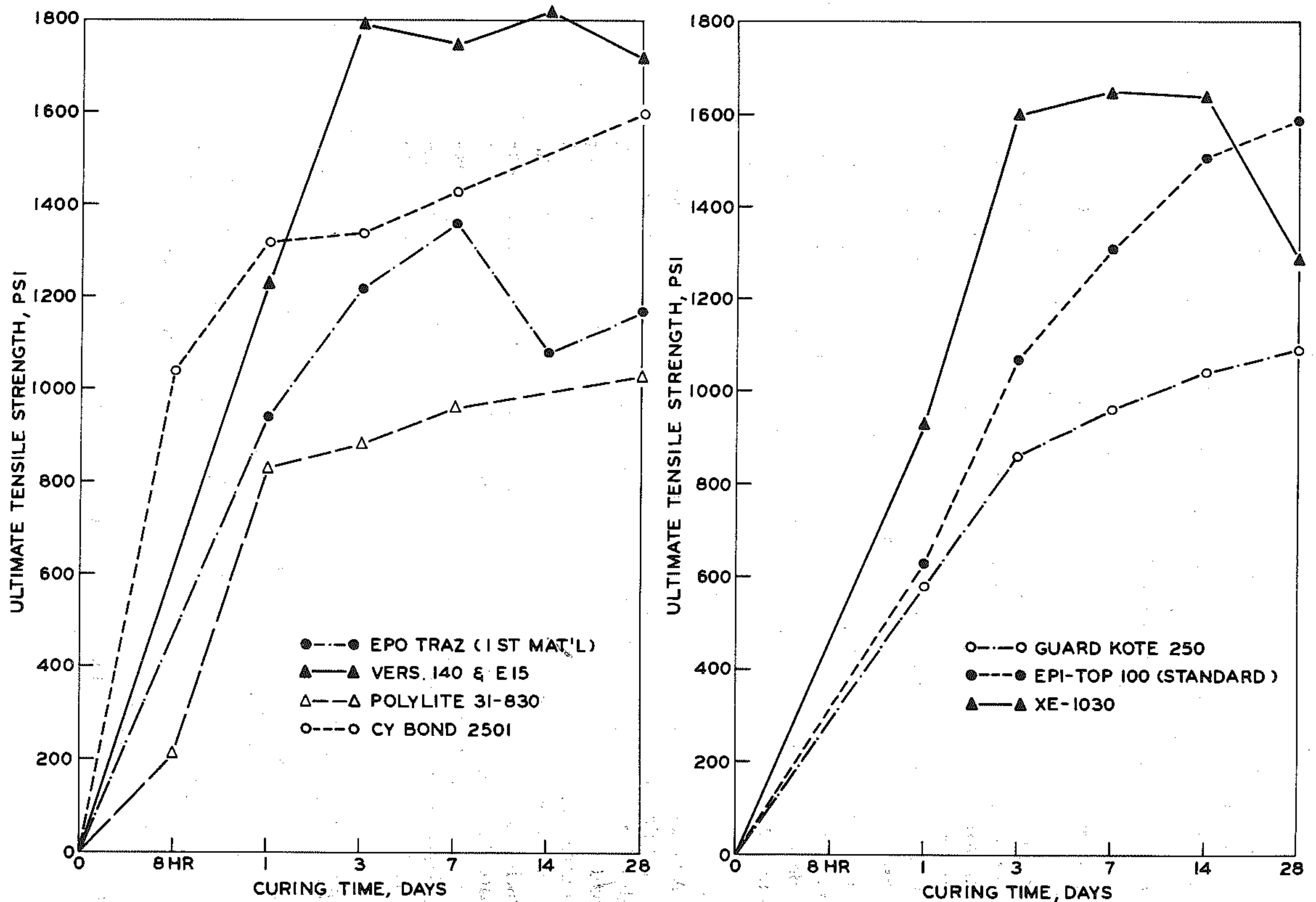


Figure 5. Tensile strength of resin mortars.

Tensile Strength

The same materials which were tested in compression were also tested in tension, of which only the polyester mortars were set sufficiently to allow an eight-hour test. The graphs in Figure 5 show that the resin mortars, unlike the hydraulic mortars, build up a high tensile strength.

Bond Strength in Shear to Concrete

The same materials that were tested in compression were also tested to determine their shear bond strength to concrete. All of these materials developed a substantial bond strength except the polyester resin mortar Polylite 31-380 (Fig. 6). Broken surfaces of this material developed a strong odor of uncured polyester which would seem to indicate that some of the material was catalytically insensitive. The other polyester resin mortar, Cy Bond 2501, showed a substantial loss in strength between the 7 and 28 day tests. This is attributed to progressive shrinkage which weakened the bond between these successive readings.

The graphs also show that in many cases the first 50 freeze-thaw cycles tended to enhance the bond strength; subsequent freeze-thaw tests, however, showed a weakening effect. In many of the tests of these high strength resin mortars, failure would occur through the concrete block instead of at the bonded surface.

Bond Strength in Shear to Steel

The same materials that were tested for their bond strength to concrete were also tested for their bond strength to steel. The major difference noted between the shear bond test results of the resin mortar bonded to concrete, and that to steel, was the higher values obtained by some of the stronger mortars when bonded to steel (Fig. 7).

Shrinkage Prism Length and Weight Variation

Shrinkage measurements were made on all the materials tested. Measurements of many of the materials were completed before the thermal coefficient of expansion measurements revealed that resin mortars were dimensionally very sensitive to temperature changes, and consequently had a very high thermal coefficient of expansion. Following this revelation, all subsequent shrinkage prisms measurements were accompanied by a recorded laboratory air temperature. This permitted a temperature correction to be made for each measurement and gave a shrinkage value that was

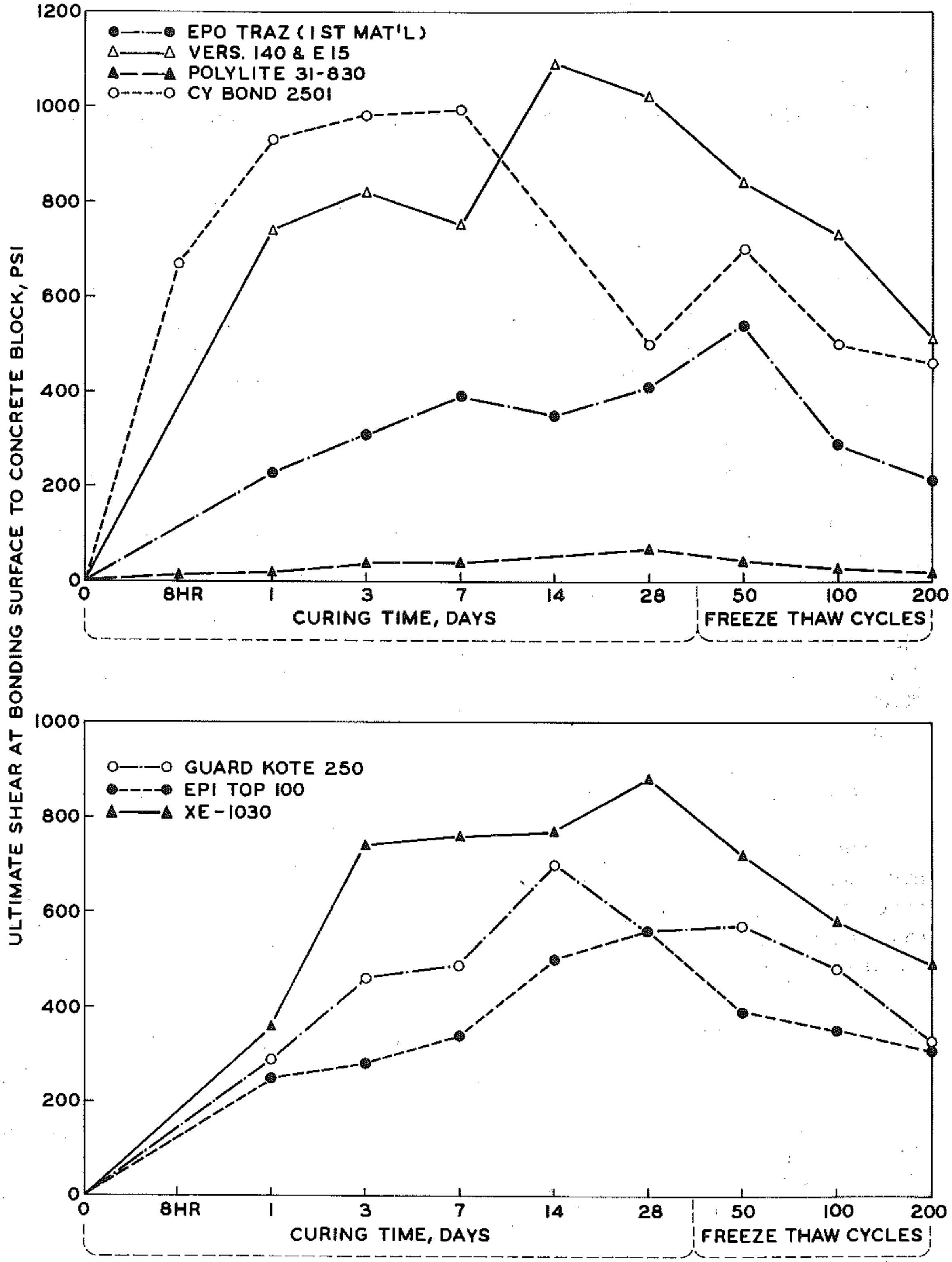


Figure 6. Resin mortars bond strength in shear to concrete.

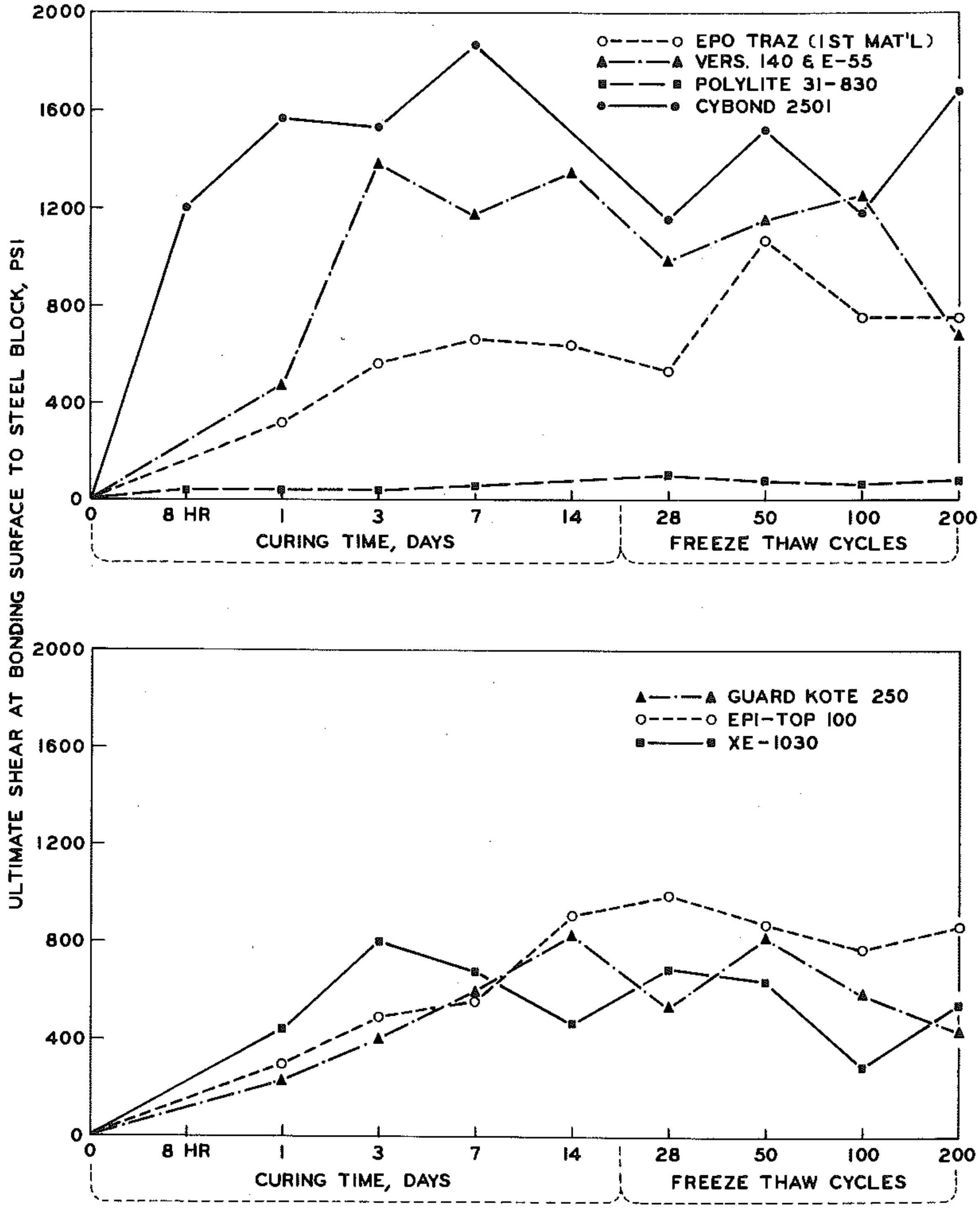


Figure 7. Resin mortars bond strength in shear to steel.

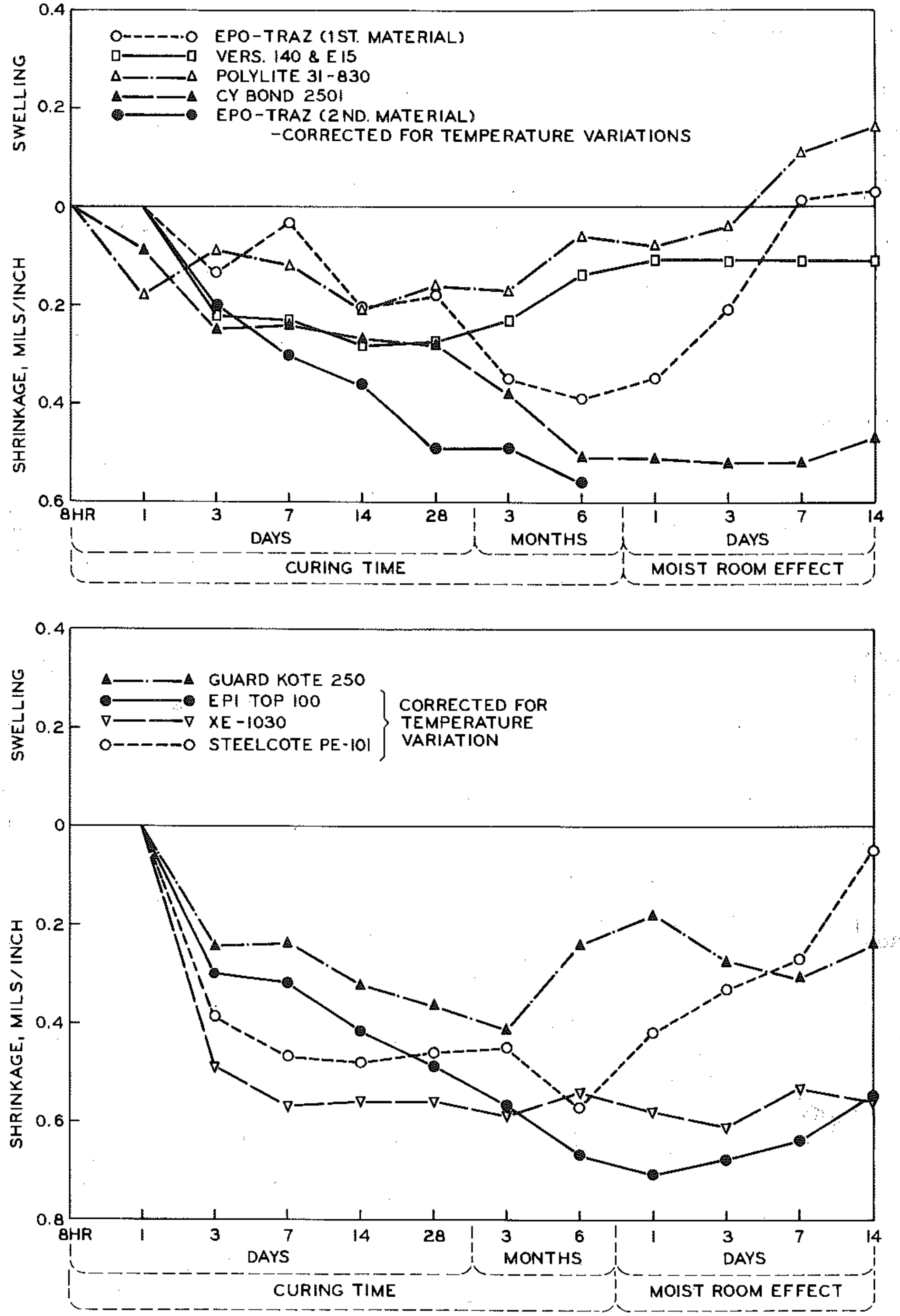
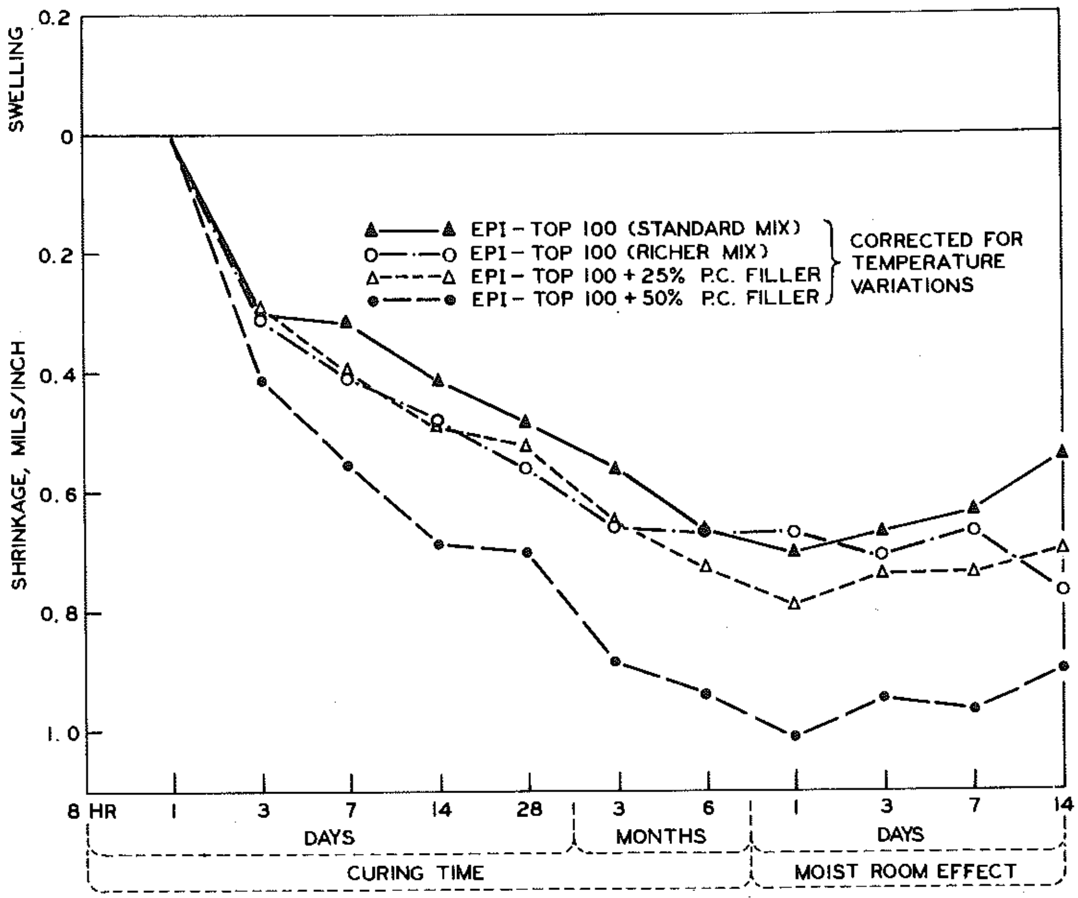


Figure 8. Shrinkage prism length variation of resin mortars.



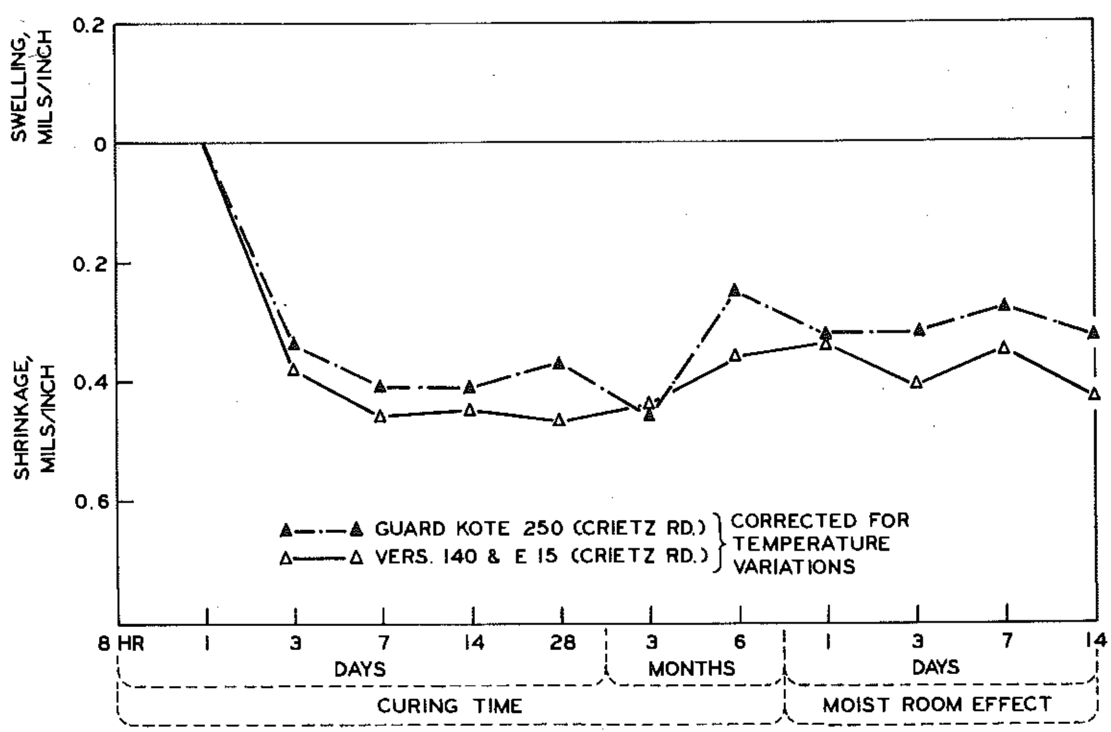
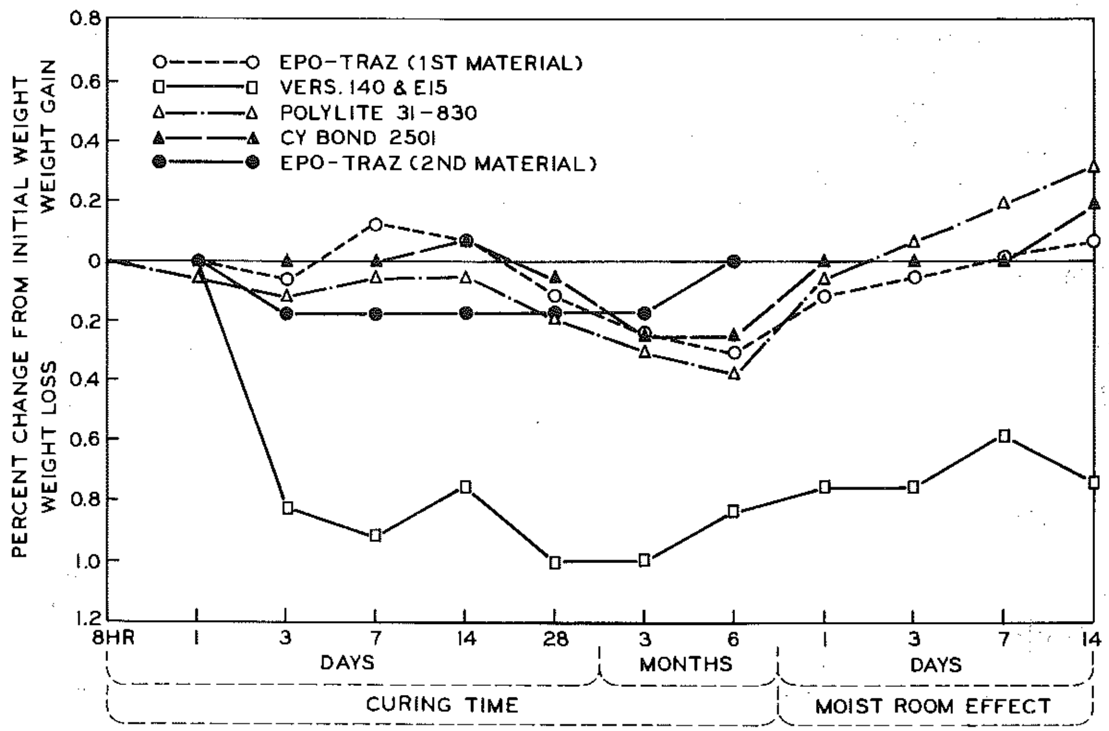


Figure 8 (Cont.). Shrinkage prism length variation of resin mortars.



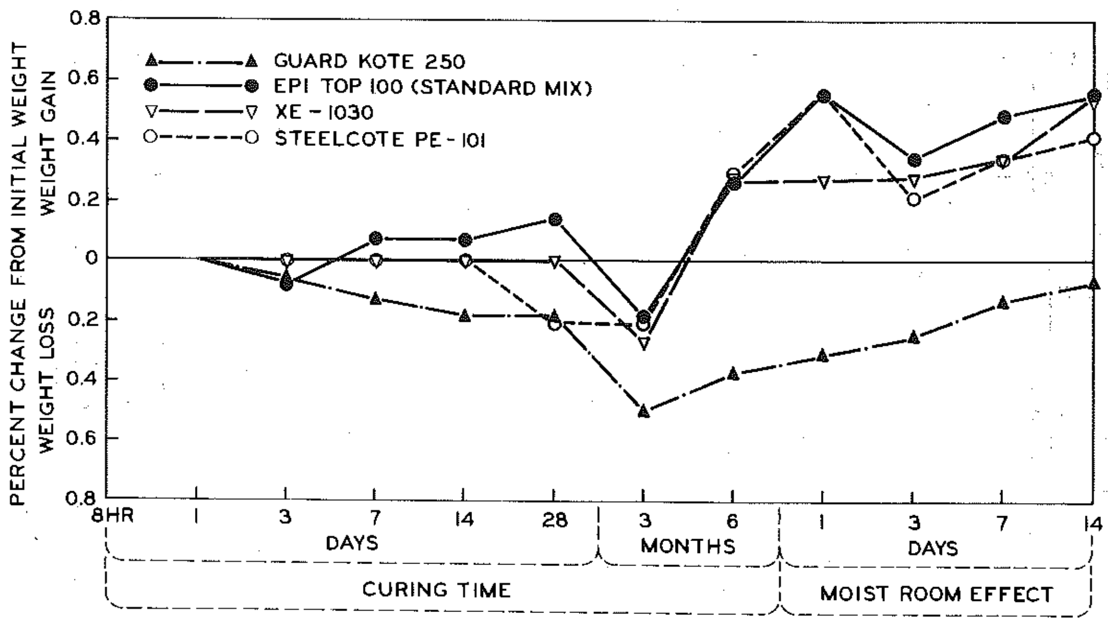


Figure 9. Shrinkage prism weight variation of resin mortars.

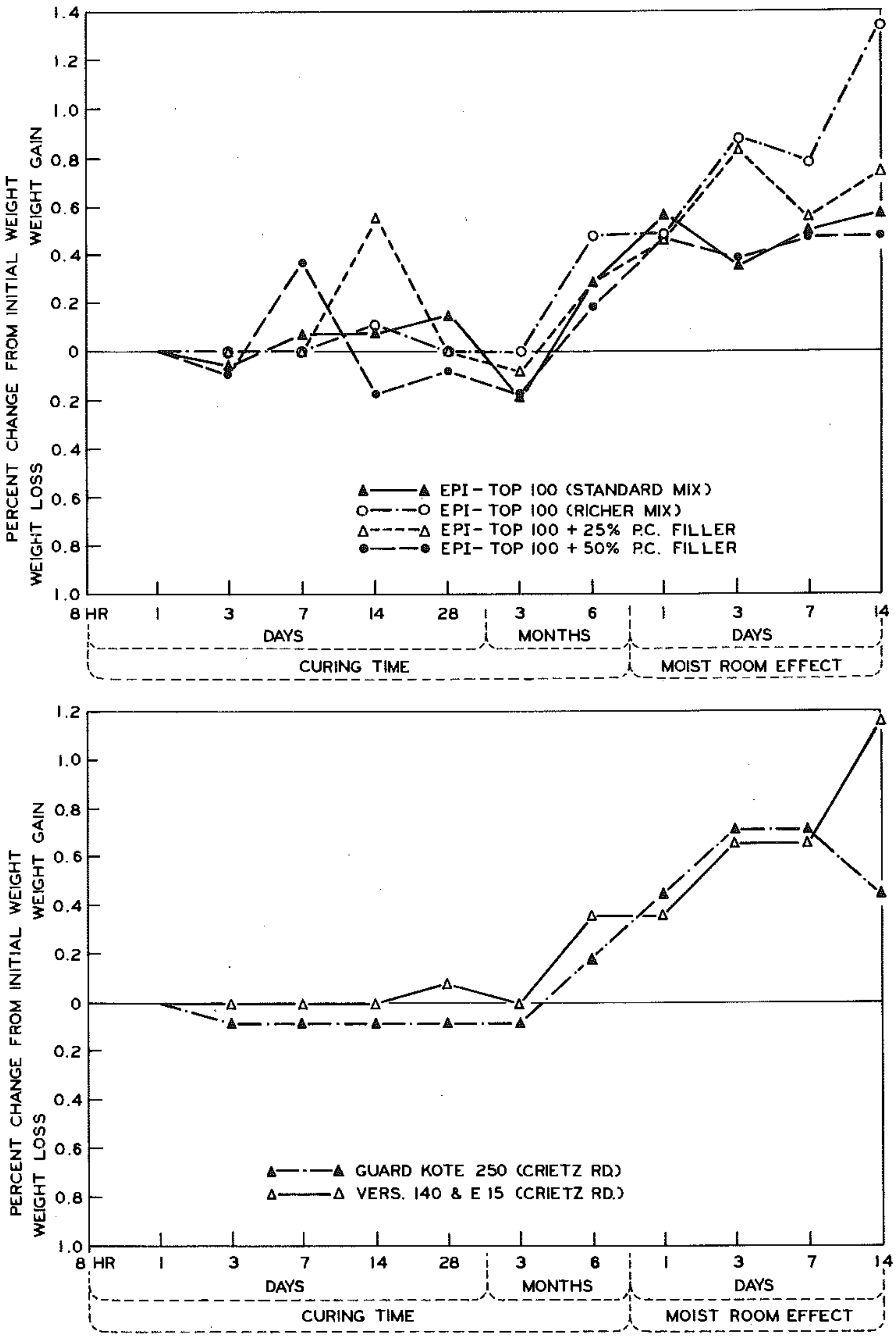


Figure 9 (Cont.). Shrinkage prism weight variation of resin mortars.

undistorted by temperature variation. Those mortars whose shrinkage performance contains a temperature correction are noted on the graphs in Figure 8. Naturally, those graphs which do not contain the temperature correction are noticeably erratic.

The weight variation graphs in Figure 9 are plotted as the percentage gain or loss in weight. Because the variations in weight are small, the prisms light, and the weighing accuracy only to the nearest gram, the graphs appear to vascillate excessively. Despite this detracting characteristic, however, the general trends of the graph are still evident. A close study of the graphs of Figures 8 and 9 indicate a substantial initial shrinkage during the first three days of curing that occurs without detectable weight loss. This apparently is caused by a realignment of the atoms of the newly formed molecule into a more consolidated arrangement. After three days, the rate of shrinkage rapidly diminishes, but continues throughout the first three months. Some of this shrinkage could possibly be caused by the slow loss of slightly volatile portions of the resin that remained uncombined. In the case of the Guardkote 250, it was suspected that some of the oil with which the epoxy was extended was lost through volatilization. This observation was noted in connection with the excessive shrinkage of Guardkote 250 in an earlier report (2) and the Creyts Rd bridge inspection report of August 4, 1971.

Another observation of interest was the erratic changes in weight that occurred in most of the epoxy mortars between the third and sixth month of measurement. It was during this time interval that the measurements were made to determine the thermal coefficient of expansion, and it was established that some small residual changes in length did result from this work. Unfortunately, however, no weight measurements were taken at this time. From the moist room duration it appears that most of these epoxy mortars absorb moisture, but none except Steelcote PE-101 undergoes a significant increase in length. Following the moist room exposure, this epoxy was allowed to air dry three weeks, during which time it shrank an average of 0.16 mils/in. below its six-month cure length. A special absorption test run on this epoxy showed that it absorbed 0.77 percent of its weight in water.

Thermal Coefficient of Expansion

Thermal coefficient measurements were made on all the materials tested and the values calculated are given in Table 3. Keeping in mind that the approximate thermal coefficient for steel and concrete is 6×10^{-6} in./in./deg F, it can be seen that these epoxy and polyester mortars expand

TABLE 3
THERMAL COEFFICIENT OF EXPANSION
OF RESIN MORTARS

Resin Mortar	Average Thermal Coefficient of Expansion, in./in./F x 10^{-6}		
	0 to 35 F	35 to 70 F	70 to 120 F
Cy Bond 2501	10.5	12.6	13.9
Polylite 31-830	13.5	17.1	15.9
Epo Traz (1st mat'l)	14.7	21.8	24.5
Epo Traz (2nd mat'l)	26.3	32.3	27.6
Versamid 140 and E15	12.5	12.9	20.6
Guardkote 250	19.5	23.2	27.2
Steelcote PE-101	21.7	23.6	30.9
XE-1030	13.8	13.7	20.3
Epi-Top 100 (standard)	15.2	16.1	22.1
Epi-Top 100 (richer mix)	16.6	17.9	23.1
Epi-Top 100 + 25 percent p.c.	15.2	16.6	23.6
Epi-Top 100 + 50 percent p.c.	16.6	17.4	24.6
Creyts Rd, Versamid 140 and E15	19.3	19.4	27.1
Creyts Rd, Guardkote 250	30.9	34.7	40.9

and contract at a rate of two to five times as much as the steel or concrete. It must also be realized that when these epoxy or polyester mortars are bonded to steel or concrete in highway bridge deck applications, thermal strains will result as the temperature changes. These strains will be in proportion to both the temperature change and the difference between the thermal coefficients. Realizing the basic incompatibility, resin producers have 'flexibilized' their products to compensate for, or minimize, the problem. Hence, flexibilized mortars will stretch and compress easily without building up high stresses that might cause tensile or compressive failures.

TABLE 4
RESIN MORTAR TENSILE MODULUS OF ELASTICITY

Resin Mortar	Temperature, F	Tensile Modulus of Elasticity x 10^6 100 psi	200 psi	400 psi	800 psi
Cy Bond 2501	0	--	0.40	0.44	0.51
	35	--	0.40	0.43	0.51
	76	0.28	0.30	0.39	0.42
	120	0.18	0.20	0.16	--
Polylite 31-830	0	--	0.33	0.36	0.38
	35	--	0.33	0.36	0.36
	76	0.20	0.20	0.17	--
	120	0.03	--	--	--
Epo Traz (1st mat'l)	0	(Not tested because of material depletion.)			
	35				
	76				
	120				
Epo Traz (2nd mat'l)	0	--	0.28	0.33	0.38
	35	--	0.23	0.23	0.21
	76	0.03	--	--	--
	120	0.02	--	--	--
Versamid 140 and E15	0	--	0.35	0.40	0.46
	35	--	0.33	0.38	0.44
	76	--	0.30	0.36	0.42
	120	0.04	0.03	--	--
Guardkote 250	0	--	0.35	0.40	--
	35	--	0.33	0.36	--
	76	--	0.23	0.21	--
	120	--	--	--	--
Steelcote PE-101	0	--	0.30	0.33	0.40
	35	--	0.28	0.32	0.36
	76	--	0.23	0.26	0.30
	120	0.12	0.11	0.07	--

Resin Mortar	Temperature, F	Tensile Modulus of Elasticity x 10^6 100 psi	200 psi	400 psi	800 psi
XE-1030	0	--	0.30	0.35	0.39
	35	--	0.28	0.33	0.37
	76	--	0.27	0.31	0.35
	120	--	0.25	0.27	0.28
Epi-Top 100	0	--	0.28	0.35	0.41
	35	--	0.27	0.32	0.38
	76	--	0.25	0.30	0.33
	120	0.05	0.04	--	--
Epi-Top 100 + 25 percent p.c.	0	--	0.30	0.33	0.38
	35	--	0.30	0.31	0.35
	76	--	0.23	0.23	0.18
	120	0.03	--	--	--
Epi-Top 100 + 50 percent p.c.	0	--	0.28	0.33	0.39
	35	--	0.27	0.31	0.36
	76	--	0.20	0.19	0.16
	120	0.03	--	--	--
Epi-Top 100 (richer mix)	0	--	0.28	0.33	0.38
	35	--	0.30	0.32	0.36
	76	--	0.20	0.21	0.16
	120	0.03	--	--	--
Creyts Rd, Versamid 140 and E15	0	--	0.30	0.33	0.34
	35	--	0.28	0.32	0.33
	76	--	0.27	0.30	0.32
	120	0.05	0.02	--	--
Creyts Rd, Guardkote 250	0	--	0.28	0.30	--
	35	--	0.22	0.28	--
	76	0.18	0.16	0.11	--
	120	--	--	--	--

When used to patch concrete loaded in compression these mortars fail to transfer load, and thus cause high stress concentrations in the original concrete that surrounds the patch.

Tensile Modulus of Elasticity

This test was run on all the materials tested, except the Epo Traz, whose initial supply was depleted by earlier test specimens. The results are given in Tables 4 and 5. An examination of the results shows that the relationship between stress and strain in these resin mortars is very sensitive to temperature; being very flexible at high temperatures (low modulus) and very rigid at low temperatures (high modulus). It is interesting to note, however, that even in its most rigid condition, the maximum modulus attained by any of these resins is only about one-tenth the modulus of concrete and about one-hundredth the modulus of steel. These relative modulus values must be considered when contemplating the use of these resin mortars with concrete or steel.

Flexural Fatigue Characteristics

As with the tensile modulus tests, all materials were tested in fatigue except the first supply of Epo Traz which was depleted by earlier test specimens. The test results of this work are shown in Tables 6 and 7. Table 6 shows the calculated stresses developed at mid-span in the epoxy mortar during fatigue testing. It is interesting to note that the live load flexural stress developed at 0 F in most of these resin mortars constituted only about half the total stress developed. The other stress contributing factors included shrinkage, thermal contraction, and dead load flexure. Of these factors, the shrinkage stress was calculated from shrinkage values shown in Figure 8 and the tensile modulus of elasticity values shown in Table 4. In this computation it was assumed that the mortar was restrained from actually shrinking by the steel bar to which it was bonded. The thermal contraction stresses were calculated from the thermal coefficient of expansion values in Table 3 and the tensile modulus values in Table 4; this computation not only assumed the restraint afforded by the steel bar, but also took into account the steel's thermal shortening as well. This was effected by using the difference between the mortar's and steel's thermal coefficients. Since both the shrinkage and thermal stresses were additive and would place a load on the steel bar, a correction was necessary for the stress relief which occurred due to compression of the bar. Even though this represented only a small value, it was calculated and is included in Table 6. The dead load and live load stresses were calculated from their respective loading placed on a simple beam whose moment of inertia was

TABLE 5
RESIN MORTAR TENSILE MODULUS OF ELASTICITY
(120 F Tests)

Resin Mortar	Temper- ature, F	Tensile Modulus of Elasticity x 10^6			
		25 psi	50 psi	75 psi	100 psi
Cy Bond 2501	120	0.170	0.160	0.170	0.180
Polylite 31-830	120	0.067	0.056	0.047	0.034
Epo Traz (2nd)	76	0.033	0.029	0.029	0.031
	120	0.015	0.015	0.015	0.015
Versamid 140 and E15	120	0.071	0.057	0.050	0.041
Guardkote 250	120	0.016	0.010	---	---
Steelcote PE-101	120	0.130	0.130	0.120	0.120
XE-1030	120	0.200	0.200	0.210	0.220
Epi-Top 100	120	0.072	0.062	0.057	0.054
Epi-Top 100 + 25 percent p.c.	120	0.024	0.025	0.029	0.034
Epi-Top 100 + 50 percent p.c.	120	0.035	0.032	0.031	0.031
Epi-Top 100 (richer mix)	120	0.034	0.032	0.029	0.028
Creyts Rd, Versamid 140 and E15	120	0.074	0.064	0.053	0.046
Creyts Rd, Guardkote 250	120	0.017	0.012	---	---

TABLE 6
CALCULATED TENSILE RESIN MORTAR STRESSES AT MID-SPAN
OF COMPOSITE BEAM DURING FATIGUE TESTING

Resin Mortar	Test Temp, F	7-Day Shrinkage, psi	Thermal Contraction, psi	Stress Reduction From Steel Bar Strain, psi	Dead Load Flexure, psi	Live-Load Flexure (max, deflect.) psi	Total Tensile Stresses, psi
Cy Bond 2501	R.T.*	62	---	-2	27	360	447
	35	74	112	-5	29	430	640
	0	79	184	-7	32	491	779
Polylite 31-830	R.T.	23	---	-1	18	196	236
	35	30	147	-4	26	339	538
	0	31	234	-6	27	370	656
Epo Traz (2nd mat'l)	R.T.	9	---	0	4	29	42
	35	66	256	-5	21	248	586
	0	78	507	-13	27	360	959
Versamid 140 and E15	R.T.	57	---	-1	26	349	431
	35	57	101	-4	28	390	572
	0	69	191	-6	29	420	703
Guardkote 250	R.T.	32	---	-1	19	207	257
	35	46	241	-6	27	370	678
	0	60	406	-12	30	460	944
Steelcote PE-101	R.T.	92	---	-2	21	237	348
	35	118	217	-7	26	339	693
	0	132	388	-12	29	400	937
XE-1030	R.T.	126	---	-2	24	299	447
	35	142	96	-4	25	329	588
	0	148	185	-8	27	380	732
Epi-Top 100 (standard)	R.T.	77	---	-1	23	278	377
	35	91	130	-4	25	329	571
	0	98	226	-8	27	370	713
Epi-Top 100 (richer mix)	R.T.	76	---	-2	19	207	300
	35	104	152	-5	25	319	595
	0	112	261	-8	27	370	762
Epi-Top 100 + 25 percent p.c.	R.T.	88	---	-2	21	237	344
	35	110	136	-5	25	329	595
	0	120	241	-8	27	370	750
Epi-Top 100 + 50 percent p.c.	R.T.	122	---	-2	19	207	346
	35	152	132	-5	25	319	623
	0	158	241	-9	27	360	777
Creyts Rd, Versamid 140 and E15	R.T.	96	---	-2	23	278	395
	35	101	166	-5	26	339	627
	0	115	301	-9	26	349	782
Creyts Rd, Guardkote 250	R.T.	62	---	-1	15	166	242
	35	62	291	-7	23	278	647
	0	82	560	-13	25	329	983

* Room temperature

TABLE 7
FLEXURAL FATIGUE TEST RESULTS OF RESIN MORTAR AND STEEL COMPOSITE BEAMS

Resin Mortar	Flexural Cycles to Failure x 10^6		
	Room Temp.	35 F	0 F
Cy Bond 2501	0.2	---	---
Polylite 31-830	1.0	---	---
Epo Traz (2nd mat'l)	1.1	1.1	2.3+
Versamid 140 and E15	1.1	0.6	---
Guardkote 250	1.0	0.6	---
Steelcote PE-101*	1.2	1.3	0.3
XE-1030**	1.2	---	---
Epi-Top 100 (standard)	1.2	0.4	---
Epi-Top 100 (richer mix)*	1.2	0.1	---
Epi-Top 100 + 25 percent p.c.	1.2	1.3	0.1
Epi-Top 100 + 50 percent p.c.	1.2	1.0	0.1
Creyts Rd, Versamid 140 and E15	1.2	0.6	---
Creyts Rd, Guardkote 250	1.2	1.0	0.1

Note: Unless (**) which indicates one beam, or (*) which indicates two beams, all results shown above are the average of three test beams.

the composite value of the two materials. The calculation, however, was complicated by the following factors:

1) The tensile modulus of elasticity of the resin mortar varied with both the temperature range and the stress magnitude (Tables 4 and 5).

2) The variation in the mortar's tensile modulus caused a variation in the ratio between the tensile moduli of the mortar and the steel; this caused the moment of inertia of the composite section to vary with both the temperature range and stress magnitude.

3) The variation in the moment of inertia produced a variation in the equivalent live loading that resulted from the constant deflection imposed by the flexural fatigue testing. Therefore, the equivalent live loading increased with a decrease in temperature.

4) The equivalent concentrated dead load did not vary with the moment of inertia and hence the dead load stresses would never be proportional to the live load stresses from one temperature range to the next.

The stresses shown in Table 6 were calculated using the tensile modulus of elasticity value which most nearly corresponded to the total stress produced.

As previously stated, the strain gages were of little academic value, and hence their recorded data were omitted from this report. However, the following impressions were deduced from their records.

Strain Distribution - It appeared that the resin mortar had some plastic characteristics which allowed it to partially distribute the maximum strain at mid-span all along the mortar lying in the center third of the beam. This was evident because the strain gage at the 3/8-point, which should theoretically have carried only 75 percent of the maximum strain at mid-span, was actually being strained all the way from 80 to 95 percent of the maximum. This would emphasize the ease with which this material creeps internally during plastic flow. As would be suspected, the mortar distributed this strain more uniformly at room temperature than at the two lower temperatures.

Appearance at Failure - Shortly before failure occurred, which always consisted of a tensile crack in the mortar, there would appear a shortening or elongation in the strain gage reading. Apparently, the weakest section in the high strain area would begin to yield with excessive plastic flow.

This would substantially reduce the magnitude of the strain in the mortar on either side of the affected area. The strain gage, depending upon its location with reference to the affected area, would read accordingly. Beam failure usually occurred within a couple of hours after the weakest area yielded. The resulting crack disrupted the control circuit, which ran through the silver paint stripe, and shut the machine off.

Table 7 shows that all the resin mortars except Cy Bond 2501 successfully completed one million cycles of fatigue testing at room temperature. Table 6 shows that the stress on these mortars at room temperature were due to shrinkage and flexure, and the total magnitude was quite low. Table 7 further shows that only a few of the resin mortars completed one million cycles at 35 F, and Table 6 indicates that these failures resulted from a large increase in the stresses. Table 6 indicates that there was not only a substantial rise in the shrinkage and flexural stresses, but also the additional thermal stress caused by the differential rate of contraction between the mortar and steel. The increase in the shrinkage and flexural stresses was caused by the increase in the tensile modulus of elasticity which for some mortars was substantial (Table 4).

A study of these tables also shows another large increase in total stresses between 35 and 0 F, and that only one resin mortar tested well at 0 F -- the Epo Traz epoxy. The first two of the three Epo Traz beams ran one million cycles at 0 F before they were removed to make room for the next beams. With the third beam, however, it was decided to run it to failure. This was done and the beam ran through four million cycles at 0 F. This fatigue performance, when compared with the other resin mortars, was exceptionally good, and it led to speculation as to whether the mineral filler contained in this epoxy could have been partially responsible for its unique success. To check this possibility, the Epi-Top 100 epoxy, of which we had an abundant supply, was run four different ways with complete sets of tensile modulus prisms, thermal coefficient and shrinkage prisms, and fatigue beams. The consistency of these four sets is described in this report under the section on mortar preparation and the proportioning weights are given in Table 1. The results of this work are shown in Tables 4 through 6. They seem to indicate that the mineral filler substantially improved the mortar's fatigue testing characteristics, but did little to change its basic properties, except possibly to lower its tensile modulus of elasticity at room temperature for higher loads. The richer mortar appeared to hinder the epoxy's fatigue performance.

DISCUSSION

The purpose of this work, as explained in the Introduction, was to evaluate the suitability of resin mortars as protective coatings and wearing courses for the steel surface of orthotropic bridge decks, and as a mortar for patching deep spall areas in concrete bridge decks. The performance that the mortar had to achieve to attain this suitability was also described in the Introduction. The balance of the report was concerned with tests and evaluation designed to reveal the mortar's physical properties; those relevant to these specific applications.

Resin Mortar Performance on Orthotropic Bridge Decks

Interpretation of Test Results - The fatigue testing was designed to simulate flexural strain which would occur on negative moment areas of the orthotropic decks. Table 7 shows the results of this work, and indicates that, in general, resin mortars are not well suited for this application. Table 6 shows that shrinkage and thermal factors contribute heavily to the total stresses developed during cold weather and that to stay within the capacity limits of the mortar, live and dead load stresses must be substantially reduced.

Discussion of Key Characteristics - From the physical properties relevant to this application, it would appear that the greatest problem is presented by the differences between the thermal coefficients of expansion of steel and the resin mortars; a lesser but still significant factor is the shrinkage of these mortars. Epo Traz, even though it had one of the highest thermal coefficients, was the only mortar to perform satisfactorily in fatigue testing. The most obvious reason for this success was its lower tensile modulus of elasticity; this permitted lower stresses than were developed in other mortars, especially at room temperature where the material's fatigue limit was practically untaxed. One factor which could have affected and improved the material's tensile modulus was the filler with which it was extended; this could have contributed an internal fluidizing effect which allowed greater elastic flow. The improvement produced by a filler in the fatigue testing characteristics of the Epi-Top 100 mortar adds support to this contention. The type of filler used could also have a strong bearing; for example, the spherical particles of a fly ash filler might have a greater fluidizing influence than the random shaped particles of a crushed mineral filler. Filler particle shape, however, was not considered here.

Although no test was set up to specifically simulate the performance of resin mortars on a bridge deck patch, much of the test data obtained in this work is pertinent to that application. The only exception would be the tensile modulus of elasticity which is not nearly as applicable as the compressive modulus. The only compressive modular work done for this study was some preliminary measurements made with 2-in. compression cubes to determine the relationship of the elastic limit to the ultimate load. The results obtained from this preliminary work indicated that the compressive modulus ranged in magnitude from a value equal to the tensile modulus to a value three times as great; depending upon the nature of the resin.

As outlined in the Introduction, a patching mortar or patching concrete must be an effective substitute for the concrete it replaces; hence, it must maintain full contact and a strong bond at all times with the boundaries and substrate of the original concrete, and it must effectively carry its share of the compressive load that results from the composite design.

Interpretation of the Test Results - An examination of the test data in this report indicates that for most mortars, the shear bond and compressive strengths would adequately substitute for the replaced concrete, but problems arise when the shrinkage, thermal, and elasticity data are examined.

1) Shrinkage. The shrinkage characteristics of epoxy mortars vary greatly. The average shrinkage value is about one-third less than that associated with portland cement concrete. Compared with concrete, this is good; but it still means that the resin mortar will develop craze cracking and pull away from the patch boundary.

2) Thermal Coefficient of Expansion. These values of resin mortars, as shown in Table 3, are seen to vary from twice to five times as much as the value of concrete. Thus, during a temperature change, the dimensions of resin mortar will want to contract or expand much more than concrete. This means that when a resin mortar is bonded to concrete, any temperature change will induce a shearing stress at the bonding plane proportional to the difference in the thermal coefficients of expansion. In cold climates where the temperature variation is great, this shearing stress may exceed the strength of the concrete and the concrete substrate will fail in shear. Similar tensile failures may occur from thermal stress around the boundary of a patch area. This, of course, will free the resin mortar from any restraint and it will pull further away from the boundaries of a small patch or develop prominent craze cracking in a large patch. In either case, the

resin mortar will no longer protect the concrete substrate. If the resin is formulated to be very flexible such that it will stretch and compress easily without building up high shear or tensile stresses, then it will not develop sufficient stress to shear the concrete and it will maintain its bond. However, this may cause stress concentrations in the old concrete around a patch.

3) Modulus of Elasticity. In a bridge deck of composite design, the steel stringers are carrying all of the tensile stresses and the concrete is carrying most of the compressive stresses. To function effectively in this type of bridge deck, a patch must pick up compressive stress from the concrete at one end, carry it the length of the patch, and transmit it back to the concrete at the other end; just as the concrete did that it replaced. To do this it must have a compressive modulus of elasticity that is similar to concrete. This means that under the same load it will elastically compress the same increment of length or develop the same strain as concrete. To illustrate, assume the live load to be uniformly distributed across the width of the deck. The unit stress at any particular depth in the concrete will be constant across the width and the concrete will compress under the stress an increment of length which can be determined by its modulus of elasticity. Now, if the concrete in a small area in that deck cross-section were chipped out and replaced with a material having a lesser modulus of elasticity, conditions would be different. The concrete and new material in a cross-section of the deck would both be compressed the same increment of length, but the new material would not carry its share of the load. This means that the concrete adjacent to the patch would have to pick up the extra load. Depending upon the size of the patch, the resulting stress concentrations would eventually cause additional failure in the surrounding concrete; the larger the patch area, the worse the situation.

Although the compressive modulus of elasticity was not specifically measured for this report, it is known from preliminary work to vary from the same value as the tensile modulus to a value three times as great, depending upon the particular resin. The greatest potential value of any resin in this report is Cy Bond at 1.53 million, and it is still much less than concrete, which is at approximately 3.0 million. This simply means that no resin mortar is compatible enough to be used as a patching material on a concrete bridge deck, except for smaller and shallow, non-structural patches to restore rideability.

CONCLUSIONS

From the discussion section of this report it was determined that, in general, most resin mortars are not well suited for use as orthotropic bridge deck surfacing material because of shrinkage and high thermal stresses. These cause them to crack which exposes the vulnerable steel surface to corrosive surface moisture and deicing salts. One epoxy resin mortar, Epo Traz, showed qualities required in an orthotropic surfacing material, and might be worthy of a field test. Its suitability could be attributed to its low tensile modulus of elasticity and possibly to the mineral filler with which it was extended. Experimental work showed that a resin mortar's fatigue life in tension could be extended with the addition of a mineral filler.

The discussion also established that resin mortars are totally unsuited for use as patching material for concrete bridge decks, particularly for larger and deeper patches (below the top steel). Properties which render them unfit are their shrinkage, high thermal coefficients of expansion, and low compressive modulus of elasticity.

It must not be concluded from this report that epoxy resins are totally unsuitable for use with concrete. They do a satisfactory job in the following applications: as a surface or penetrating sealant for concrete; as a bonding material for bonding fresh concrete to existing concrete; as an injection grouting material to repair cracked or fractured concrete; and as a mortar or grout to secure anchor bolts or rebars. Flexibilized epoxies have performed quite well as thin and uniform (up to 1/2 in.) wearing surfaces with hard aggregates for skid resistance and also in thin, flexible deck waterproofing membrances under bituminous surfaces.

RECOMMENDATIONS

If the Epo Traz epoxy resin is still available, it might be worthwhile trying it as a topping on the Creyts Rd orthotropic bridge deck over I 496 (S05 of 23081A) where the present epoxy mortars have failed to protect the steel surface, particularly in the south span. It might be used on one half, while some other material recommended for this use could be applied on the other half.

It is also recommended that the use of epoxy or polyester mortar patching mixes in bridge deck spall areas be discouraged in favor of the use of fast-set hydraulic cement type mixtures that contain no chloride.

Further work is also needed to determine the effect of well-graded stone such as 25A with sand, and mineral fillers on the thermal and elastic properties of patching mixes using organic binders such as epoxies and polyesters. Much research has been, and is being done in the area of 'polymer concretes' which seems to indicate that with a proper gradation of stone-sand-filler and the proper resin binder, a mixture with cured properties very close to those of portland cement concrete may be achieved.

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