POLYMER CONCRETE OVERLAY TEST PROGRAM

FINAL REPORT

by

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PREFACE

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

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16. Abstract

The results in this report were obtained during the test program which began in 1973. Physical properties of various polymer concretes are listed. They include compressive strength, splitting tensile strength, bond strength, the modulus of elasticity, shrinkage and thermal coefficients. A description is also presented of three polymer concrete overlays and one polymer chip seal that were placed on bridge decks.

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INTRODUCTION

The deterioration of bridge decks has gained national attention during the past decade as millions of dollars were spent for repairs. The cause of much of the deterioration has been blamed on the use of deicing chemicals, although inadequate design and construction practices contributed to the problem. Deterioration has been found mostly in the form of concrete section loss due to scaling and spalling. This has created not only overstressing of the deck but a driving hazard as well. Conventional repair methods such as overlaying with asphalt concrete or portland cement concrete were generally found to be unacceptable for two reasons. First, the asphalt concrete overlay provided only a wearing surface and offered little protection from future deterioration due to chemical corrosion. Second, although portland cement concrete overlays provided an improved wearing surface and increased the structural capacity of the deck, their prolonged curing time was judged unacceptable in some cases because of extended disruption of traffic flow. For these reasons a structural overlay material called polymer concrete was developed. It cures rapidly, improves the structural quality of the existing deck, and provides protection from deicing chemicals.

In 1973, the Federal Highway Administration sponsored a study of polymer concrete materials by the Oregon State Highway Division. Part of the initial task consisted of analyzing various resins in the laboratory to find the most promising for producing a polymer concrete in the field. Up to that time only limited work had been done with polymer concrete in the United States. Most of the developmental work had been concentrated on a system known as polymer impregnation (1, 2, and 3). In that system a low viscosity monomer penetrates into a fully cured and dried portland cement concrete element. This is followed by heating the monomer to $165^{o}F$ ($73.9^{o}C$) which causes it to polymerize. This system greatly improves the structural properties of the original concrete element. Recent reports have described the successful impregnation of entire bridge decks (4, 5).

The production of polymer concrete consists of mixing a well graded, good quality aggregate with a resin binder. The liquid resin is transformed into a solid through a chemical reaction known as polymerization. This reaction can be accomplished by three methods which are: (1) radiation, (2) initiator-heat and (3) initiator-promoter. The third system is used almost exclusively in the production of polymer concrete in the field.

By combining various monomers and resins, different properties were enhanced in the finished polymer concrete. The ability to use chemical compounds to control the allowable work time and rate of cure over a large temperature range added to the appeal of polymer concrete for structural overlays.

During the initial laboratory work several resin suppliers and manufacturers were contacted and invited to submit resin formulations suitable for polymer concrete. At the conclusion of the screening process 13 resin formulations were selected for additional study. One of the systems selected was a monomer blend containing 95% methyl methacrylate (MMA) and 5% trimethyol propane trimethacrylate (TMPTMA). This system was used to a great extent in the polymer impregnation work because of its low viscosity. Using benzoyl peroxide and dimethyl aniline for the initiator and promoter respectively, several polymer concrete mixes were made to produce test cylinders and small overlays. Compressive strengths of over 8,000 psi (55.1 MPa) were consistently recorded after a 24-hour cure when cylinder fabrication time was limited to under 10 minutes. When polymer concrete made with the MMA systems was used on small overlays however, excessive evaporation and drainage of the monomer caused the surface to be weak and subject to abrasion. Because of these problems, work with methyl methacrylate was abandoned in Oregon and full attention was devoted to polyester styrene systems. Experimental bridge deck patching has been reported by the Brookhaven National Laboratory using a methyl methacrylate polymer concrete (6).

The initial polyester styrene system examined in the laboratory consisted of blending styrene with a flexible polyester resin (GR 511) and a rigid polyester resin (GR 941). Both of these resins were products of the Marco Division of the W. R. Grace Company. Using the proportions 23% styrene, 38.5% GR 511, and 38.5% GR 941, several small polymer concrete mixes were prepared. The workability and the compressive strength of mixes containing different resin loadings were examined. In addition, the chemical additives which affect the rate of polymerization were examined in a series of workability tests. By varying the initiator, methyl ethyl ketone peroxide, and the promoter, cobalt octoate, between 0.5% and 2.5% for each, the allowable work time of mixes was regulated at room temperature. When the lower percentages of additives were used, the allowable work time was extended but the rate of cure was slowed to an unacceptable amount. Hydroquinone was then found to inhibit the rate of polymerization for a short period of time without greatly extending the total cure time.

In order to study the behavior of resins at different temperatures, a time-to-gel study was conducted within the normal working temperature range. By varying the additive proportions within different temperature ranges it was found the gel time of the binder could be predicted. This allowed mix designs to be prepared with a satisfactory work time at several different temperature levels.

A silane coupling agent was added to the resin in many of the initial mixes to gain a chemical bond to the aggregate in addition to the physical bond between the polyester styrene resin and the aggregate. The small gain realized in the structural properties did not justify the high cost of this material. Silane was eliminated for the polymer concrete mixes, but is still specified for use in the tack coat.

Polymer concrete mixes that were prepared by hand in the laboratory appeared too dry when an 8.5% resin content was used, while a resin content of 14% appeared too wet when mixed with a well graded aggregate. Because of the relatively high cost of the resin, a great deal of work was done in attempting to reduce the amount of binder required to produce a dense concrete. Emphasis was placed on developing an aggregate gradation that would minimize the voids to be filled by the resin. Results of testing showed the amount of fines in the mix was very important. Because of its low viscosity, the resin tended to drain from the aggregate if sufficient fines were not available. Excessive fines, on the other hand, caused additional resin to be required to coat the greater surface area. A design gradation of between 6% to 8% for material passing the No. 200 seive was finally specified.

Most of the laboratory trial batches were mixed by hand using a large bowl and spoon. A Hobart dough mixer and a small electric driven concrete mixer were used on some of the larger laboratory batches. When 6 ft x 6 ft x 1.5 in. (1.8 m x 1.8 m x 38 mm) polymer concrete overlays were placed in the mainte-nance yard, larger gasoline powered mixers were used. The conventional rota-ting drum concrete mixer and the paddle type mortar mixer were both used on several projects. The wiping motion of the paddles and the overall ease in clean-up of the mortar mixer and the tendency of fines to build up on the drum of the conventional mixer are the reasons why the mortar mixers are preferred over the conventional concrete mixer.

Good bonding between the polymer concrete overlay and the substrate concrete received much attention during the development process. Through the use of a resin tack coat adequate bonding was gained in the laboratory. When field work began, only partial bonding of the polymer concrete to the existing con-crete was realized. Additional study of substrate preparation and allowable moisture content produced a cleaning procedure that ensured satisfactory bonding.

Included in this report are results of tests to determine modulus of elasticity, thermal coefficient, shrinkage coefficient and the results of a freeze-thaw study. A report is also presented on three polymer concrete overlays and one polymer concrete chip seal overlay that were placed on bridge decks.

Finally, descriptions are included covering the technical assistance provided to Idaho Transportation Department during their polymer concrete overlay project and the Polymer Concrete Materials Seminar hosted by the Oregon State Highway Division.

TEST DESCRIPTIONS AND RESULTS

Resin Gel Time Study

The ability to control the gel time (allowable work time) of polymer concrete mixes at different temperatures was found to be of primary concern. During early testing, sets of six 2-in. (51 mm) cubes were molded to measure the workability of various polymer concrete mixes and the effect of continued manipulation on strength. An evaluation of the stiffness during mixing and the difficulty in finishing was determined as the mix was placed in the cube molds at 5 minute intervals. The test cubes were then allowed to cure for 24 hours and tested for comparative compressive strength. Testing was conducted at room temperature $72^{\circ}F$ to $75^{\circ}F$ ($22.2^{\circ}C$ to $23.9^{\circ}C$) and also at reduced temperatures of $56^{\circ}F$ ($13.3^{\circ}C$) and $60^{\circ}F$ ($15.6^{\circ}C$).

The amount of time required to mix, place and finish the polymer concrete was defined as handling time. During the early phase of the gel time study the handling time was purposely extended to exceed the allowable work time. This resulted in the polymer concrete becoming too stiff and the compressive strength of the polymer concrete to decrease (see Figure 1). Allowable work time was then extended with the introduction of hydroquinone as an inhibitor. The time available for placing the mixes was extended to 1.5 hours in the laboratory at $75^{\circ}F$ ($23.9^{\circ}C$) with a corresponding increase in cure time.

The rate of polymerization of polyester styrene resin was found to be dependent upon many factors. These include the amount of initiator, promoter and inhibitor, along with environmental factors such as temperature, humidity, and amount of ultraviolet light. Using a Sunshine Gelmeter, the gel time of several resins was studied in the laboratory. Gel time is the elapsed time from when the initiator and promoter are added to the resin until the resin first begins to solidify. The proportions of the chemical additives were varied, along with the temperature, to determine suitable formulas for field application within a range of normal working ambient temperatures. Much of the initial gel testing work was concentrated on a resin designated LB 183-13. After some problems occurred in the field, however, a slightly more flexible resin, GR 11044, was studied for use in polymer concrete. Both resins were produced by the Marco Division of W. R. Grace Co. The following tables (1A through 1E) show the results of the time-to-gel study using different concentrations of additives at different temperatures and the two resins.

Workability

The ease of mixing, placing, and finishing polymer concrete was also examined during the laboratory phase of this work. Mixes containing either natural or crushed aggregate were evaluated while being prepared by hand. The resin content of the mixes was varied from 8% to 14% by weight of aggregate.

These batches were mixed in a steel mixing bowl using a steel spoon. The size of the batches was approximately 0.77 lbs (.35 kg). Generally speaking,

-4-

2" Cubes
24 hr. Cure
8½% Resin Content

_____ 1.5% Initiator   _ _ _ 0.5% Initiator
       0.75% Promoter   0.25% Promotor

$°C = (°F-32)/1.8$ 1000 psi = 6894.8 kPa   1" = 25.4 mm
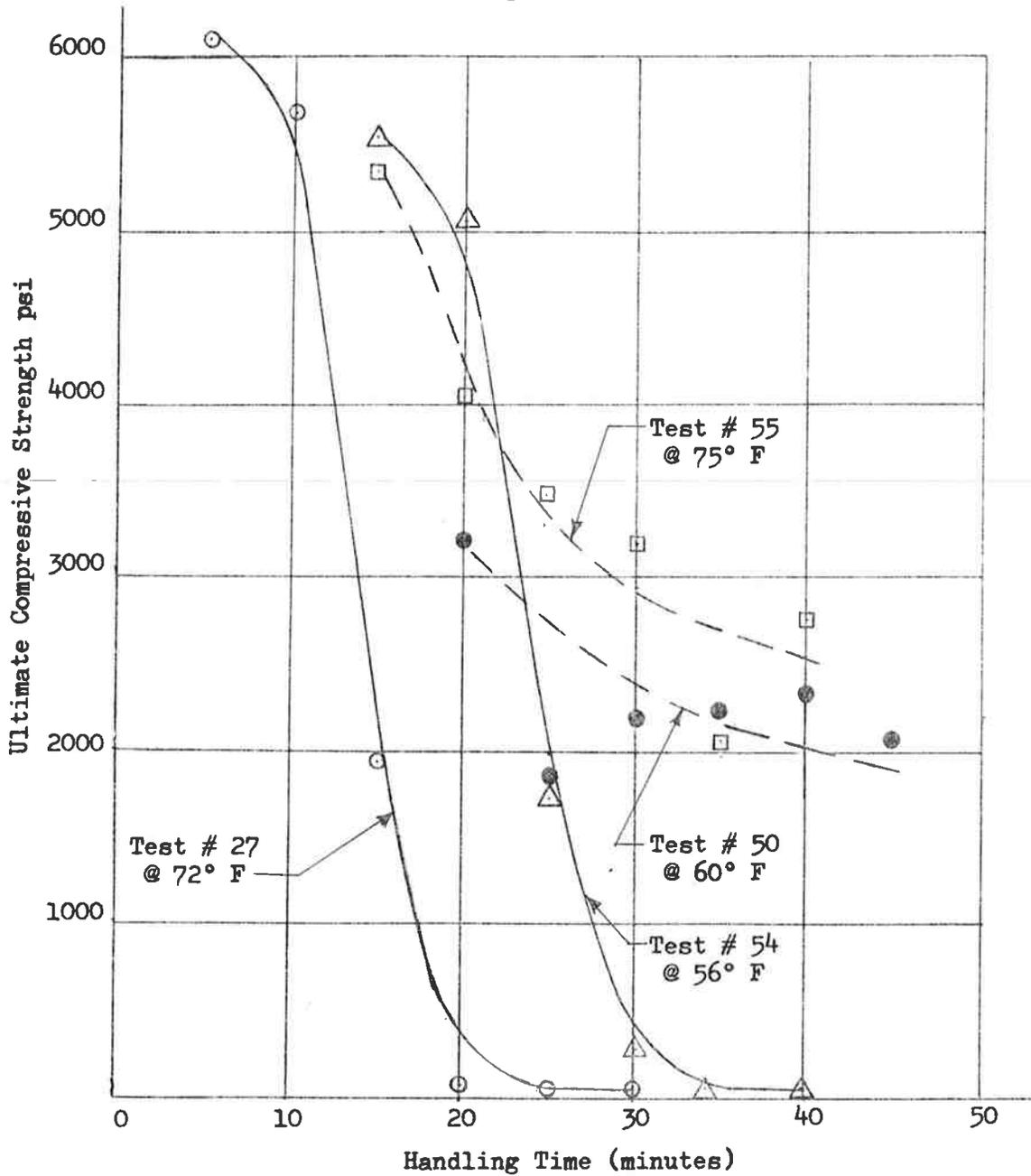
Effect of initiator-promoter and mixing temperatures
on ultimate strength vs. handling time.

Figure 1

RESIN GEL TIME STUDY

Table 1A
Resin LB183-13
74 F (22.4°C)

Test	MEKP %(1)	Co Oc %(2)	HQ ppm(3)	Gel Time - min.
1	1.5	1.0	100	11
2	1.5	1.0	200	20
3	1.5	1.0	400	43
4	1.0	1.0	100	25
5	1.0	1.0	200	45
6	1.0	1.0	400	207
7	1.5	.75	100	12
8	1.5	.75	200	26
9	1.5	.75	400	68
10	1.0	.75	100	27
11	1.0	.75	400	215
12	1.5	.50	100	16
13	1.5	.50	200	25
14	1.5	.50	400	73
15	1.0	.50	100	25
16	1.0	.50	200	50
17	1.0	.50	400	240

Table 1B
Resin LB183-13
90°F (32.2°C)

Test	MEKP %(1)	Co Oc %(2)	HQ ppm(3)	Gel Time - min.
1	1.5	1.0	100	9
2	1.5	1.0	200	14
3	1.5	.75	400	28
4	1.5	.75	100	10
5	1.5	.75	200	15
6	1.5	.50	400	45
7	1.5	.50	0	3
8	1.5	.50	100	7
9	1.5	.50	200	9
10	1.5	.25	400	20
11	1.5	.25	0	2
12	1.5	.25	100	6
13	1.5	.25	200	33
14	1.0	1.0	100	11
15	1.0	1.0	200	17
16	1.0	1.0	400	152

(1) methyl ethyl ketone peroxide
(2) cobalt octoate
(3) tert-butyl hydroquinone

Test	MEKP %(1)	Co Oc %(2)	HQ ppm(3)	Gel Time – min.
17	1.0	.75	0	5
18	1.0	.75	100	12
19	1.0	.75	200	25
20	1.0	.75	400	112
21	1.0	.50	0	4
22	1.0	.50	100	15
23	1.0	.50	200	35
24	1.0	.50	400	155
25	1.0	.25	0	5
26	1.0	.25	100	37
27	1.0	.25	200	45
28	1.0	.25	400	180+

Table 1C
Resin LB183-13
50°F (10°C)

Test	MEKP %(1)	Co Oc %(2)	HQ ppm(3)	Gel Time – min.
1	2.0	.5	0	10
2	2.0	.5	100	60
3	2.0	.5	200	105
4	2.0	.5	300	150
5	1.5	.5	0	10
6	1.5	.5	100	50
7	1.5	.5	200	105
8	1.5	.5	300	240+
9	1.0	.5	0	50
10	1.0	.5	200	65
11	2.5	.5	0	5
12	2.5	.5	200	35

Table 1D
Resin LB183-13
40°F (4.4°C)

Test	MEKP %(1)	Co Oc %(2)	HQ ppm(3)	Gel Time – min.
1	2.0	.5	0	15
2	2.0	.5	100	60
3	1.5	.5	0	20
4	1.5	.5	100	240
5	2.5	.5	0	15
6	2.5	.5	100	25
7	2.5	.5	200	55

(1) methyl ethyl ketone peroxide
(2) cobalt octoate
(3) tert-butyl hydroquinone

Resin Gel Time Study (continued)

Table 1E
Resin GR11044
77°F (25°C)

Test	MEKP %(1)	Co Oc %(2)	HQ ppm(3)	Gel Time – min.
1	2.0	.5	200	16
2	2.0	.5	400	42
3	2.0	.25	100	20
4	2.0	.25	200	28
5	2.0	.25	400	61
6	1.5	1.0	200	21
7	1.5	1.0	400	59
8	1.5	.75	200	24
9	1.5	.75	400	70
10	1.5	.50	200	26
11	1.5	.50	400	95
12	1.5	.25	100	30
13	1.5	.25	200	44
14	1.0	1.0	100	23
15	1.0	1.0	200	53
16	1.0	.75	100	29
17	1.0	.75	200	56
18	1.0	.50	0	17
19	1.0	.50	100	37
20	1.0	.25	0	23
21	1.0	.25	100	72
22	.75	.75	100	52
23	.75	.75	200	120
24	.75	.50	0	20
25	.75	.50	100	57
26	.75	.50	200	145
27	.75	.25	0	24
28	.75	.25	100	85
29	.50	.50	0	28
30	.50	.50	100	110
31	.50	.25	0	48
32	.50	.25	100	180+
33	1.0	.75	200	69

(1) methyl ethyl ketone peroxide
(2) cobalt octoate
(3) tert-butyl hydroquinone

workability improved as the amount of liquid binder increased. However, some bleeding of the surface occurred when the resin content exceeded 12%. The harshness of several crushed aggregate gradations required slightly greater resin content to produce the same workability obtained with natural gravels. Depending on the gradation, suitable workability was found using resin contents of between 10% and 12% when mixing by hand.

In addition to the laboratory study, several 6 ft x 6 ft x 1.5 in. (1.8 m x 1.8 m x 38 mm) polymer concrete overlays were placed in the field using two mixing techniques and several methods of finishing and compacting. Both a conventional rotating drum mixer and a paddle-type mortar mixer were used to blend the polymer concrete. After being in service for approximately 30 minutes some material build-up was noted on the vanes and sides of the drum mixer. There was also material build-up on the paddles of the mortar mixers after 30 minutes, but the mixer's walls were wiped clean by the blades. Because of the greater ease of cleaning, the mortar mixer is preferred over the conventional drum mixer. One disadvantage of the mortar mixer is that only relatively small quantities can be mixed at a time. Experience has shown the mortar mixers are capable of mixing polymer concrete at between one-third to one-half their rated mortar capacity.

Polymer concrete can not be finished like conventional concrete because it lacks fluidity and it tends to be sticky. The methods used to finish and compact the 6 ft x 6 ft x 1.5 in. (1.8 m x 1.8 m x 38 mm) test slabs included the following:

- Light steel beam screed - 5 in. x 6.7 lb (130 mm x 10 kg/m) channel.

- Light steel beam screed with internal concrete vibrator clamped to it - 5 in. x 6.7 lb (130 mm x 10 kg/m) channel.

- Heavy steel beam screed - 10 in. x 42 lb (250 mm x 62 kg/m) H beam.

- Heavy steel beam screed with an external form vibrator bolted to it - 10 in. x 42 lb (250 mm x 62 kg/m) H beam.

- Light screed and vibrating sled compactor - Wacker Packer.

- Light screed and static asphalt concrete roller - 600 lb (272 kg) Ray-Go.

- Light screed and vibrating asphalt concrete roller - 600 lb (272 kg) Ray-Go.

After examining the surface texture and density of the field test sections, the vibrating sled and static roller were selected as producing the more desirable overlay. The resin content used in this field work also varied from 10% to 12%. Excessive liquid was brought to the surface in some cases at the higher resin loading when the polymer concrete was overworked with the finishing equipment.

An experiment using a Bidwell dense concrete finishing machine proved to be successful. Two 4 ft x 16 ft (1.2 m x 4.9 m) test slabs were finished and

consolidated using a Bidwell OF-400. Although the resin content of these slabs was reduced to 8% and 9%, good workability was obtained. The results of this trial indicated a well consolidated polymer concrete overlay with a smooth riding surface could be produced with reduced resin content if the proper placing equipment is used.

Aggregate Gradation Study

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

Approximately 50 tests were made on natural gravels passing the 1/2 in. (12.7 mm) sieve to arrive at a gradation giving minimum voids in dry-rodded samples. Three fine-grained fillers, portland cement, cottrell flour, and pozzolan, were included in some of the tests. Portland cement was selected as a filler material for the polymer concrete development because of its uniform grain size and also because it was more easily obtainable. The effectiveness of cement in reducing voids in the dry-rodded aggregate is demonstrated by the values in Table 2. Although the minimum void content was found at 14% cement, 6% cement was selected for the standard mix proportion (gradation VIII-c) since additional filler contributed significantly to the surface area to be coated with only a minor increase in density. For the entire results of the gradation study see Appendix C.

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

A study was also made on gap-graded aggregates in an attempt to reduce the void volume. Minimum void contents of 18% were obtained, but since this value was only slightly lower than that for the uniformly graded aggregate with 6% cement, it was not low enough to make it economically desirable to separate and reblend the material.

When aggregate moisture content was found to reduce essential polymer concrete properties, a study was initiated to determine acceptable limits. Laboratory results showed the maximum allowable aggregate moisture content to be approximately 0.5%. That meant all aggregate used in polymer concrete work would require special drying.

When the polymer concrete study had progressed to the point where large quantities of dry aggregate were required for field projects, it was found the optimum gradation determined in the laboratory was not economically available. Further laboratory study was then made to find an acceptable aggregate gradation with tolerance limits which could be produced commercially.

Table 2

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

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

The following gradation band was found to be most acceptable and closely follows the 3/8 in. to 0 (9.5 mm to 0) Fuller's maximum density curve. It is suitable for both natural and crushed aggregate.

Sieve Size	Percent Passing
1/2 in. (12.7 mm)	100
3/8 in. (9.5 mm)	100-86
1/4 in. (6.3 mm)	85-71
No. 10 (2.0 mm)	47-40
No. 40 (.42 mm)	23-18
No. 200 (0.075 mm)	8-6

The amount of material passing the No. 200 sieve is of particular importance since excessive amounts will require additional resin for complete surface coating, while insufficient amounts will allow the resin to drain from the larger aggregate. A deficiency of fines can be corrected by adding portland cement or pozzolan.

When crushed aggregate was specified on one polymer concrete bridge deck overlay project, it was purchased from an asphalt concrete producer who dried the aggregate in an asphalt concrete plant drier. The pug mill in the plant was first cleaned by running aggregate through it to remove any asphalt residue. This aggregate was wasted. The 0.5 in. to No. 4 (12.7 mm to 4.7 mm) aggregate component was then dried and discharged through the pug mill into a 5 cu yd (3.8 m³) dump truck. The No. 10 to 0 (1.5 mm to 0) component was also dried and discharged into another 5 cu yd (3.8 m³) dump truck. Both were stored under cover until needed. This aggregate was proportioned at the job site to produce the designed final gradation (Table 3, Column 3). A description of this work appears in the section on bridge deck overlays.

Dry mix concrete, which is available at home improvement centers and building supply stores, was examined as a potential source of dry natural aggregate for polymer concrete. A sieve analysis of the dry mix determined that an excessive amount of material passing the No. 200 sieve was present in the over-the-counter stock (Table 3, Column 5). By reducing the amount of cement in several sacks an acceptable aggregate gradation was attained. Arrangements were made with the dry mix producer to reduce the cement content in order to meet gradation requirements. The aggregate gradation shown in Table 3, Column 6 is representative of the material specially prepared in 90 lb (40.8 kg) sacks and successfully used in the production of polymer concrete for a bridge deck overlay and miscellaneous concrete patching projects.

Table 3

AGGREGATE GRADATIONS(a)

Percent Passing

Sample No.	1	2	3	4	5	6	7	8	9	10
Sieve Size										
1/2	100	100	100	98	100	100	100	100	100	100
3/8	87	96	86	85	91	88	86	86	86	86
1/4	71	67	71	77	68	66	-	-	-	-
#4	53	53	61	76	61	56	60	60	60	60
#8	44	45	42	57	60	46	43	43	43	43
#16	38	38	31	35	54	40	30	31	31	31
#30	28	25	22	23	45	33	23	23	23	24
#50	12	15	15	17	24	16	15	16	18	20
#100	7.4	10	11	13	18	8	12	14	15	17
#200	6.5	9	7	10	16	6.3	10	12	14	16

(a) Aggregate samples 1, 2, 5, and 6 are natural gravels.
Aggregate sample 3, 4, 7, 8, 9, and 10 are crushed gravels.

(b) The material passing #200 includes portland cement.

Aggregate Source:	
Walling Sand & Gravel	Col. 1 and 2
D & D Paving	Col. 3, 7, 8, 9 and 10
Hilroy Pit	Col. 4
Ross Island Sand & Gravel	Col. 5 and 6

Compressive Strength Tests

The strength of polymer concrete was found to be dependent on many factors during early compression testing. Using both cubes and cylinders, studies were conducted to determine the effects of such variables as type of resin, binder concentration, and aggregate gradation on ultimate compressive strength. Other variables examined in subsequent testing included ambient temperature during mixing, placing and curing, chemical additive concentrations, and moisture content of the aggregate.

During the initial testing, allowable work time was limited to approximately 10 minutes at $70^{o}F$ ($21.1^{o}C$) without the use of an inhibitor. Later testing with an inhibitor showed the allowable work time could be extended to 1.5 hours without apparent loss of compressive strength although the total cure time was also extended. The aggregate gradation in Table 3, Column 1 was used in much of the early testing. Both the gradation and type of aggregate were changed in the later testing when it was determined that large quantities of this gradation were not readily available from commercial sources.

To compare strengths at different polymer loadings, compressive tests were conducted on samples containing 8.5% and 10% resin (by weight of aggregate). Cylinders tested after 24 hours had an average compressive strength of 10,300 psi (71.0 MPa) for the 10% mix, while an average compressive strength of 7,900 psi (54.4 MPa) was obtained for the 8.5% mix. These samples did not contain inhibitor and provided allowable work times of under 10 minutes. The results of testing other polymer concrete mixes with 8.5% and 10% resin content, but containing the inhibitor hydroquinone, indicated average compressive strengths of 7,075 psi (48.7 MPa) and 7,935 psi (54.7 MPa), respectively, when tested after a 24-hour cure. Handling time of these mixes was extended to 45 minutes.

Before the use of an inhibitor was adopted, tests were made to study the effects of extending the time of working on compressive strength of polymer concrete mixes. Ultimate compressive strengths of over 5,000 psi (34.5 MPa) for uninhibited specimens were consistently recorded with 8.5% resin content mixes when the handling time was under 10 minutes and the polymer concrete was allowed to cure for 24 hours. As handling time was extended to 25 minutes, the compressive strengths dropped to 3,000 psi (20.7 MPa). The allowable work time was then extended when mixes were prepared containing an inhibitor. One mix containing 10% resin and 450 ppm hydroquinone was mixed and placed in cylinders after delays of 30, 60, and 90 minutes following mixing. Allowing a 24-hour cure at room temperature, the cylinders yielded ultimate compressive strengths of 7,820 psi (53.9 MPa), 8,490 psi (58.5 MPa), and 7,980 psi (55.0 MPa), respectively. These breaks indicated the allowable work time had been successfully extended.

The effect of ambient temperature during mixing, placing, and curing was examined during two studies. The investigation was conducted at two temperature levels: $68^{o}F$ ($20^{o}C$), and at a range of $56^{o}F$ to $60^{o}F$ ($13.3^{o}C$ to $15.5^{o}C$). In the first test an 8.5% resin content was used to prepare two groups of polymer concrete cubes containing no inhibitor. One group was initiated at 0.5% and promoted at 0.25%, while the other group was initiated

at 1.5% and promoted at 0.75%. A delay in placing and finishing the polymer concrete varied from 5 to 40 minutes while the cure time remained constant at 24 hours for all specimens (see Figure 1).

The mix containing 1.5% initiator was found to have a compressive strength of 5,700 psi (39.3 MPa) when worked for 10 minutes and only 100 psi (690 kPa) when worked for 20 minutes at approximately 72°F (22.2°C). The mix containing 0.5% initiator meanwhile was found to have a compressive strength of 5,500 psi (37.9 MPa) when worked for 15 minutes and 3,500 psi (24.1 MPa) when worked for 25 minutes at approximately 72°F (22.2°C).

When tested at the lower temperature, 56°F (13.3°C), however, the polymer concrete made with the higher initiator concentration developed a compressive strength of 5,600 psi (38.6 MPa) after a handling time of 15 minutes and only 200 psi (1,380 kPa) when the delay in placing and finishing was extended to 30 minutes. When polymer concrete containing the lower concentrations of initiator and promoter was mixed and cured at 60°F (15.5°C) it registered an ultimate compressive strength of 7,200 psi (49.6 MPa) when worked for 20 minutes. When the handling time was extended to 40 minutes with this system, the cylinders broke at 2,000 psi (13.9 MPa). The results from this test indicated that even at lower temperatures, an uninhibited mix containing 1.5% initiator and 0.75% promoter set up too rapidly to be used as a batch-mix overlay. The polymer concrete containing the lesser amount of initiator and promoter did not fully polymerize at the lower temperature within a 24-hour period.

Satisfactory results were obtained with polymer concrete mixes when an inhibitor was used to extend the allowable work time. Figure 2 shows a comparison of compressive strength of polymer concrete mixes with a handling time of 30 minutes when made and cured at 57°F and 69°F (13.9°C and 20.6°C). Cylinders were tested at 5 and 24 hours to determine early strength characteristics. When tested after a 5-hour cure, the specimen that was prepared and cured at 57°F (13.9°C) failed at 2,900 psi (19.9 MPa) while the specimen that was cured at 69°F (20.6°C) broke at 4,500 psi (31.0 MPa). After a 24-hour cure, however, the specimens failed at 7,900 psi and 9,400 psi (54.5 MPa and 64.8 MPa) respectively. Results of this testing clearly show the value of the inhibitor in extending allowable work time while maintaining an acceptable rate of polymerization.

The effect of aggregate moisture on compressive strength was investigated when polymer concrete mixes were prepared using LB 183-13 resin. The moisture content within the mix was controlled at 0, 2, 4 and 6 percent by weight of the aggregate. Mixes providing a 45 minute allowable work time were cast into 3 in. x 6 in. (76 mm x 152 mm) cylinders and cured at room temperature. Figure 3 shows a decrease in ultimate compressive strength as the moisture content is increased. The mix prepared with a zero percent moisture content failed at 8,500 psi (58.6 MPa) while the samples containing 6% moisture broke at only 2,100 psi (14.5 MPa). All specimens were tested after a 24-hour cure. Because of these results, only dry aggregate was specified in overlay work. An extension of the aggregate moisture study was used to determine the benefits of using silane as an additive to enhance the bond between the aggregate and the resin. The silane concentration was varied from zero percent to 4% by weight of the resin for comparison purposes. The results shown in Figure 4

Test # 249
3" X 6" Cylinders
Resin Content 12%
30 Minute Handling Time
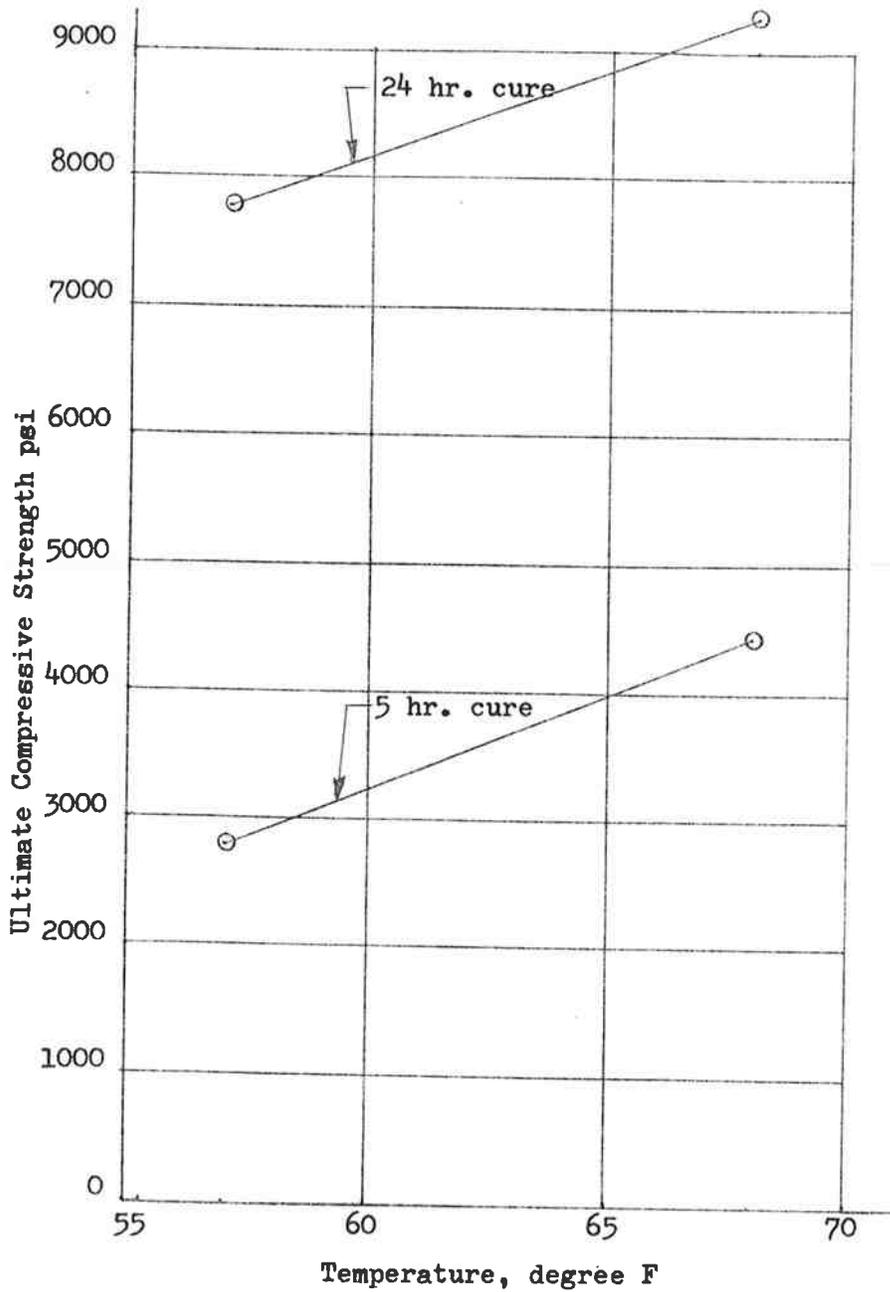
Compressive Strength vs. Curing
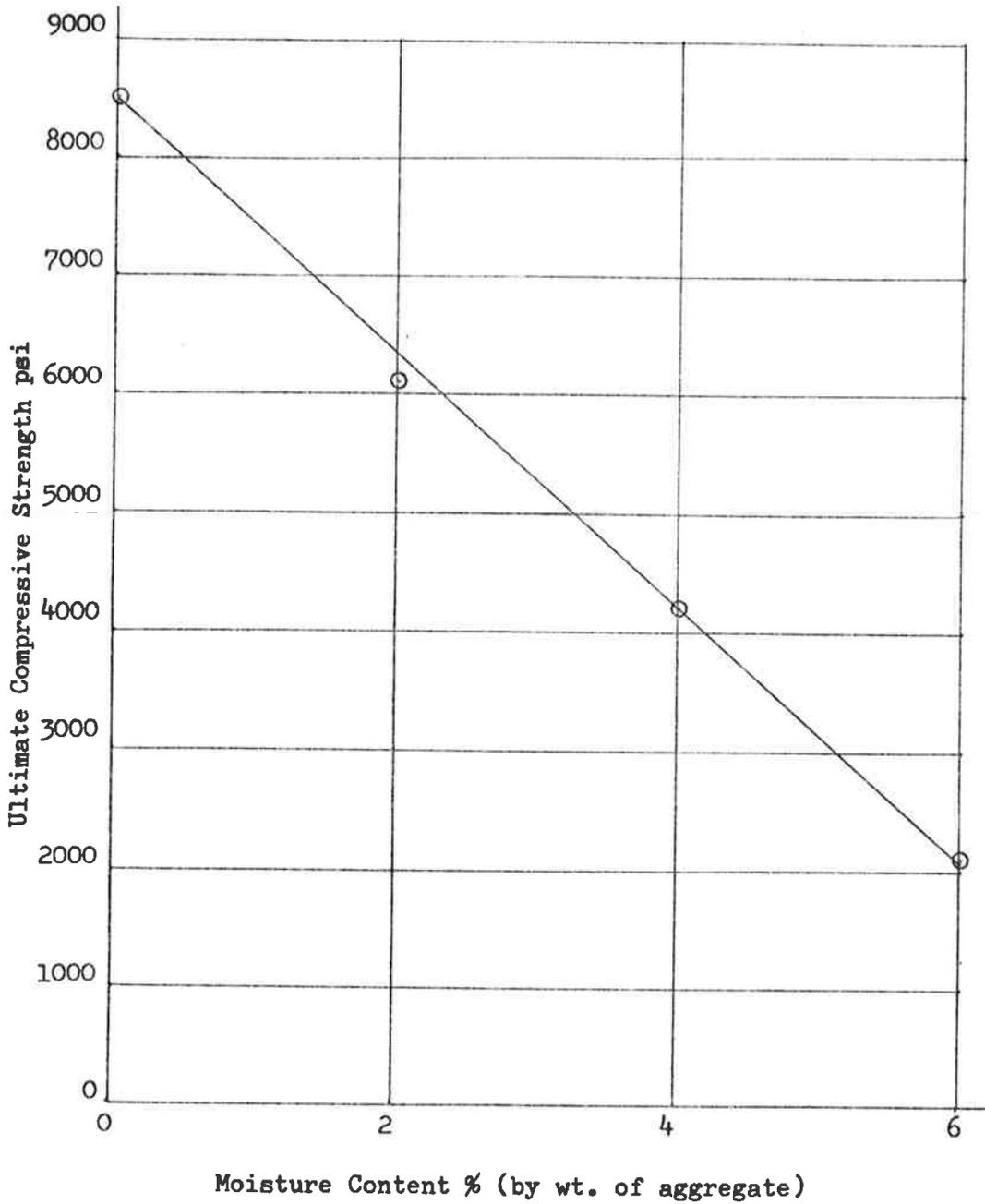Temperatures at different cure times

Figure 2

3" X 6" Cylinders
Resin Content 10%
Ambient Temp. 72°F (22.2°C)
24 hr. Cure

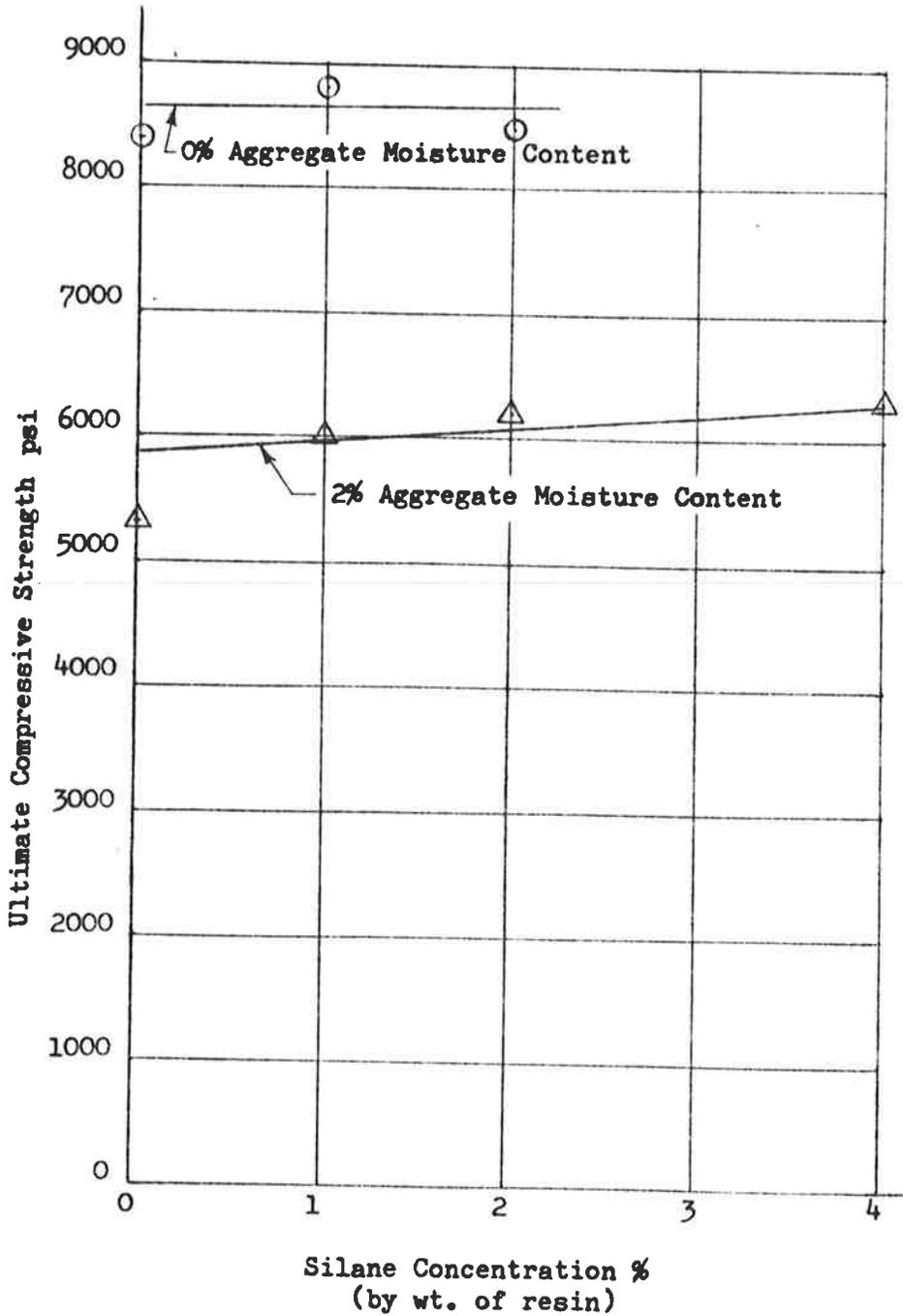1000 psi = 6894.8 kPa   1" = 25.4 mm

Compressive Strength vs. Aggregate Moisture Content

Figure 3

3" X 6" Cylinders
Resin Content 10%
24 hr. Cure

1000 psi = 6894.8 kPa   1" = 25.4 mm

Compressive Strength vs. Silane Concentration

Figure 4

indicate only a small increase in compressive strength was gained by the addition of silane. Because silane is very expensive, it is recommended for use only in the resin tack coat to improve bonding.

Bond Tests

One of the most important elements in successfully applying a structural overlay is the ability to acquire good bonding between the overlay and substrate. The bond shear criteria established for the polymer concrete overlays was 200 psi (1,380 kPa) when tested in shear by applying a force parallel to the interface in a guillotine apparatus.

The bond testing program consisted of testing several different resin binders in making both polymer concrete mixes and tack coats. Included were methyl methacrylate, three polyester styrene blends, and a proprietory mix called Radgrout. The polymer concrete mixes were normally placed on 6 in. x 6 in. x 21 in. (152 mm x 152 mm x 533 mm) portland cement concrete beams that had been previously cast and cured. Additional polymer concrete overlays were cast on larger concrete slabs measuring 6 in. x 12 in. x 6 ft (152 mm x 305 mm x 1.8 m) long for conducting surface preparation studies. The cure time for the polymer concrete mixes varied from 24 hours to 7 days depending on the particular variable being studied. Immediately before testing, 4 in. (102 mm) diameter cores were taken through the overlay and base material. Figure 5 shows the apparatus used during the bond shear test. Complete results of the bond test program are shown in Table 4.

During initial testing, the resin content in the polymer concrete mixes was varied within the range of 8% to 14%. The overlays were placed on surfaces that had been prepared by wire brushing only. No resin tack coat was used for bonding because it was expected an adequate amount of resin would drain from the overlay to satisfy the need at the interface. This procedure did not provide consistently high bond strengths between the substrate concrete and the overlay although some high bond strengths were recorded.

A revised procedure was adopted whereby the substrate surface was sandblasted to produce a more desirable bonding surface. In addition, a variety of resin tack coats, both promoted and unpromoted, were examined. The unpromoted tack coats were used to provide a longer allowable work time. This procedure was followed before the use of inhibitors was investigated. Results of these early tests showed the use of a promoted tack coat on a sandblasted surface produced consistently high bond values. The failures of the test specimens when using this procedure were typically in the base concrete and not at the interface. The average bond values exceeded 400 psi (2,760 kPa) consistently.

The effect of tack coat quantity on bonding strength was examined as the thickness of the tack coats was varied from 15, 20, 35, to 50 mils (.38 mm, .51 mm, .88 mm to 1.27 mm). Test results indicated the thickness did not appreciably affect the bond strength as all performed equally well. A two-tack-coat system was also examined for performance. The first tack coat was applied to the substrate concrete and allowed to cure slowly in an attempt to gain good penetration. The second tack coat was applied immediately before

Figure 5. Bond-shear testing apparatus.

Table 4

BOND TEST RESULTS

Test No.	Polymer Mix Resin* %	Surface Preparation	Tack Coat	Cure Time	Bond Strength, psi Core Number			
					1	2	3	4
78	C 12	Wire Brush	None	24 hr	16	SO	SO	SO
14	B 12	Wire Brush	None	48 hr	357	143	76	SO
15	B 10	Wire Brush	None	24 hr	505	444	517	388
16	B 10	Wire Brush	None	96 hr	215	181	SO	SO
17	B 10	Wire Brush	None	7 hr	142	SO	SO	SO
18	B 9	Wire Brush	15 mils**	24 hr	72	SO	SO	SO
19	B 8	Wire Brush	50 mils**	24 hr	454	267	---	---
20	B 8½	Wire Brush	50 mils**	24 hr	321	326	---	---
21	B 8½	Wire Brush	20 mils	24 hr	SO	SO	---	---
25	B 8½	Wire Brush	35 mils	24 hr	551+	409+	456+	461+
28	B 8½	Sandblasted	15 mils	24 hr	519+	452+	347+	556+
29	B 8½	Sandblasted	35 mils	24 hr	503+	534+	---	---
30	B 8½	Sandblasted	50 mils	24 hr	258+	239+	454+	375+
31	B 8½	Sandblasted	15 mils**	24 hr	402	659	557	724
32	B 8½	Sandblasted	35 mils**	24 hr	258	162	---	---
33	B 8½	Sandblasted	50 mils**	24 hr	185	446	463	237
41	B 8½	Sandblasted Wet Surface	35 mils	24 hr	364+	455+	450+	352+ DT
42	B 8½	Sandblasted / Sandblasted	15 mils	24 hr	643 Oil	297 Oil	312+ DT	---
45	B 8½	Sandblasted / Acid Solution	15 mils	24 hr	SO Oil	SO Oil	402+	404+
46	B 8½	Sandblasted / TSP Solution	15 mils	24 hr	SO Oil	SO Oil	582+	507+

* See Appendix A for resin blends.
** Unpromoted.
SO Spun off during coring.

+ Failure in core and not at interface.
DT Direct tension test.
Sandblasted / Acid Solution = Beam initially cleaned by sandblasting
Acid Solution = Beam cleaned by acid solution after oil contamination.

1000 psi = 6.89 MPa
1 mil = 0.025 mm

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Table 4
(continued)

Test No.	Polymer Resin*	Mix %	Surface Preparation	Tack Coat	Cure Time	Bond Strength, psi Core Number			
						1	2	3	4
51	B	8½	Sandblasted	15 mils	24 hr	497+	533+	540+	434+
81	E	10	Wire Brush	None	96 hr	70	155	SO	SO
82	E	12	Wire Brush	None	96 hr	SO	SO	SO	SO
83	E	14	Wire Brush	None	96 hr	SO	SO	SO	SO
84	E	10	Sandblasted	15 mils	24 hr	667	538	235 DT	572
85	E	10	Sandblasted	35 mils	24 hr	570	652	325+ DT	670
96	A	10	Sandblasted	15 mil	24 hr	684	927	765	814
170	A	8½	Sandblasted Wet Surface	15 mil	12 days	80	557	383	477
200	A	10	Sandblasted Wet Surface	2-15 mil	14 days	617+	617+	708+	619+
204	A	10	Sandblasted	15 mil	14 days	240	418+	425+	269+
206	A	12	Sandblasted	2-15 mil	14 days	643+	601+	543+	---
212	A	12	Sandblasted	20 mil	19 hr	428+	443+	535+	640+
213	A	12	Sandblasted	30 mil	19 hr	390+	437+	481+	493+
215	A	12	Sandblasted	30 mil	72 hr	460+	511+	465+	523+
216	A	12	Sandblasted	30 mil	72 hr	---	---	---	---
217	A	12	Sandblasted	2-15 mil	72 hr	---	---	---	---
218	A	12	Sandblasted Flame Dry Φ	30 mil	72 hr	429+	320+	240+	214+
219	A	12	Sandblasted	30 mil	72 hr	440	420	248	601
220	A	12	Sandblasted Flame Dry Φ	30 mil	72 hr	---	---	---	---

* See Appendix A for resin blends.   + Failure in core and not at interface.
SO Spun off during coring.   Φ Water soaked surface.
DT Direct tension test.

1000 psi = 6.89 MPa
1 mil = 0.025 mm

Table 4
(continued)

Test No.	Polymer Mix Resin*	%	Surface Preparation	Tack Coat	Cure Time	Bond Strength,psi Core Number			
						1	2	3	4
221	A	12	Sandblasted Oven Dry Φ	30 mil	48 hr	---	---	---	---
222	A	12	Sandblasted Oven Dry Φ	30 mil	48 hr	---	---	---	---
223	A	12	Sandblasted Oven Dry Φ	30 mil	48 hr	292+	280+	284+	368+
224	A	12	Sandblasted Flame Dry Φ	30 mil	72 hr	---	---	---	---
225	A	12	Sandblasted Flame Dry Φ	30 mil	72 hr	---	---	---	---
249	L	12	Scarified	20 mil	48 hr	812+	611+	544+	---
256	L	12	Scarified	15 mil	7 days	351+	159+	316+	---
257	L	12	Scarified & Sandblasted	18 mil	8 days	688+	---	---	---
258	L	12	Scarified	20 mil	11 days	430+	417+	---	---
269	L	11	Scarified & Sandblasted	15 mil	34 days	177+	341+	---	---
270	L	12	Scarified & Sandblasted	15 mil	34 days	344+	---	---	---
271	L	10	Scarified & Sandblasted	15 mil	34 days	290+	---	---	---

* See Appendix A for resin blends.
+ Failure in core and not at interface.
Φ Water soaked surface.

1000 psi = 6.89 MPa
1 mil = 0.025 mm

the polymer concrete overlay was placed. Good bonding was recorded with this system when the substrate was prepared in a satisfactory manner.

Only one bond test was performed with polymer concrete that was made with methyl methacrylate because it was decided that evaporation and viscosity problems had to be solved for this system before it would make a suitable overlay material.

A study of various surface preparation and cleaning methods was made on oil contaminated beams fabricated to simulate field conditions. The methods examined were: (1) sandblasting, (2) washing with a dilute acid solution, (3) washing with a tri-sodium phosphate solution, and (4) removal of the surface mortar by scarification. The two commercial machines used to scarify the surface were a Tennant paint stripe remover and a McDonald scabbler. The most satisfactory results were obtained by surface scarification, although sandblasting of sound concrete also produced good results. Bond strength values after scarification can be found in Table 4.

Tests were also conducted to examine the effect of moisture in the substrate on the ability to bond a polymer concrete overlay. Early results indicated adequate bonding was obtained on a beam containing surface moisture. In Test No. 41 water was ponded on a concrete slab until 30 minutes before a 35 mil (0.88 mm) resin tack coat and a 1.5 in. (38 mm) polymer concrete overlay were applied. Several days later cores were removed from the slab and a bond shear test was performed on the overlay. The results indicated a bond strength of over 400 psi (2,760 kPa) was attained. An initial conclusion that surface moisture had little effect on bond proved to be erroneous when poor bonding occurred on the first bridge deck overlay project. A combination of cold weather and moisture was suspected as causing the bonding problem. Laboratory testing on beams subjected to moisture and low temperature and various surface drying methods was then performed. Results from this work indicated the need for a dry and relatively warm surface [(50°F) (10°C)] to allow good resin penetration and complete polymerization of the tack coat. Attempts to lower the viscosity of the resin, LB 183-13, by adding styrene did not improve bonding strength but rather lowered it in most cases. A literature search of epoxy concrete studies found water vapor leaving the concrete surface to be a potential problem in acquiring good bond (7). This was equally true with a polyester styrene resin tack coat.

The results from the bonding studies show adequate bonding can be obtained if the substrate material is properly prepared. The base material must be sound, clean, dry, and at the proper temperature at the time the tack coat is applied.

Splitting Tensile Test

The tensile strength of several polymer concrete mixes was examined by testing 3 in. x 6 in. (76 mm x 152 mm) cylinders in splitting tensile loading in accordance with ASTM C496. This testing was normally performed on specimens that were allowed to cure 24 hours, although some testing was done at longer cure times. The resin formulation, resin content and silane concentration

were varied to study their effects on tensile strength. The relationship between splitting tensile strength and ultimate compressive strength was also noted. The results of the splitting tensile studies are found in Table 5.

In the first test, three cylinders that had previously been subjected to five cycles of a freeze-thaw test in air were tested for splitting tensile strength. These cylinders were tested 42 days after fabrication. The results of this test indicated a splitting tensile strength of this polymer concrete to be above 1,500 psi (10.3 MPa), which is over two times that of conventional portland cement concrete.

In the next series of tests, polymer concrete cylinders were fabricated using LB 183-13 resin at 8.5% and 10% resin contents. Allowing a one-day cure, the cylinders were tested with an average 5% increase in tensile value noted due to the increase in resin content. The average splitting tensile strength for the 8.5% mix was calculated at over 1,300 psi (8.9 MPa).

A further study compared the tensile strength of polymer concrete mixes containing a 10% resin content but with different resin binders. The polymer concrete made with a combination of LB 183-13 and GR 941 resins provided the highest average splitting tensile strength of 1,489 psi (10.3 MPa) after a one-day cure, while the lowest average splitting tensile strength was 805 psi (5.6 MPa) for the polymer concrete containing GR 511 resin. Polymer concretes made with LB 183-13 resin and GR 11044 resin had approximately the same average tensile strength of 1,315 psi (9.1 MPa).

The effects of using silane, a coupling agent, on splitting tensile strength was also investigated. Polymer concrete mixes were prepared using silane concentration of zero to two percent by weight of the resin. Overall results indicated the addition of silane did not improve the splitting tensile strength.

Finally, the ratio of splitting tensile strength to ultimate compressive strength was found to average 0.157 when a comparison was made using the results from 10 tests without regard to the binder used.

Modulus of Rupture

Several polymer concrete mixes were tested in flexure in accordance with ASTM C78. All testing was performed on 6 in. x 6 in. x 21 in. (152 mm x 152 mm x 533 mm) beams which were fabricated in three lifts and consolidated with a 1 in. (25 mm) diameter concrete vibrator as shown in Figure 6. During the initial testing, two sets of three beams were cast using LB 183-13 resin. The resin content of one set was designed at 8.5% and the other designed at 10% by weight of the aggregate. The method of curing was varied as one beam from each set was placed in an oven for one hour at 140°F (60°C) to ensure complete polymerization. These beams were then allowed to continue curing at room temperature before being tested. After a total curing period of 24 hours, all beams were subjected to a third-point-loading test until failure. Both the load and deflection at failure were recorded. Figure 7 illustrates testing in progress. The results of this test show the beams that had been placed

Table 5

RESULTS OF SPLITTING TENSILE TESTS

Test No.	Resin*	Resin Content %***	Aggregate Gradation**	Allowable Work Time (min.)	Age (days)	Splitting Tensile Strength (psi)	Compressive Strength (psi)	ft/fc
27	A	8.5	1	10	42	1,575	-	-
164	A	10	2	20	1	1,376	8,512	0.162
165	A	8.5	2	20	1	1,368	8,207	0.166
166	A	10	2	20	1	1,281	8,812	0.145
167	A	8.5	2	20	1	1,238	7,534	0.164
172	A	10	2	20	1	1,355	8,413	0.161
173	N	10	2	20	1	1,422	10,042	0.141
174	N	10	2	20	1	1,556	10,594	0.147
180	D	10	2	20	1	1,295	8,966	0.144
181	D	10	2	20	1	1,284	8,612	0.149
194	H	10	3	-	3	1,220	-	-
195	J	10	3	-	3	805	-	-
207	L	10	2	-	8	1,312	-	-
250	L	12	4	20	1	1,093	5,835	0.187

* See Appendix A for resin blends.
** See Table 3 for gradation.
*** Percent by weight of aggregate.

1000 psi = 6.89 mpa

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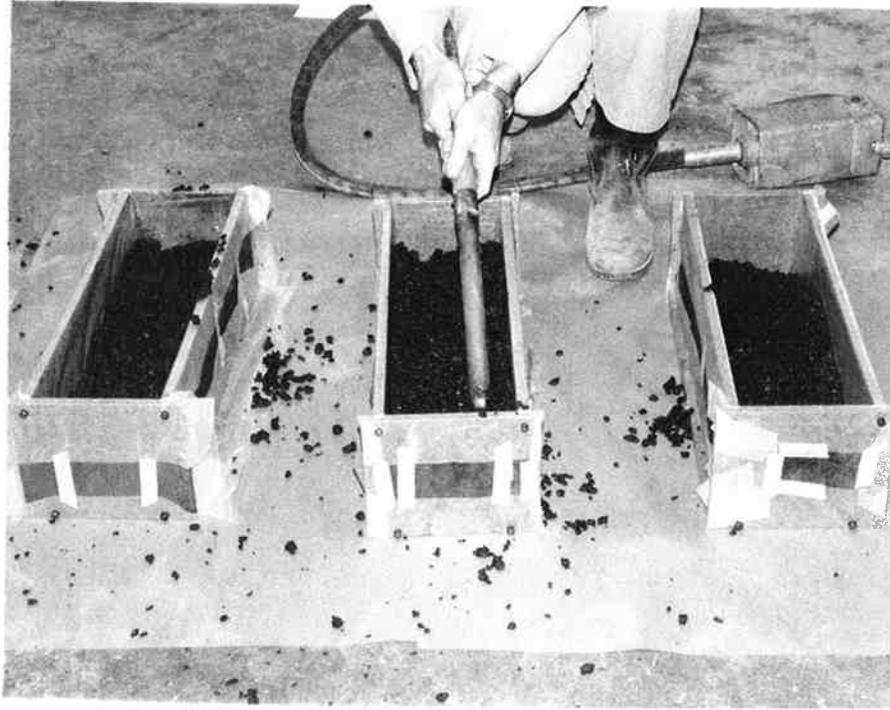
Figure 6. Consolidation of polymer concrete beams.
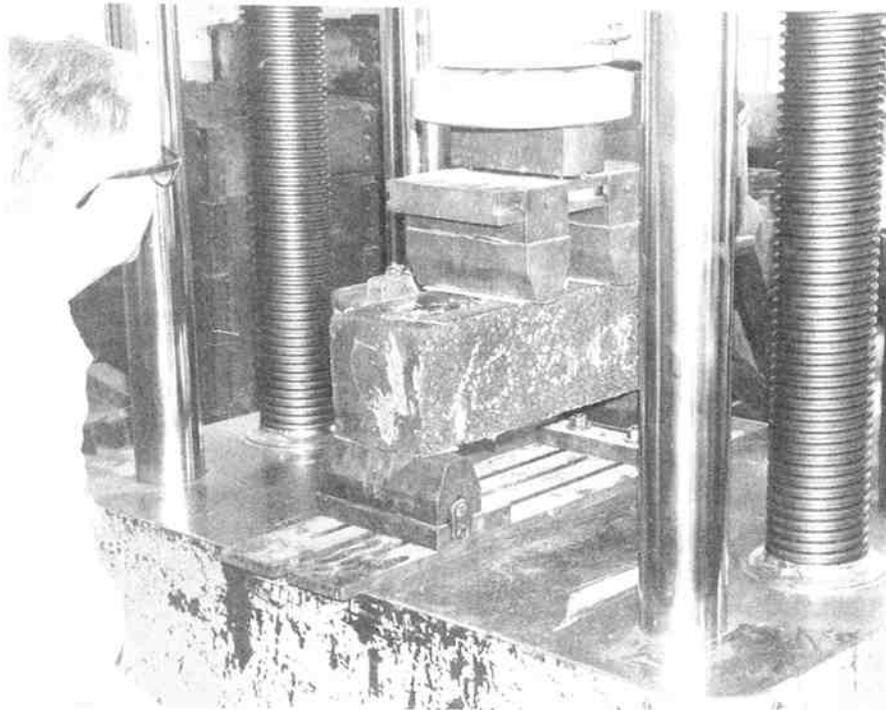
Figure 7. Third point loading for modulus of rupture test.

Table 6

MODULUS OF RUPTURE

Test No.	Resin*	Resin Content (%) ***	Aggregate Gradation**	Unit Weight lbs/cf	Ultimate Load (lbs)	Modulus of Rupture (psi)	Maximum Deflection (in.)
183-1	A	10	2	144.9	24,900	2,075	.0475
183-2	A	10	2	143.0	21,750	1,813	.0365
183-3	A	10	2	143.8	22,600	1,883	.0490
184-1	A	8.5	2	132.8	16,750	1,395	.0360
184-2	A	8.5	2	134.4	15,800	1,316	.0355
184-3	A	8.5	2	131.8	15,800	1,316	.0400
194	H	10	3	141.5	22,000	1,833	.0700
195-1	J	10	3	–	10,030	836	.0860
195-2	J	10	3	–	11,720	977	.0970
205	L	10	3	–	25,900	2,159	.0650

* See Appendix A for resin blends.
** See Table 3 for gradation.
*** Percent by weight of aggregate.

1 lb/cf = 16.02kg/m³
1 lb   = .453 kg
1000 psi= 6.89 MPa
1"   = 25.4 mm

in the oven had a slightly higher modulus of rupture than those cured entirely
in air. This indicated complete polymerization may not have occurred in all
specimens. The beams having the 10% resin content exhibited an average modu-
lus of rupture of 1,925 psi (13.3 MPa), which was 43% higher than the beams
with the 8.5% resin content. Results of the flexure tests are presented in
Table 6.

The modulus of rupture of a polymer concrete beam made with a flexible resin,
GR 511, averaged 906 psi (4.2 MPa). The average deflection at failure was
0.091 in. (2.3 mm) which was approximately twice that of the beams containing
LB 183-13 resin.

In the final test, a polymer concrete beam constructed with GR 11044 as the
binder failed at a stress of 2,160 psi (14.9 MPa). This beam was tested after
a three-day cure. A comparison of the modulus of rupture of the beams made
with the LB 183-13 resin and the GR 11044 resin show relatively close values.

Modulus of Elasticity

The modulus of elasticity of several different polymer concrete mixes was
examined during this study. Individual test data are shown in Table 7.
The polymer concrete samples were cast in 6 in. x 12 in. (152 mm x 305 mm),
cylinders and tested at various intervals during curing. The apparatus used
to measure the deformation is shown in Figure 8.

During the first test, two samples were made using a 8.5% resin content (Test
No. 44). The handling time was varied to study its effect on the modulus of
elasticity for the particular resin formulation used. The first mix was
placed and finished in 12 minutes and tested at 1, 3, and 7 days. The modulus
of elasticity increased from 1.8×10^6 psi (12.4 GPa) at 1 day to 2.6×10^6 psi
(17.9 GPa) in 7 days when loaded to a maximum stress level of 3,000 psi (20.7
MPa) (Figure 9). The increase in the elastic modulus indicated complete
polymerization of the polymer concrete had not occurred at the end of 1 day.
The handling time of the second sample was extended for 30 minutes by delaying
the placing and finishing after mixing. This sample was tested at 1 and 3
days. The testing at day 1 had to be curtailed at a stress level of 1,400 psi
(9.7 MPa) because of excessive strain. The cylinder failed during the third
day test at 1,730 psi (11.9 MPa) with a corresponding "E" value of 0.4×10^6
psi (2.76 GPa). The difficulty in placing the material in the mold and the
results of this test indicated that a partial polymerization had occurred
before the polymer concrete was compacted and finished. This overhandling
caused the binding capability of the resin to be substantially reduced. The
early failure of the second cylinder showed the need of an inhibitor to extend
the allowable handling time. It was at this time that hydroquinone was found
to slow the polymerization to an acceptable rate. All further work utilized
hydroquinone to produce handling times in excess of 30 minutes at moderate
temperatures.

The LB 183 resin was used to study the effects of resin content on the modulus
of elasticity in Tests No. 144 and No. 145. Figure 10 shows the "E" values at
3 and 77 days. The modulus of elasticity was not recorded at 1 day because

Table 7

MODULUS OF ELASTICITY

Test No.	44	99	144	145	146	194	195	249
Resin[1]	B	A	A	A	D	H	J	L
Resin Content[2]	8.5	10.0	10.0	8.5	10.0	10.0	10.0	12.0
MEKP[3]	2.0	2.0	2.0	2.0	2.0	1.5	1.5	2.0
Co Oc[3]	0.25	0.5	0.5	0.5	0.5	0.25	0.25	0.5
A174[3]	2.0	2.0	2.0	2.0	2.0	1.0	1.0	0.0
HQ[4]	0.0	425	400	400	400	200	200	200

Age in days	"E" Values[5]							
1	1.85	---	NG	NG	NG	.84	0.46	2.56
3	2.38	---	2.43	1.67	1.97	1.62	0.57	---
7	2.60	---	2.86	2.07	2.45	1.81	0.48	2.90
11	2.67	3.16	---	---	---	---	---	---
14	---	3.27	---	---	---	---	---	2.90
28	---	---	---	---	---	---	---	2.91
44	---	---	3.43	2.48	2.62	---	---	---
77	---	---	3.43	2.63	2.70	---	---	---
117	---	3.38	---	---	---	---	---	---

[1] See Appendix A for resin blends.
[2] Percent by weight of aggregate.
[3] Percent by weight of resin.
[4] Parts per million by weight of aggregate.
[5] 1×10^6 lbs/sq. in.

1000 psi = 6.89 MPa
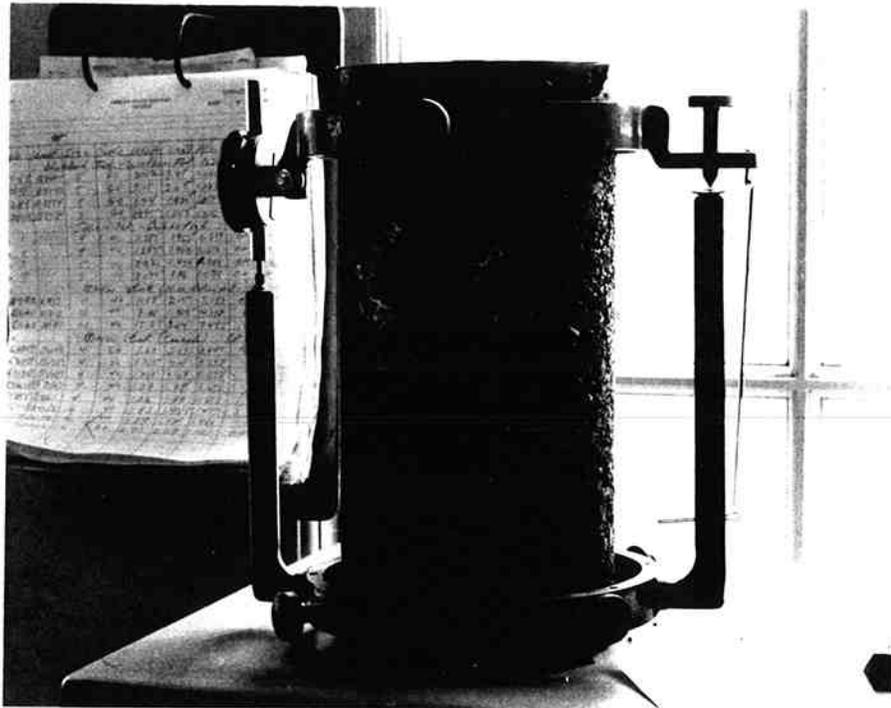
Figure 8. Apparatus for strain measurements.

Test # 44
6" X 12" Cylinder
8½% Resin Content
12 Minute Handling Time

1000 psi = 6894.8 kPa   1" = 25.4 mm
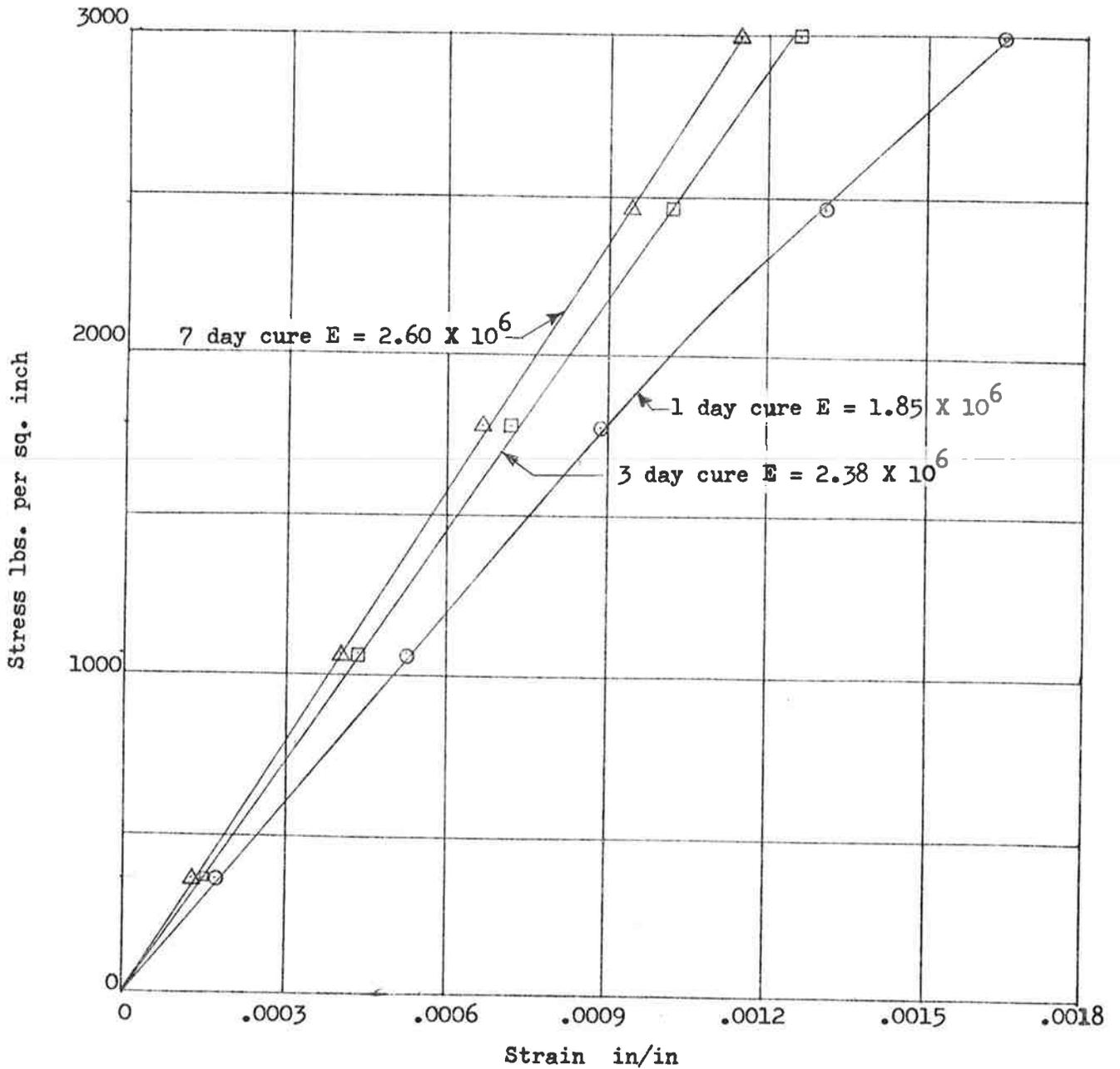
Stress-Strain curves at
different cure times.

Figure 9

6" X 12" Cylinders
1000 psi = 6894.8 kPa
1" = 25.4 mm

Test # 144
10% Resin Content

Test # 145
8½% Resin Content

Test #144
3 day cure E = 2.43 X 10^6
77 day cure E = 3.43 X 10^6

Test #145
3 day cure E = 1.67 X 10^6
77 day cure E = 2.63 X 10^6

Stress lbs. per sq. inch

Strain in/in

Stress-Strain curves for polymer
concretes with different resin content.

Figure 10

the polymer concrete was not sufficiently cured. This was due to a combination of low temperature during initial curing and the high concentration of inhibitor (400 ppm). The sample containing 10% resin had an "E" value of 3.43 x 10^6 psi (23.6 GPa) at 77 days while the sample containing 8.5% resin had an "E" value of 2.63 x 10^6 psi (18.1 GPa) at 77 days. There was a substantial gain in the modulus of elasticity between the 7 and 44 day tests also.

The modulus of elasticity of a polymer concrete mixture made with GR 511, a more flexible resin, was examined in Test No. 195. Using an inhibitor concentration of 200 ppm and 10% resin content, the polymer concrete cured sufficiently to test at 1, 3, and 7 days. The modulus of elasticity for this mix was calculated to be approximately 0.5 x 10^6 psi (3.4 GPa).

Another modulus of elasticity test was performed on a polymer concrete prepared with GR 11044 resin. The results of this test are plotted in Figure 11 at curing times of 1, 7, and 28 days. The "E" values measured at these times were 2.56 x 10^6 psi, 2.90 x 10^6 psi, and 2.91 x 10^6 psi (17.6 GPa, 20.0 GPa, and 20.0 GPa) respectively. These values indicated that nearly complete polymerization had occurred at 7 days with the inhibitor concentration at 200 ppm.

Thermal Coefficient Test

The first thermal coefficient study was conducted on 3 in. x 6 in. (76 mm x 152 mm) polymer concrete cylinders with an 8.5% resin content. The specimens were cast and cured for several days at room temperature. Measurements of length were made at room temperature, 140°F (60°C), and -10°F (-23.3°C) with a dial indicator as shown in Figure 12. The specimens were heated in an oven for 24 hours and cooled in a freezer for 24 hours during the testing cycles. Initial results indicated the polymer concrete made with polyester styrene to have a nonlinear coefficient of thermal expansion. The average value for the three specimens tested was 7.8 x 10^{-6} in/in/$^\circ$F for room temperature to -10°F (23.3°C), while from room temperature to 140°F (60°C) the average coefficient was 9.8 x 10^{-6} in/in/$^\circ$F (Test No. 27).

During Tests No. 56 and No. 70, the thermal coefficient was measured at intermediate temperatures to more clearly define the temperature vs. length curve. Using an 8.5% resin content, measurements were made at -10°F (-23.3°C), 35°F (1.7°C), 68°F (20°C), 100°F (37.8°C), and 140°F (60°C). The results of this test were in close agreement with the earlier findings. Increasing the resin content to 10% as shown in Test No. 70, Table 8, did not alter the results significantly, but the coefficient of thermal expansion appeared to be greater at the higher temperatures.

The thermal coefficients of the polymer concrete mixes tested were somewhat higher than that of portland cement concrete, which is around 6.5 x 10^{-6} in/in/$^\circ$F. The resulting potential differential movement between the polymer concrete and the substrate concrete was not expected to cause any problems, provided the overlays were kept thin and adequate bond was obtained. By lowering the modulus of elasticity of the polymer concrete, reductions in the required bond strength could be achieved.
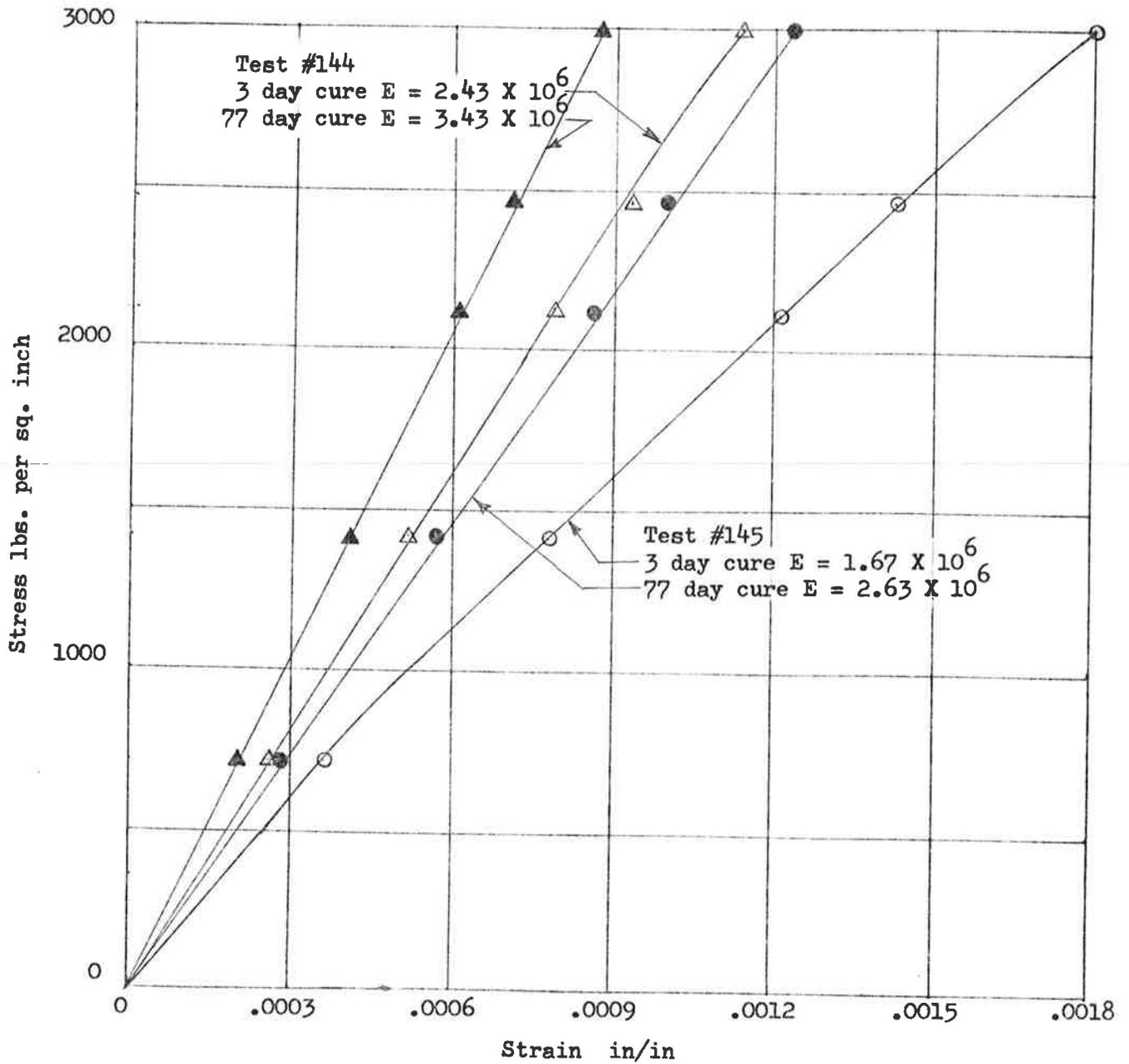
Test # 249
6" X 12" Cylinder
12% Resin Content
30 Minute Handling Time

1000 psi = 6894.8 kPa   1" = 25.4 mm
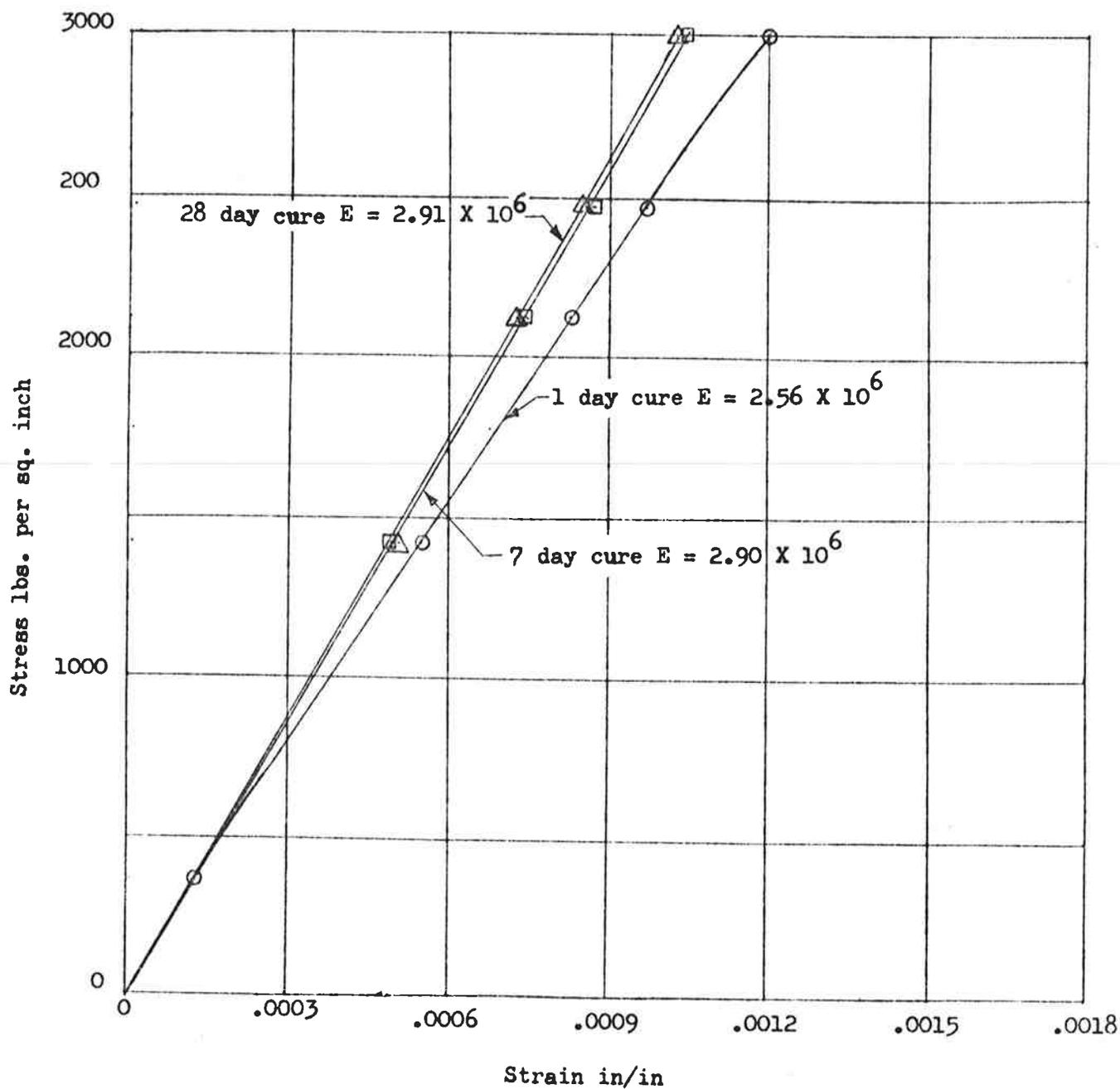
Stress-strain curve at different cure times

Figure 11
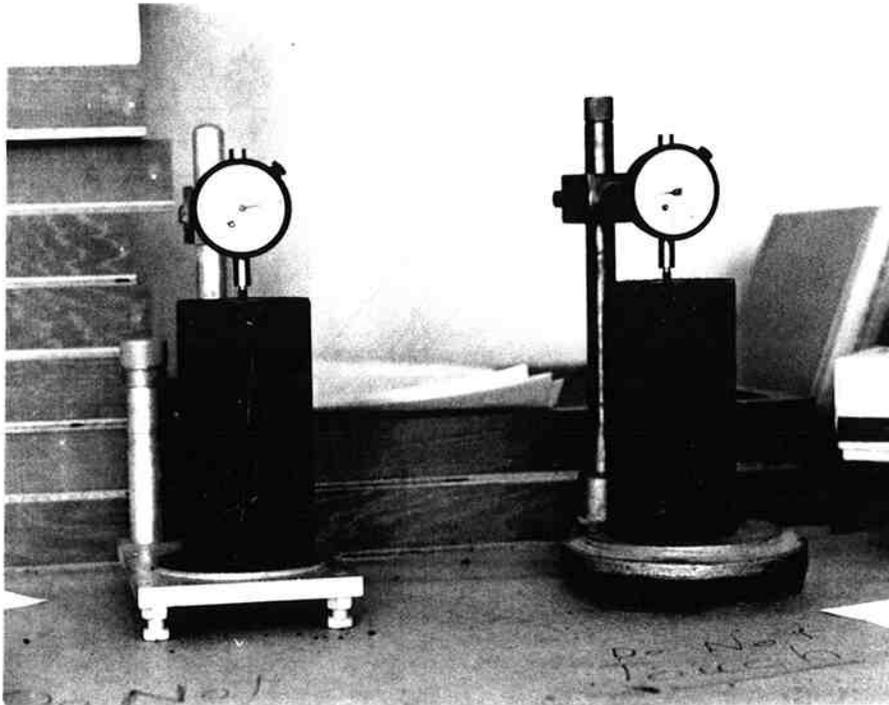
Figure 12. Dial indicator used in thermal coefficient tests.

Table 8

THERMAL COEFFICIENT TEST RESULTS

TEST NUMBER

Composition	27	56	70
Resin[1]	B	B	B
Resin Content[2]	8.5	8.5	10
MEKP[3]	1.5	0.5	0.5
Co Oc[3]	0.75	0.25	0.25
A 174[3]	2.0	2.0	2.0

Temp. Range °F	Coefficient of expansion, 10^{-6} in/in/°F		
-10 to 35	--	7.3	6.9
-10 to 70	7.8	--	--
35 to 70	--	7.9	7.9
70 to 100	--	9.9	9.6
100 to 140	--	9.5	10.6
70 to 140	9.8	--	--

[1] See Appendix A for resin blends.
[2] Percent by weight of aggregate.
[3] Percent by weight of resin.

1" = 25.4 mm
C° = 5/9(F°-32)

Shrinkage Coefficient Tests

An investigation of curing shrinkage was made to determine the suitability of polymer concrete as an overlay material. The examination of polymer concrete shrinkage was conducted on a variety of mixes to compare the effects of different resins, resin contents, rates of cure, and aggregate gradations. The results of this work are found in Table 9.

In the first test series, 3 in. x 6 in. (76 mm x 152 mm) cylinder samples were cast with 8.5% and 10% resin contents. Shrinkage measurements were made after 3 hours and continued for 14 days while the samples remained in their molds. Of the four cylinders cast for each mix, one was placed permanently in a measuring apparatus (Figure 12) while the others were measured and removed after each reading. The same apparatus was used to measure the thermal coefficient. At the end of 14 days, the samples were removed from their casting molds and measured for an additional 14 days. While in the molds, the shrinkage was quite low and had apparently stabilized after 5 or 6 days. During the first 24 hours after removal from the molds, however, a dramatic additional shrinkage occurred for both mixes. This was followed by a shrinkage at a diminishing rate for several more days. Results indicated the amount of shrinkage was affected by the amount of binder used. The total shrinkage strain after 28 days was 0.0012 in/in for the 10% mix and .0009 in/in for the 8.5% mix. Each of the specimens contained LB 183-13 resin, 1.5% initiator and 0.75% promoter (Tests No. 23 and No. 24).

In the next test series, two additional cylinder samples were cast in 3 in. x 6 in. (76 mm x 152 mm) molds. This time each contained 8.5% resin, but with different amounts of initiator and promoter. These samples were removed from their molds in 3 hours and at that time shrinkage measurements began. Average measurements indicated a strain of 0.00038 in/in in 1 day and 0.00051 in/in in both 5 and 28 days for the sample containing 1.5% initiator (Test No. 56). The average strain for the sample containing 0.5 % initiator was 0.0009 in/in in 1 day, 0.0010 in/in in 5 days, and 0.0011 in/in in 28 days (Test No. 57). Measuring difficulties prevented shrinkage values being taken during the first 3 hours while the specimens were in the molds. However, it appeared 70% of the shrinkage occurred within the first 24 hours (see Figure 13).

Because of these high shrinkage values, a study was made to determine the effect of increasing the percentage of aggregate material passing the No. 200 sieve on polymer concrete shrinkage. Four aggregate gradations were selected which basically follow the maximum density curve except for the fine material. The material passing the No. 200 sieve was varied between 10% and 16%. A 12% resin content was used due to previous testing which determined it to be sufficient to produce a workable and compactible mix for each gradation. The various aggregate gradations are found in Table 2, columns 7, 8, 9 and 10.

After mixing and placing, shrinkage measurements were made at approximately 2-hour intervals during the first day and then periodically for two weeks. Test results indicate no noticeable reduction in shrinkage was accomplished by increasing the fine material. All measurable shrinkage occurred during the first 24 hours in all specimens. The calculated value of the coefficient of shrinkage of each specimen is found in Table 9 for Tests No. 244 through No. 247.

Table 9

SHRINKAGE FOR VARIOUS POLYMER CONCRETE MIXES

					TEST NUMBER					
	23	24	56	57	227	228	229	230	238	244
Composition Resin*	B	B	B	B	A	A	L	L	A	L
Resin Content %	8.5	8.5	8.5	8.5	12	12	10	12	12	12
Aggregate **	1	1	1	1	1	2	2	2	2	7
Temp. °F	68	68	70	70	70	68	68	68	65	68
					Shrinkage Strain in/in					
Cure Time (hrs)										
2	—	—	—	—	.0008	—	—	—	—	.0003
3	—	—	—	—	—	—	—	—	.0083	—
4	.00011	—	—	—	.0010	—	—	—	—	.0014
5	.00011	—	.00018	.00066	—	—	—	—	.0019	.0023
6	—	—	—	—	—	—	.0012	.0012	—	—
7	.00016	—	—	—	—	—	—	—	—	—
8	.00018	—	.00025	.00066	—	—	.0018	—	.00277	.00284
Cure Time (days)										
1	.00023	.00041	.00038	.00085	.0010	.009	.0027	.00265	.00277	.00284
2	.00023	.00041	.00038	.00085	—	—	—	—	.00277	.00284
3	.00023	—	—	—	.00388	.0035	.0027	.00265	—	—
4	.00025	—	—	—	—	.0041	—	—	—	.00284
5	.00027	—	.00050	.0010	—	.0041	—	—	—	—
6	.00027	—	—	—	—	—	.0027	.00265	.00277	—
7	—	—	—	—	—	—	—	—	—	—
8	.00027	.00050	.00050	.0010	.00388	.0041	.0027	.00265	.00277	.00284
12	—	—	—	—	—	—	—	—	—	—
14	.00027	.00050	.00054	.0011	—	—	.0029	.00265	—	.00284
15	.00058	.00065	—	—	—	—	—	—	—	.00284
28	.00093	.00121	.00055	.0011	—	—	—	—	—	—

* See Appendix A for resin blends.
** See Table 3 for aggregate gradation.

$C° = 5/9(F° - 32)$
1" = 25.4 mm

Table 9

(continued)

TEST NUMBER

Shrinkage Strain in/in

Composition	245	246	247	251	252	253	254	265
Resin*	L	L	L	L	L	L	L	L
Resin Content %	12	12	12	10	10	14	14	12
Aggregate**	8	9	10	7	8	9	10	6
Temp. °F	68	68	68	76	76	76	76	68
Cure Time (hrs)								
2	—	—	.0003	.0014	.0019	.0016	.0014	—
3	.0014	.0014	—	—	—	—	—	—
4	.0028	.0017	.0020	—	—	—	—	—
5	.0031	—	.0023	—	—	—	—	—
6	—	—	—	.0016	.0022	.0019	—	—
7	—	.0025	—	—	—	—	.0017	.0022
8	—	—	.0023	—	—	—	—	—
Cure Time (days)								
1	.0031	.0025	.0029	.0019	.0025	.0019	.0025	.0022
2	.0031	.0025	.0029	.0019	.0025	.0019	.0025	.0022
3	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—
5	.0031	.0025	.0029	—	—	—	—	—
6	—	—	—	—	—	—	—	—
7	—	—	—	.0022	.0025	.0022	.0025	.0022
8	—	—	—	—	—	—	—	—
12	.0031	.0025	.0029	—	—	—	—	—
14	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—
28	—	—	—	—	—	—	—	—

* See Appendix A for resin blends.
** See Table 3 for aggregate gradation.

$C° = 5/9(F°-32)$
$1" = 25.4$ in/in

-40-

Shrinkage Strain vs. Time

Figure 13

3" X 6" Cylinders
Temp. 70°-76°
10 Minute Handling Time
8.5% Resin Content

°C = (°F - 32)/1.8
1" = 25.4 mm

Test #57
0.5% Initiator
0.25% Promoter

Test #56
1.5% Initiator
0.75% Promoter

Test #57

Test #56
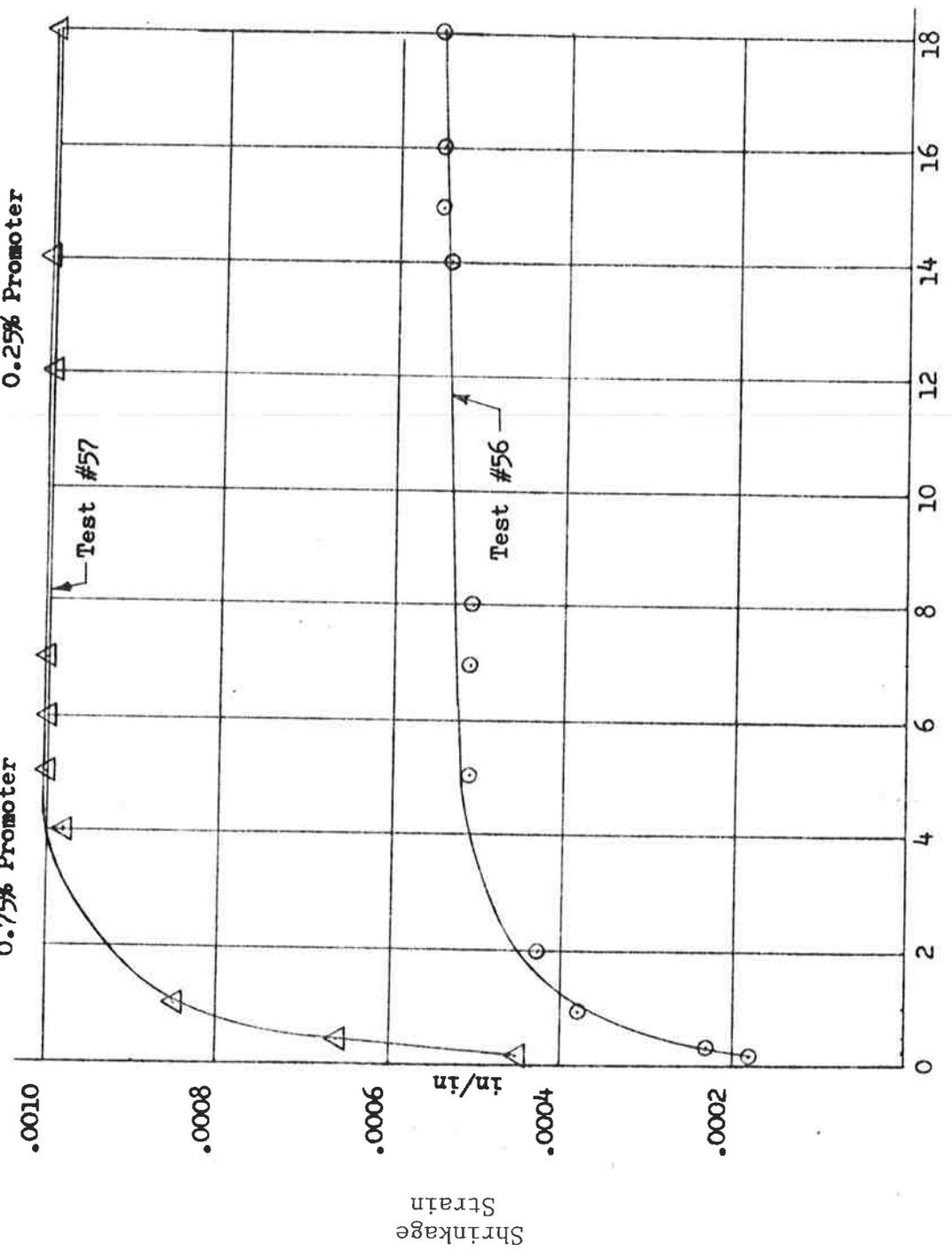
Time in days

Shrinkage
Strain

in/in

.0010

.0008

.0006

.0004

.0002

Although the total shrinkage coefficient of some polymer concrete mixes were in excess of 0.002 in/in it was assumed most of the shrinkage would occur while the resin was in a semisolid state and cracking of thin overlays would not occur. The larger shrinkage coefficients occurred in mixes having the greater resin contents. By keeping the resin content at a minimum and the overlay thin, curing shrinkage stress can be greatly reduced. All of the earlier polymer concrete overlays were placed 1.5 in. thick and some minor shrinkage cracks were noted within two days after placement.

If the 0.002 in/in shrinkage were to be concentrated in, say, three cracks on a 200 ft overlay, each of these cracks would be possibly 2 x 25 ft x 12 in/ft x 0.002 in/in = 1.2 in. wide. This, of course, would be intolerable. It would also be highly unlikely, since for this to occur the overlay would have to be essentially unbonded. Since significant bond is probable, the cracks would be more equally distributed and smaller. The ideal situation would be to have all shrinkage strain to go into tensile stress below the ultimate strength with no cracks.

Freeze-Thaw Resistance Test

An investigation of freeze-thaw resistance of polymer concrete began with six 2-in. (51 mm) cubes being cast using LB 183 resin. Using an 8.5% resin content mix, the cubes were cast and allowed to cure for 24 hours before being subjected to alternate freeze-thaw cycles. The freeze-thaw test consisted of freezing the polymer concrete cubes in air at $-10^{\circ}F$ $(-23.3^{\circ}C)$ followed by thawing in water at $68^{\circ}F$ $(20^{\circ}C)$. Two complete cycles were accomplished each day with the freeze portion of one cycle extending overnight. At the end of 150 cycles, an average loss in weight of 2.43% was recorded. The cubes appeared to be losing fine sand particles when rubbed with the hand. A combination of segregation and a lack of good compaction during casting is believed to have contributed to some of the freeze-thaw loss. Also, the many edges on a cube may have increased the weight loss in these specimens.

The next freeze-thaw resistance study was performed on six 3 in. x 6 in. (76mm x 152 mm) cylinders. Two of these cylinders were made of 4,000 psi (27.6 MPa) portland cement concrete while the remaining four were made of polymer concrete. The resin content of two of the polymer concrete cylinders was 8.5% and two contained 10% (by weight of the aggregate); these mixes correspond to Tests RM 63 and RM 62 respectively. After casting, the polymer concrete samples were allowed a 24-hour cure before testing began. The portland cement concrete specimens were allowed a 28-day cure. As in the first test, the specimens were frozen in air at $-10^{\circ}F$ $(-23.3^{\circ}C)$ and thawed in water at $68^{\circ}F$ $(20^{\circ}C)$ with two cycles occurring each day. Figure 14 shows one cylinder of each set after 100 cycles.

Results after 150 cycles show the polymer concrete made with 10% resin content had an average weight loss of 0.90% while the 8.5% mix recorded an average weight loss of 1.11%. These values appear to be satisfactory when compared to the average weight loss of 43.3% exhibited by the portland cement concrete samples. Further test data are found in Table 10.
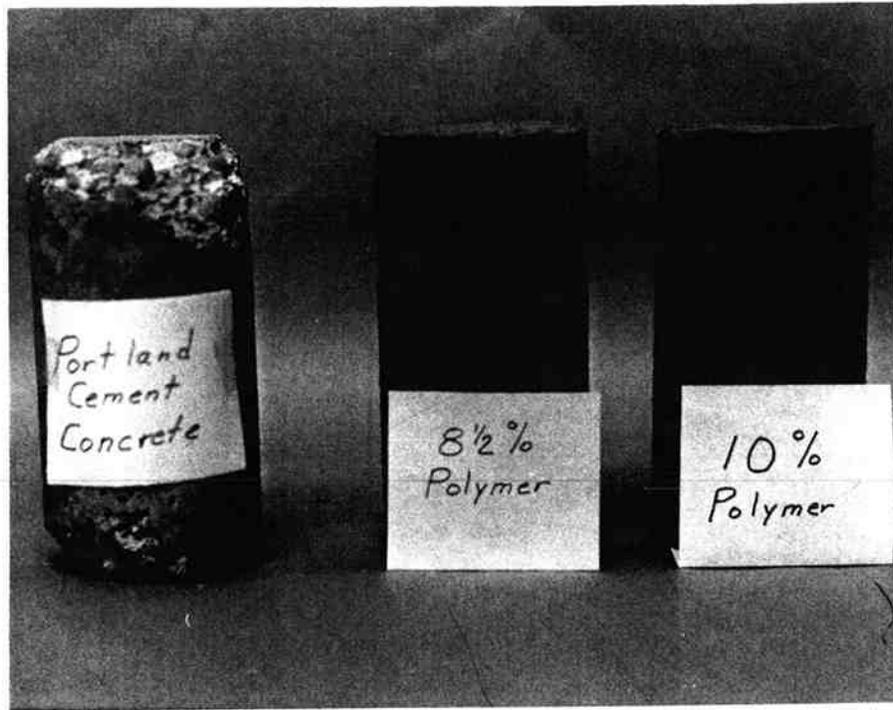
Figure 14. Freeze-thaw resistance test cylinders after 100 cycles.

Table 10

FREEZE-THAW TEST RESULTS

TEST NUMBER

Composition	RM 62	RM 63	Reference Concrete
Resin [1]	A	A	4,000 psi
Resin Content [2]	10	8.5	Portland Cement
MEKP [3]	2.0	2.0	Concrete
Co Oc [3]	0.5	0.5	28 day cure
HQ [4]	20200	200	
Aggregate	Wall #1	Wall #1	

Cycles	Average Weight Loss in Percent		
25	.40	.58	.92
50	.51	.75	.95
100	.76	.97	5.20
150	.90	1.11	43.30

[1] See Appendix A for resin blends.
[2] Percent by weight of aggregate.
[3] Percent by weight of resin.
[4] Parts per million by weight of aggregate.

1000 psi = 6.89 MPa

Permeability Test

The electrical resistance procedure was used to test the permeability of polymer concrete overlays. In this test, the electrical resistance of one square foot of overlay is measured with respect to reinforcing steel embedded in the portland cement concrete substrate. This method has found wide acceptance in measuring the quality of bridge deck waterproofing membranes. Resistance readings greater than 500,000 ohms signify an acceptable membrane (11).

To determine the permeability of polymer concrete overlays in the laboratory, portland cement concrete test slabs were cast measuring 1.5 ft (0.45 m) square and 3.5 in. (89 mm) thick. The slabs contained two No. 4 bars with 1.5 in. (38.1 mm) of cover. A 1.5-in. (38.1 mm) polymer concrete overlay was then placed on the slab after the application of a 15-mil (0.38 mm) resin tack coat. The overlay was consolidated and screeded with a 2 by 4 ft board. The first polymer concrete overlay contained 8.5% resin and natural aggregate. The overlay was allowed a 48-hour cure before testing began. Within minutes after applying water to the surface, the resistance dropped from infinity to 40,000 ohms, thus showing a failing membrane. A second slab was also overlaid with a 1.5-in. (38.1 mm) polymer concrete overlay, but this time a 50-mil (1.3 mm) tack coat was applied. Once again the overlay was consolidated with a 2 by 4 ft screed. As before, the resistivity dropped from infinity to 40,000 ohms upon wetting, indicating moisture was penetrating the overlay system.

Next, a two-15-mil (0.38 mm) tack coat system was applied followed with a 1.5-in. (38.1 mm) polymer concrete overlay. The first tack coat was applied and allowed to cure before the second tack coat and overlay were placed. The same method of consolidation was used as described. A 48-hour cure period was permitted before the permeability testing resumed. Readings after a 3-hour soaking time remained above 10,000,000 ohms, indicating an excellent membrane had been obtained. Moisture appeared to penetrate the overlay, but was prevented from reaching the concrete slab because of the two-tack-coat system.

In an additional laboratory test, a 1.5-in. (38.1 mm) overlay containing 10% resin was placed with a single 15-mil (0.38 mm) tack coat on a slab. Greater emphasis was placed on consolidation to reduce the void content within the overlay as a concrete vibrator was inserted into the polymer concrete before it was screeded. As before, a 48-hour cure time was allowed before the permeability test began. The overlay was then soaked continuously for 2 hours with resistance readings of over 10,000,000 ohms being recorded. This test demonstrated an impermeable polymer concrete system is possible with good consolidation.

A polymer concrete overlay that was placed on the Santiam River Bridge was tested for permeability one day after installation. Twenty-two readings were made at about 5 ft (1.5 m) intervals along the deck. Twelve readings were above 500,000 ohms, while only two were below 100,000 ohms. Minor shrinkage cracking and a lack of full compaction were blamed for the less than satisfactory results. Details of this overlay are presented in the next section of this report.

Bridge Deck Overlays

The first attempt to place a polymer concrete overlay on a bridge deck in Oregon occurred in April 1975. The work was performed by a State bridge maintenance crew with the assistance of laboratory personnel. The work consisted of placing a 1.5 in. (38 mm) thick overlay on one 30 ft (9.1 m) long by 24 ft (7.3 m) wide span of the Santiam River Bridge in the City of Jefferson. The overlay was placed on only one 12 ft (3.6 m) lane during each of two days. The deck preparation for this project consisted of sandblasting the day before the overlay was placed and further removal of dust and debris by brooming and high pressure air on the morning of the work. To enhance bonding of the overlay, a two-tack-coat system was used. The tack coat material was the same resin used to make the polymer concrete. The formulation for the tack coat and polymer concrete are shown in Table 11. The first 15 mil (0.38 mm) tack coat was applied to the deck with paint rollers and allowed to dry 60 minutes before placement of the overlay began. The second 15 mil (0.38 mm) tack coat was applied immediately ahead of the overlay.

Two 5-cu ft (0.14 m^3) mortar mixers were used to mix the polymer concrete. The specially graded aggregate selected for the polymer concrete was purchased in 80 lb (36.3 kg) sacks after it had been dried. The LB-183 resin used as the binder was acquired in 55 gal (208 l) drums and proportioned in 5 gal (18.9 l) cans. The polymer concrete was mixed on the bridge adjacent to the work area for approximately two minutes before it was placed on the deck.

At the beginning of the overlay the polymer concrete was deposited into a hopper which spread the concrete to the desired elevation on the deck. When the vibrator on the hopper broke, the remaining portion of the overlay was screed to the desired thickness with an I beam.

The polymer concrete was compacted with a 600 lb Ray-Go roller. Every effort was made to complete the compaction within ten minutes after the polymer concrete was mixed and placed. This method was successful as adequate compaction and a good riding surface were achieved.

It required three hours to mix, place and finish the overlay during the first day. This time was reduced to 1-1/2 hours on the second day because everyone was familiar with the placement procedure.

In spite of the 55°F (12.7°C) air temperature, the polymer concrete set up sufficiently in 1-1/2 hours to allow traffic on the overlay on both days.

The immediate evaluation of the overlay was positive but after one week in service, the installation was rated unsuccessful because the overlay failed to bond to the deck.

In addition, large shrinkage cracks and cracks due to impact loading developed within three weeks after construction. The overlay was removed from the deck after being in service for only fourteen weeks. During removal an examination revealed virtually no bonding had occurred between the polymer concrete and the existing deck surface except in small isolated areas. The quality of the polymer concrete however, appeared to be very good.

Table 11

SANTIAM RIVER BRIDGE
RESIN FORMULATIONS AND COMPRESSIVE STRENGTHS

	(April 9) Polymer Concrete (April 10) 1976	
	Mix 1	Mix 1
Resin[1]	L	L
Resin Content[2]	10	10
MEKP[3]	2.0	2.0
Co Oc[3]	1.0	1.0
Silane A-174	1.0	1.0
HQ[4]	200	200
Aggregate[5]	3/8" minus natural, gradation #2, Table 3	

	Tack Coat			
Resin	L	L	L	L
Thickness (mils)	15	15	15	15
MEKP[3]	2.0%	2.0%	2.5%	2.0%
Co Oc[3]	1.0%	1.0%	1.0%	1.0%
Silane A-174[3]	2.0%	1.0%	2.0%	1.0%
HQ[4]	None	200 ppm	None	200 ppm
Cure Time	24 hrs.			

	April 9	April 10
Average Ultimate Compressive Strength, psi	6040	5830

1000 psi = 6.89 MPa
 1 mil = 0.025 mm
 1"   = 25.4 mm

1 See Appendix A for resin blends.
2 Percent by wieght of aggregate
3 Percent by weight of resin.
4 Parts per million by weight of aggregate
5 See Table 3, page 13 for aggregate gradation.

Table 11
(continued)

SANTIAM RIVER BRIDGE
RESIN FORMULATIONS AND COMPRESSIVE STRENGTHS

	(June 23) Polymer Concrete (June 24) 1976		
	Mix 1	Mix 1	Mix 2
Resin[1]	L	L	L
Resin Content[2]	12	12	14
MEKP[3]	1.5	1.5	1.5
Co Oc[3]	0.125	0.125	0.125
HQ[4]	200	200	200
Aggregate[5]	3/8" minus crushed, gradation #3 , Table 3		

	Tack Coat	
Resin	L	L
Thickness (mils)	18±	18±
MEKP[3]	1.25	1.25
Co Oc[3]	0.125	0.125
Silane A-174[3]	4.0	4.0
HQ[4]	200	200

Cure Time	3 hrs	5 hrs	24 hrs	7 days
Average Ultimate Compressive Strength, psi	761	1,500	5,900	8,621

1000 psi = 6.89 MPa
1 mil = 0.025 mm
1" = 25.4 mm

[1] See Appendix A for resin blends.
[2] Percent by weight of aggregate.
[3] Percent by weight of resin.
[4] Parts per million by weight of aggregate
[5] See Table 3, page 13 for aggregate gradation.

After an investigation in the laboratory, the bonding failure was attributed to the cold, moist condition of the deck during placement. A subsequent requirement that polyester styrene polymer concrete be placed only on a dry surface and at temperatures above 55°F (12.7°C) eliminated most of the bonding problems. The use of a slightly more flexible resin which could withstand shrinkage strain was also approved for further overlay work.

The second attempt to overlay one span of the Santiam River Bridge occurred on June 23 and 24, 1976. As before, the work was done by State maintenance forces with assistance from the laboratory personnel. This time the overlay was more successful. The project began with an emphasis on a good deck preparation. Two days preceding the overlay, the deck surface was scabbled to remove contaminated and unsound concrete. Approximately 1/4 in. (6.3 mm) of the surface mortar was removed by a MacDonald pneumatic scabbler, Model U5 (Figure 15). The rate of scarifying was approximately 120 sq ft (11.1 m²) per hour. This was relatively slow, but because of the size of the work area, a larger scarifier could not be used economically. Further deck cleaning was accomplished by sandblasting just prior to overlaying after traffic had been detoured from the work area.

Shortly before the overlay began, a brief meeting was held with the maintenance workers to acquaint them with polymer concrete and to assign specific duties. Following this meeting the batching area was organized immediately adjacent to the bridge. The mixing facilities consisted of two 5 cu yd (3.8 m) dump trucks containing the polymer concrete aggregate and a 16 ft x 6.5 ft, (4.9 m x 2 m) trailer. The trailer was remodeled to allow two 5 cu ft (.14 m²) mortar mixers to discharge polymer concrete directly into wheelbarrows. A table holding two 55-gal (208 1) barrels of resin were also placed on the trailer for mixing convenience. The promoter and inhibitor were added to the resin barrels before they were placed on the table in order to reduce the resin blending time. The initiator was added to the resin just before each polymer concrete batch was mixed. Some difficulties arose in trying to mix the promoter and the inhibitor into the 55-gal (208 1) barrels. A steel rod with a hook at the end, powered by a variable speed drill, proved to be an effective agitator.

A 1/2 in. (12.7 mm) minus crushed aggregate was used for this overlay. It was proportioned at the job site in quantities of 25% 1/2 in. to 1/4 in. (12.7 to 6 mm), 70% passing the 1/4 in. (6.3 mm) sieve, and 5% portland cement. The aggregate was purchased from a local asphalt concrete supplier after being dried at 350°F (176.6°C). It was then stored in a warehouse in two 5 cu yd (3.8 m³) dump trucks until needed on the project.

In order to prepare accurate quantities of materials for batching, a volumetric measuring system was devised for proportioning aggregate. This consisted of placing small bolts through the wall of 5-gal (18.9 1) measuring cans at a predetermined elevation. Initially, the cans were filled to the desired depth from 6 in. x 6 in. (152 mm x 152 mm) slide gates that were fabricated in the tailgate of the dump trucks. The portland cement filler was volumetrically measured and added to the fine aggregate at this time. When the required number of aggregate cans were filled, they were placed on the trailer near the mixers for immediate use.

Figure 15. Deck preparation by scabbling.

During the first day, no definite mixing time was established. The polymer concrete was discharged from the mixer when it looked thoroughly mixed. This required a mix time of approximately 2 minutes. The polymer concrete was then transported to the deck by wheelbarrow.

Just before the polymer concrete was discharged from the wheelbarrow onto the deck, a single 18-mil (0.46 mm) resin tack coat was applied by paint rollers. The tack coat was mixed and issued to the workmen in half-gallon quantities. Every effort was made to cover the tack coat with the polymer concrete overlay within a 5-minute period. In order to help judge the area that was to be covered by a half gallon of tack coat, the screed rails were marked at predetermined intervals. Once the polymer concrete was deposited onto the deck, it was spread evenly with shovels and rakes. A 12 ft (3.6 m) long, 4 in. x 4 in. (102 x 102 mm) H pile was then used as a strike-off screed. The screed rode on wood "2 by 4's" that were placed at the roadway centerline and in the gutter. This method produced a uniform polymer concrete thickness of 1.5 in. (38.1 mm) before compaction. The screed was operated by two men.

When the polymer concrete was deposited beyond the length of one section of the screed rails, the rails were removed and polymer concrete was placed in the void. At this time, the compaction of a 12 ft wide by 8.0 ft long (3.6 x 2.4 m) section began. Total time to mix, place and finish each section was less than 20 minutes. The allowable handling time was estimated to be 45 minutes at the ambient temperature of $75^{\circ}F$ ($23.9^{\circ}C$) for the particular resin system used.

A vibrating sled compactor weighing about 100 lbs (45.3 kg) and used primarily to compact soil or asphalt concrete was used to compact the polymer concrete. Cores taken from the overlay indicated a consolidation of 0.25 in. (6.3 mm) was obtained.

The total time required to mix, place, and compact a one-lane section measuring 12 x 30 ft (3.6 x 9.1 m) was one hour. This included a five minute delay when the mixers were cleaned during the batching operation.

The mixers were cleaned by adding two gallons of methylene chloride and 35 lbs (15.9 kg) of coarse aggregate to each mixer and allowing them to run for about 2 minutes. The solvent and aggregate were then dumped into a wheelbarrow and an additional 35 lbs (15.9 kg) of coarse aggregate was added to each mixer to absorb any remaining solvent. After a brief mixing, this aggregate was also dumped into the wheelbarrow for disposal at the job site.

While the mixers were being cleaned, the hand tools and wheelbarrows were rubbed with methylene chloride to remove polymer residue. Intermediate cleaning of mixers and tools was essential to prevent material build-up as the work progressed.

At the completion of the first day's work, an examination of the overlay surface revealed aggregate segregation had occurred. An aggregate sample was obtained from the fine aggregate truck through the 6 x 6 in. (152 x 152 mm) gate for study. Results of the sieve analysis indicated the sample to be deficient in fines. By shoveling the fine aggregate into the measuring cans from within the truck box, the segregation problem was eliminated.

When work began on the second day, the resin content was increased from 12 to 14% for comparison purposes. No apparent difference was noted in the mixing or placing of the polymer concrete containing the larger resin content, but during compaction excessive resin came to the surface. A decision was made to return to the 12% resin content after an area of 12 x 12 ft (3.6 x 3.6 m) had been placed. The 12% formula was used for the remainder of the work.

The time required to complete the polymer concrete overlay during the second day was also one hour. An improvement in the overlay surface was noted due to the elimination of aggregate segregation.

A number of cylinders were made and tested from material mixed each day. The compressive strength of the cylinders was high enough after a 5-hour cure to allow traffic on the overlay at that time. Average compressive strength and resin formulation can be found in Table 11.

A visual inspection of the overlay was made periodically after the installation. Small shrinkage cracks appeared in the overlay during the first week, and they continued to grow into large transverse cracks. At first, reflective cracking was suspected, but cores revealed the cracking was only in the overlay and not in the substrate concrete. The entire deck was chain dragged but no delaminations were found, which indicated good bonding was achieved. Four-inch (102 mm) diameter cores were also removed from the deck to determine bond shear values. Unfortunately, all but one core broke too close to the interface during removal to conduct these tests. All failures were within the substrate concrete. The bond shear strength on the single useable core was 688 psi (4745 kPa) indicating excellent bond.

After nearly five years in service, the overlay still appears well bonded to the deck. There is some ravelling in the lane where aggregate segregation was a problem during construction and at the meet line between pours.

Because of the early favorable results reported for the Santiam River Bridge, a second structure received a polymer concrete overlay in May, 1977. This time the entire deck of the Crooked River Bridge in Central Oregon was overlaid with a 1.5 in. (38.1 mm) lift of polymer concrete. This structure is 180 ft (54.9 m) long and carries 2-lane traffic on a 28 ft (8.5 m) wide deck. It is located on a sag vertical curve and a 9° horizontal curve. The deck required an overlay due to several noticeable surface problems. Some of these problems were: moderate transverse cracking, surface polishing and wear in the wheel tracks, and slight scaling along the lower gutter line.

Deck preparation consisted of the removal of the top 0.25 in. (6.3 mm) of surface mortar by scabbling. Two MacDonald U5 scabblers were rented and used during the week preceding the overlay. Final cleaning was accomplished by sandblasting just prior to overlaying.

Unlike the previous overlay, natural gravel aggregate was used to make polymer concrete. It was obtained prepackaged in 90 lb (40.8 kg) sacks from Ross Island Inc., a producer of premix concrete. It was dry, graded, and ready for use when delivered. The gradation of several sacks was examined and found to

be acceptable. The uniformity of the polymer concrete and the east of hand-ling during mixing attested to the advantage of buying polymer concrete aggregate in this manner.

On the day preceding the overlay, a brief meeting was held with the workers to acquaint them with polymer concrete. A slide presentation of the earlier laydown was shown along with diagrams of the work area, a list of work assign-ments, and a tentative work schedule. After the meeting, the promoters and inhibitor were blended into the barrels of resin by using a bent rod attached to a 1/2 inch electric drill. One barrel, which was designated for tack coat use, received silane in addition to the other additives. This barrel was clearly marked with fluorescent paint to ensure its proper usage.

On the first day of the overlay, supplies and materials were hauled to the job site. Vehicle traffic was restricted to one lane as no detour was available. The lane to be overlaid received a light sandblasting followed by cleaning with high pressure air. The polymer concrete batching area was established approximately 400 ft (121.9 m) from the bridge site.

In order to keep a steady flow of material arriving on the deck during the overlay, four mixers were rented for this project. Three were mortar-type paddle mixers and one was a conventional rotary concrete mixer. Because of mechanical problems however, most of the mixing was done with only two mortar mixers.

As batching of the polymer concrete began, a 15-mil (0.38 mm) tack coat was placed on the deck in an area which would be covered immediately by the over-lay. Hand held radios were used to communicate between the batching area and the bridge deck in order to maintain close synchronization. The resin needed for the tack coat was stored in 5-gal (18.9 l) cans on the bridge sidewalk, adjacent to the work area. As tack coat material was needed, it was measured into a 1-gal (3.8 l) container and initiated. This procedure prevented pre-mature polymerization of the tack coat during most of the overlay.

Because of the distance between the batching area and the deck, a front-end loader was used to transport the polymer concrete. Allowing a two-minute mixing time, the entire mixing and transporting cycle was completed in approximately four minutes.

As the polymer concrete was deposited onto the deck, it was quickly spread by shovel and rake to a depth of about 2 in. (52 mm). A modified 4 in. (102 mm) H beam, riding on a 1.75 in. (44 mm) thick screed rail was used to strike the polymer concrete off at a desired depth. When compacted, this produced a finished 1.5 in. (38.1 mm) thick overlay.

In order to reduce the potential for shrinkage cracking and possible creep due to the steep superelevation of 0.1 ft/ft (0.1 m/m), the initial batches of polymer concrete contained 10% resin content. When the first few batches appeared too dry, the resin content was increased to 12%. After consolidation produced wet spots on the surface, the resin content was reduced to 11% and and used at that level throughout the remaining work. Minor changes were also made in the initiator concentrations as the work progressed to adjust

allowable work time for different ambient temperatures. Table 12 presents resin formulations and mix data for this overlay.

In order to allow for equipment cleanup, several planned delays occurred each day. Approximately every hour, methylene chloride and aggregate were added to the mixers and allowed to agitate for several minutes to remove material build-up from the blades and sidewalls. At the same time, the bucket of the front-end loader, the hand tools, the screed rail, and the compactor were also cleaned with methylene chloride. After each cleanup, an automotive wax was applied to the screed and compactor where contact would be made with polymer concrete. The wax reduced material build-up as the overlay was placed.

During the first day a vibrating sled compactor was used for consolidation An attempt to compact the material in the longitudinal direction failed because the superelevation was too great and the overlay could not support foot traffic. The direction of the sled travel was changed to transverse because of these problems. The sled was allowed to travel downgrade to the gutter by vibration and gravity and then retrieved to the high side of the lane by ropes. This method of compaction produced a poor riding surface because of transverse ridges. The general quality of the polymer concrete appeared good as the material was well consolidated and the surface texture was relatively uniform.

Two hours after the last section was completed traffic was allowed on the overlay. The extremely rough ride experienced by vehicles on the overlay demonstrated the need for a new finishing technique. Unfortunately, the bridge was located in an area where conventional consolidation equipment was not immediately available.

Before the overlay work on the second day, a lawn roller was acquired to consolidate the westbound lane. The roller was approximately 2 ft (0.61 m) in diameter, three feet wide (0.9 m), and weighed 200 pounds (90.7 kg) when filled with water. Initially, the roller was used in the longitudinal direction, but when footprints were found after rolling, the direction was changed to transverse. As before, compaction was accomplished by allowing the roller to move downgrade by gravity to be retrieved by ropes. The roller appeared to produce a smoother surface than the vibrating sled, although some shoving was still noticeable. The area immediately adjacent to the curb had to be consolidated by hand tamping each day.

In spite of the different compaction method, the surface of the westbound lane was somewhat rough. Small transverse ridges were created during rolling. The ridges were not considered to be serious as traffic was expected to remove many of them within a short period of time. When the westbound lane was opened to traffic after a two hour cure, it produced a ride only slightly better than the eastbound lane.

The rate of placing the polymer concrete overlay was approximately 800 sq ft (74.3 m^2) per hour although it took nearly 6 hours to complete the work each day. This was due to mechanical breakdowns, equipment cleaning and rain showers. Provisions were made to maintain a dry deck during rain showers by placing sheets of plastic ahead of the overlay. When the rain ended the

Table 12

CROOKED RIVER BRIDGE
RESIN FORMULATIONS AND COMPRESSIVE STRENGTHS

	(May 24)		Polymer Concrete (May 25)		
Resin[1]	Mix 1 L	Mix 2 L	Mix 3 L	Mix 3 L	Mix 4 L
Resin Content[2]	10	12	11	11	11
MEKP [3]	1.5	1.0	1.0	1.0	1.25
Co Oc [3]	0.25	0.25	0.25	0.25	0.25
DMA [3]	0.20	0.20	0.20	0.20	0.20
HQ[4]	100	100	100	100	100
Aggregate[5]	3/8" minus Natural, gradation #5, Table 3				

	Tack Coat	
Resin[1]	L	L
Thickness (mils)	$15^{\pm}$	15
MEKP [3]	1.25	1.25
Co Oc [3]	0.25	0.25
DMA [3]	0.20	0.20
Silane A-174 [3]	3.2	3.2
HQ[4]	100	100
Cure Time	2 days	3 days
Average Ultimate Compressive Strength, psi	7,600	8,200

[1] See Appendix A for resin blends.
[2] Percent by weight of aggregate.
[3] Percent by weight of resin.
[4] Parts per million by weight of aggregate
[5] See Table 3, page 13 for aggregate gradation.

1000 psi = 6.89 MPa
1" = 25.4 mm

sheets were removed and any wet spots were quickly dried with a propane torch before the overlay work continued.

On the day following the overlay, soundings were made on the entire deck to determine if bonding had been achieved. The results indicated delamination was present in a few isolated areas. Eight 4-in. (102 mm) diameter cores were removed from the overlay 2 weeks after construction. When the cores were tested in bond shear only one had less than 50% of the break in the substrate material, indicting satisfactory bond. The average bond value was above 220 psi (1.5 MPa).

Cylinders that were cast at various times each day were tested at 2 and 3 days. The average ultimate compressive strengths were 7,600 psi (52.4 MPa) at 2 days, and 8,200 psi (56.5 MPa) at 3 days.

The results of deck deflection measurements made at several locations within each span indicated the deck was stiffened by the polymer concrete overlay. Throughout the middle panels, original deflections of 0.044 in. (1.1 mm) were typically reduced to 0.017 in. (0.43 mm). In the outside panels, deflections of 0.017 in. (0.43 mm) were diminished to approximately 0.010 in. (0.25 mm).

Approximately one month after its installation, the polymer concrete overlay was covered with a one-inch leveling course of asphalt concrete because of the surface roughness. Except for the surface problem created by inadequate finishing techniques, the overlay was considered a success.

In September 1977, a Bidwell low slump bridge deck finishing machine was used to consolidate and finish two polymer concrete test panels. After several adjustments in the frequency of vibration and rate of travel of the screed, the observed results were very favorable. The Bidwell machine produced a uniformly finished surface with a satisfactory texture. The resin content of the polymer concrete was reduced to 8% due to the ability of the Bidwell machine to finish relatively dry mixes. The information gained from Oregon's experimental overlay projects was used by the states of Idaho and Oklahoma to successfully place polymer concrete bridge deck overlays.

On August 5 and 6, 1980, the Oregon State Highway Division successfully placed a built-up polymer concrete Type B overlay on South Fork Ash Creek Bridge (No. 491A) in Independence, Oregon. The overlay was composed of four layers of resin and sand-sized aggregate.

The bridge deck was in good condition although there were some tight, transverse shrinkage cracks. There were no delaminations detected when a chain drag test was performed, and the chloride ion content was below 0.0075% by weight of concrete at the 1 in. (25 mm) depth. The bridge roadway was 81 ft (24.7 m) long by 38 ft (11.6 m) wide.

Several days before the overlay began the deck surface was thoroughly cleaned by sandblasting to remove all dirt, oil and surface laitance. On the first day the overlay was placed, selective sandblasting was performed on recontaminated areas.

The resin selected for the overlay was Derakane 411-C-50, a product of Dow Chemical. It is a thermosetting, medium viscosity vinyl ester, generally used in fabricating fiber-reinforced plastic structures and equipment. The aggregate chosen for the project was Wedron El-8 chips, which were washed and dried before being packaged in 100 lb (45.3 kg) sacks.

Before attempting to place the polymer chip seal on the bridge deck, several trial applications were made on concrete slabs at the laboratory. The purpose of this work was to determine the cure time of the polymer concrete overlay with different concentrations of promoter and initiator, and to examine the compatibility of the resin with the aggregate.

During the day preceding the overlay, all of the chemical components, except the initiator, were thoroughly mixed into the barrels of resin. A list of these components and their proportions are found in Table 13.

On August 5, 1980, the overlay project began when traffic was removed from the westbound lane of the bridge. The deck was subdivided into two 7.6 ft (2.3 m) strips and 20 ft (6.1 m) longitudinal sections. The purpose of this sectioning was to delineate the areas that were to be coated with a specific amount of resin. The first layer of the overlay had a 2.0 lbs per sq yd (1.1 kg/m^2) resin loading while the second, third and fourth layers each received a 3.5 lbs per sq yd (1.9 kg/m^2) application. The design rate of aggregate loading was 15 lbs per sq yd (8.1 kg/m^2) per layer. The gradation of the aggregate is found in Table 14.

The resin was applied to the deck within the 7.6 ft (2.3 m) strips from 5 gal (18.9 l) cans. The cans were filled with resin before the overlay began and then placed strategically along the bridge for easy use. Just before the resin was needed it was initiated with methyl ethyl ketone peroxide from pre-measured containers. The resin was poured onto the deck in a serpentine pattern in two sections simultaneously. In this way the resin application time was reduced by one-half. Four men with 2 ft (.61 m) wide brooms spread the resin onto the deck as quickly as it was dispensed in each section.

Immediately after the resin was spread, a 5 cu yd (3.8 m^3) dump truck containing the aggregate backed over the first 7.6 ft (2.3 m) strip discharging its load through a spreader gate. As soon as the aggregate was spread, the adjacent 7.6 ft (2.3 m) strip was covered with resin in the same manner as the first strip. Once again the aggregate was spread at the conclusion of the resin application. At this point both 7.6 ft (2.3 m) strips were rolled with a large pneumatic roller which made three passes on each strip. The overlay was then allowed to cure.

After a two-hour wait, the first layer was hand swept to remove any unbonded aggregate. In areas where there was an excessive amount of aggregate the resin failed to fully cure and some small indentations were created in the overlay. These defects, however, were eliminated by the application of the successive layers.

Before starting the second layer, the deck was remarked into appropriate sections. As before, two men mixed the initiator into the 5-gallon (18.9 l)

Table 13

POLYMER CONCRETE TYPE B RESIN FORMULATIONS

| | Layer | |
| | 1 | 2, 3, & 4 |
Chemical Component	% of monomer by weight	
Surfynol 400	1.0	0.0
Silane A174	1.0	1.0
Cobalt Naphthenate (12% cobalt)	0.15	0.15
Dimethyl Aniline	0.05	0.05
Methyl Ethyl Ketone Peroxide	1.0	1.0

Table 14

NO. 8 CHIP GRADATION [1]

Sieve Size	% Passing
No. 8 (2.3 mm)	96
No. 12 (1.7 mm)	66
No. 16 (1.2 mm)	19
No. 20 (0.84 mm)	6
No. 30 (0.60 mm)	2.5

[1]Wedron E1-8 washed and dried chips

cans of resin as two men began pouring the resin onto the deck at two different sections. The time required to manually stir the initiator into the resin was approximately 30 seconds.

Unlike the first layer, six men broomed the resin into the previously placed aggregate for the second layer. When the brooming was completed, the aggregate was immediately spread and rolled into the first 7.6 ft (2.3 m) section. By rolling immediately, the possibility of disturbing the resin during curing was eliminated. This was a critical factor, especially at higher temperatures.

The second 7.6 ft (2.3 m) lane then received the second resin coating which was followed by the application and compaction of the aggregate. The second layer was then allowed to cure for approximately two hours. This time a uniform cure occurred across both lanes as no soft spots were found. A power broom mounted on a tractor then removed any loose or unbonded aggregate from the second layer.

The third and fourth layers were applied during the remainder of the afternoon. The time required for placement and curing of the various layers appears in Table 15.

One important function not previously mentioned was the clean-up that was required. Immediately after each layer was placed, the brooms and resin distribution cans were cleaned by soaking in methylene chloride for about five minutes. In this way, the equipment lasted throughout the entire project.

At 8:00 a.m. on Wednesday, traffic was diverted from the eastbound lane and placed on the polymer concrete chip seal that was applied the day before. An inspection of the deck indicated only a cleaning by the power broom was needed to prepare the surface for the overlay. Beginning at 9:00 a.m. the first of three 7.6 ft (2.3 m) strips began receiving the first coating of resin. Due to the experience gained the previous day, the time required for application was reduced by nearly a third. Each of the four layers was applied without major problems, although a few uncured areas were found in the first layer as before. The same system of rolling the aggregate immediately after their application in each 7.6 ft (2.3 m) strip was employed to ensure an undisturbed curing cycle. After the completion of the fourth layer, a three-hour cure period was again used to ensure complete resin polymerization before the lanes were opened to traffic.

During the first day, sufficient clearance was available to permit two-way, single lane, traffic on the bridge while the overlay was being applied. Only alternate direction one-way traffic was permitted during the second day.

The experimental Type B polymer concrete overlay was applied by a crew of 12 persons comprised of State Highway maintenance and laboratory personnel. The total cost of the installation was $37.34 per sq yd ($44.66 per m^2). A cost breakdown follows:

Deck Preparation	$ 2.92 / sq yd ($ 3.49/m^2)
Labor	$11.45 / sq yd ($13.69/m^2)
Equipment	$ 2.34 / sq yd ($ 2.80/m^2)
Materials	$20.63 / sq yd ($24.67/m^2)

Table 15

TIME FOR OVERLAY PLACEMENT AND ALLOWED CURE TIME

Layer	Placement Time*	Allowed Cure Time
DAY 1	in minutes	
1	13	2 hrs.
2	34	1 hr., 50 min.
3	27	1 hr., 30 min.
4	22	2 hrs., 45 min.
DAY 2		
1	20	2 hrs., 50 min.
2	22	1 hr.
3	20	1 hr.
4	17	3 hrs., 15 min.

*Placement time – the time from when the resin was first applied to the deck until when the rolling was completed.

One week following the overlay, core samples were removed from the deck to examine the quality of the overlay. The cores revealed a dense, well bonded 0.75 in. (19 mm) thick wearing surface was achieved. Electrical resistivity readings were also made on the overlay to determine the impermeability of the system. All readings were above the 25 megohms which indicated the overlay was impermeable. Another benefit derived from the application of the overlay was the increase in skid number from 47 to 73 at 40 mph.

After being in service for two years the performance of the overlay is excellent. There was only minor aggregate loss in the wheel tracks and two reflective cracks appeared over the interior deck joints which are not a problem.

Other Work

In addition to the experimental laboratory and field work, contract funds allowed Oregon to provide technical assistance to the Idaho Transportation Department in 1978, 1979 and 1980 when they attempted to place a polymer concrete overlay. Oregon also hosted a Polymer Materials Seminar in June 1979. The technical assistance consisted of training Idaho highway maintenance personnel in the use of polymer materials, helping to organize a polymer concrete overlay project and providing technical advice during this installation.

The main task undertaken by the Idaho Transportation Department was to demonstrate the feasibility of using existing construction equipment to mix and place the polymer concrete system developed in Oregon. The Idaho project began in 1978 when, after much discussion, a Daffin concrete mobile mixer was selected to mix the polymer concrete and a Bidwell OF400 deck finishing machine was chosen to do the finish work. A few changes had to be made before the mobile mixer was capable of producing a satisfactory polymer concrete. The biggest change was in the method used to add the resin into the mixing chamber. Basically, the concrete mobile mixer was used to proportion the aggregate and to mix the polymer concrete. The resin was added to the mixing chamber by means of an external pumping system. All of the pumping equipment and the resin were located on an adjacent flatbed truck that was positioned near the concrete mobile mixer. The pumping equipment consisted of two gear pumps which were powered by two A.C. motors. A bypass valve was installed on each pump and permitted the flow of resin to be temporarily stopped without turning off the motors. The proportioning of aggregate and resin into the continuous mixer was of major importance. After determining the flow rate of the resin, the aggregate gates were adjusted to discharge the correct quantity of aggregate.

The first attempt to use the pumping equipment occurred in October, 1978. The small trial batch of polymer concrete was made satisfactorily, but when the work at the bridge site began, the motors and pumps failed to operate successfully. The heat generated in the resin bypass system caused the material to set up in the piping. The overlay project was cancelled and postponed until the following year due to the onset of bad weather.

In 1979, Idaho did not begin the polymer concrete overlay project until mid-October because of difficulty in obtaining the necessary construction equipment. A change was made to improve the pumping equipment during the one-year delay. Direct current electric motors with variable speed converters were substituted for the A.C. motors. This greatly improved the control of resin flow during the blending and mixing operations.

Three days of intense preparation preceded the beginning of the overlay. During this time the deck was scabbled and sandblasted and the concrete mobile mixer and the resin pumping system were calibrated. The placement of the first 14 ft (4.2 m) lane was erratic. The quality of the polymer concrete was not entirely satisfactory, chiefly because of the condition of the mobile mixer. There was aggregate segregation in the mixer because of worn mixer blades and a distorted mixing chamber. Some minor delays also occurred when one of the pumps froze up.

When work began on the second 14 ft (4.2 m) lane, the hydraulic system in the mobile mixer failed and the project was halted. Once again bad weather prevented the continuation of the overlay until the following year.

Finally, in 1980 Idaho completed their polymer concrete project when the second 14 ft (4.2 m) lane received a 1 1/2-in. (38 mm) overlay. During this work a Gomaco low slump concrete finishing machine was substituted for the Bidwell deck finisher. Each machine performed very well in providing a good riding and well compacted overlay. Further work was still required to perfect the blending of the resin and the mixing of the polymer concrete in a continuous mixing operation like the mobile mixer. Because the quantity of resin did not always coincide with the quantity of aggregate being deposited in the mixing chamber, the polymer concrete was nonuniform at times. When the polymer concrete was resin-rich, sand was applied to the finished surface; when the mix was resin-poor, it was removed from the deck.

After the overlay was in service for six months, an evaluation indicated the overlay was performing as designed.

A three day Polymer Materials Seminar was held in Salem, Oregon during the week of June 25, 1979. The seminar consisted of lectures and demonstrations of partial polymer impregnation, polymer concrete overlays and polymer concrete patching techniques. The 57 people who registered at the seminar represented five chemical companies, six vendors of polymer materials, five state governments, one prestressed concrete manufacturer, two construction equipment manufacturers, the Bureau of Reclamation and the Federal Highway Administration. One major benefit which resulted from this seminar was an increase in the role of industry in the development of products and equipment for highway related utilization of polymer materials.

Conclusion

Polymer concrete has the potential of becoming a viable material for protecting bridge decks from deicing salts and for improving the ride characteristics of deteriorated and worn concrete. The ability of polymer concrete to cure very rapidly increases its value for repairing concrete in places where lane closures have to be kept to a minimum.

The Type B built-up polymer concrete overlay was easy to place with existing highway equipment and its performance has been very good. A possible limitation of the system may be its restriction to flat grades and slopes because of resin runoff during installation.

Some additional work is still needed with the Type A polymer concrete overlay method before it will receive wide acceptance. This work is in the areas of improving the method of batching large quantities for overlay projects and in the improvement of the properties of the resin binders.

In order to reduce the manpower requirements during batching, greater automation is needed. The problem of resin storage during mixing and a method to accurately control the flow of resin in a concrete mobile mixer, should be actively researched. An improved method of applying the resin primer to the deck prior to the placement of a polymer concrete overlay should also receive special attention. The use of both the Bidwell and Gomaco low slump concrete deck finishing machines has been satisfactory in producing a good riding and well compacted overlay.

The shrinkage of polymer concrete overlays that occurs during curing has caused some minor cracking problems. Unless this shrinkage can be greatly reduced or eliminated, scoring at fairly short intervals may be required to control cracking.

The thermal coefficient of polymer concretes used in the overlays placed to date has also caused some minor cracking to occur. The long term consequence of this cracking is unknown but it may become a serious problem under freeze-thaw conditions. If the thermal coefficient of polymer concrete cannot be altered to approximate that of the substrate concrete, the modulus of elasticity should be reduced to accomodate the difference in strain.

Finally, because of its high cost, Type A polymer concrete overlays may have to be limited to thin sections [1/2 in. maximum (12.7 mm)] where chemical resistance, improved skid resistance or rutting repairs are needed.

Resin Blends

Resin

A   16.6% Styrene, 41.7% GR511, 41.7% GR941 = LB183-13

B   23.0% Styrene, 38.5% GR511, 38.5% GR941

C   95.0% MMA, 5.0% TMPTMA

D   45.4% LB183-13, 54.6% GR511

E   100% Radgrout

F   42.8% LB183-13, 57.2% GR511

G   27.7% LB183-13, 72.3% GR511

H   50.0% LB183-13, 50.0% GR511

I   9.1% Styrene, 18.2% GR511, 72.7% GR941

J   100% GR511

K   77.7% LB183-13, 23.3% GR511

L   100% GR11044

M   50.0% Styrene, 50.0% LB183-13

N   45.4% LB183-13, 54.6% GR941

APPENDIX B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	ADDITIVE PROPORTIONS(1) (by wt of total resin)					PURPOSE OF TEST
			Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %	
1	10.0	A	1.0	0.5	–	–	–	Workability & Compression
2	12.0	A	1.5	0.75	–	–	–	Workability & Compression
3	14.0	A	2.0	1.0	–	–	–	Workability & Compression
4	14.0	A	2.5	1.25	–	–	–	Workability & Compression
5	14.0	B	2.5	1.25	–	–	–	Workability & Compression
6	10.0	B	2.5	1.25	–	–	2.0	Workability & Compression
7	14.0	B	2.5	12.5	–	–	2.0	Workability & Compression
8	10.0	B	2.5	1.25	–	–	2.0	Workability & Compression
9	8.0	B	2.5	1.25	–	–	2.0	Workability & Compression
10	8.0	B	2.5	1.25	–	–	2.0	Workability & Compression
11	8.0	B	2.5	1.25	–	–	2.0	Workability & Compression
12	10.0	B	2.0	1.45	0.1	–	2.0	Workability & Compression
13	10.0	B	2.0	1.5	0.5	–	2.0	Workability & Compression
14	12.0	B	1.5	0.75	–	–	2.0	Bond
15	10.0	B	1.75	1.35	–	–	2.0	Bond
16	10.0	B	1.5	0.75	–	–	2.0	Bond
17	10.0	B	1.75	0.86	0.3	–	2.0	Bond
18	9.0	B	2.0	1.0	–	–	2.5	Bond
19	8.0	B	2.0	1.0	–	–	2.5	Bond
20	8.5	B	1.5	0.75	–	–	2.0	Bond
21	8.5	B	1.5	0.75	–	–	2.0	Bond
22	8.5	B	1.5	0.75	–	–	2.0	Thermal Coefficient
23	8.5	B	1.5	0.75	–	–	2.0	Shrinkage
24	10.0	B	1.5	0.75	–	–	2.0	Shrinkage
25	8.5	B	1.5	0.75	–	–	2.0	Bond
26	8.5	B	1.5	0.75	–	–	2.0	Workability & Compression
27	8.5	B	1.5	0.75	–	–	2.0	Thermal Coefficient

(1) See Appendix A for resin blends and abbreviations.

APPENDIX B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (& by wt of aggregate)	RESIN(1)	Initiator MEKP %	Promoters Co Oc %	Promoters DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %	PURPOSE OF TEST
27.5	8.5	B	0.75	0.38	–	–	2.0	Workability & Compression
28	8.5	B	1.5	0.75	–	–	2.0	Bond
29	8.5	B	1.5	0.75	–	–	2.0	Bond
30	8.5	B	1.5	0.75	–	–	2.0	Bond
31	8.5	B	1.5	0.75	–	–	2.0	Bond
32	8.5	B	1.5	0.75	–	–	2.0	Bond
33	8.5	B	1.5	0.75	–	–	2.0	Bond
34	8.5	B	0.75	0.38	–	–	2.0	Freeze Thaw Resistance
35	8.5	B	0.5	0.25	–	–	2.0	Workability & Compression
36	8.5	B	0.5	0.25	–	–	2.0	Compression
37	8.5	B	0.5	0.25	–	–	2.0	Bond
38	8.5	B	0.4	0.2	–	–	2.0	Compression
39	8.5	B	0.3	0.15	–	–	2.0	Not Run
40	8.5	B	0.4	0.20	–	–	–	Compression
41	8.5	B	0.4	0.20	–	–	2.0	Bond Bond
42	8.5	B	0.4	0.20	–	–	2.0	Bond
43	8.5	B	0.4	0.20	–	–	2.0	Permeability
44	8.5	B	0.5	0.25	–	–	2.0	Modulus of Elasticity
45	8.5	B	0.4	0.20	–	–	2.0	Bond
46	8.5	B	0.4	0.20	–	–	2.0	Bond
47	8.5	B	0.5	0.25	–	–	2.0	Compression
48	8.5	B	0.5	0.25	–	–	2.0	Modulus of Elasticity
49	8.5	B	0.5	0.25	–	–	2.0	Modulus of Elasticity
50	8.5	B	0.5	0.25	–	–	2.0	Workability & Compression
51	8.5	B	0.5	0.25	–	–	2.0	Workability & Compression
52	8.5	B	0.5	0.25	–	–	2.0	Bond
53	8.5	B	0.5	0.25	–	–	2.0	Workability & Compression

(1) See Appendix A for resin blends and abbreviations.

A P P E N D I X   B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

| TEST NO. | POLYMER CONTENT (% by wt of aggregate) | RESIN(1) | ADDITIVE PROPORTIONS(1) (by wt of total resin) | | | | Silane Coupling Agent A-174 % | PURPOSE OF TEST |
			Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm		
54	8.5	B	1.5	0.75	–	–	2.0	Workability & Compression
55	8.5	B	0.5	0.25	–	–	2.0	Workability & Compression
56	8.5	B	1.5	0.75	–	–	2.0	Shrinkage
57	88.5	B	0.5	0.25	–	–	2.0	Shrinkage
58	–	B	–	–	–	–	–	Not run
59	10.0	B	1.5	0.75	–	–	2.0	Compression
60	10.0	B	1.5	0.75	–	–	2.0	Compression
61	8.5	B	1.5	0.75	–	–	2.0	Absorption & Conductivity
62	10.0	B	1.5	0.75	–	–	2.0	Absorption & Conductivity
63	8.5	B	0.5	0.25	–	–	2.0	Absorption & Conductivity
64	10.0	B	0.5	0.25	–	–	2.0	Permeability
65	8.5	B	0.5	0.25	–	–	2.0	Permeability
66	11.5	B	1.5	0.75	–	–	2.0	Absorption & Conductivity
67	10.0	B	0.5	0.25	–	–	2.0	Workability & Compression
68	10.0	B	0.5	0.25	–	–	2.0	Workability & Compression
69	10.0	B	0.5	0.25	–	–	2.0	Workability & Compression
70	10.0	B	0.5	0.25	–	–	2.0	Workability & Compression
71	8.5	B	0.5	0.25	–	–	2.0	Workability & Compression
72*	10.0	C	1.0*	–	1.0	–	–	Workability & Compression
73*	14.0	C	1.0*	–	0.5	–	–	Workability & Compression
74*	10.0	C	1.5*	–	1.5	–	–	Workability & Compression
75*	10.0	C	2.0*	–	2.0	–	–	Workability & Compression
76*	12.0	C	1.25*	–	1.25	–	–	Workability & Compression
77*	14.0	C	1.5*	–	1.5	–	–	Workability & Compression
78*	12.0	C	1.25*	–	1.25	–	–	Bond

(1) See Appendix A for resin blends and abbreviations.
* Benzoyl peroxide was used instead of methyl ethyl ketone peroxide.

A P P E N D I X   B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174	PURPOSE OF TEST
79	100.0	E	1.0	**	–	–	–	Gel time & exotherm temp.
80	100.0	E	2.0	**	–	–	–	Gel time & exotherm temp.
81	10.0	E	2.2	**	–	–	–	Bond
82	12.0	E	2.2	**	–	–	–	Bond
83	14.0	E	2.2	**	–	–	–	Bond
84	10.0	E	2.2	**	–	–	–	Bond
85	10.0	E	2.2	**	–	–	–	Bond
86	10.0	E	2.2	**	–	–	–	Compression
87	10.0	E	2.2	**	–	400	–	Compression
88	10.0	A	1.0	0.5	–	400	2.0	Workability & Compression
89	10.0	A	2.0	0.5	–	400	2.0	Workability & Compression
90	10.0	A	1.0	0.5	–	300	2.0	Workability & Compression
91	10.0	A	2.0	0.5	–	300	2.0	Workability & Compression
92	10.0	A	2.3	0.5	–	450	2.0	Workability & Compression
93	10.0	A	2.4	0.5	–	450	2.0	Compression
94	10.0	A	2.4	0.5	–	450	2.0	Compression
96	10.0	A	2.4	0.5	–	450	2.0	Bond
97	10.0	A	2.0	0.5	–	450	2.0	Permeability
98	10.0	A	2.0	0.5	–	400	2.0	Overlay
99	10.0	A	2.0	0.5	–	425	2.0	Modulus of Elasticity
100	10.0	A	2.2	0.5	–	450	2.0	Compression
101	10.0	A	2.2	0.5	–	450	2.0	Weatherometer
102	10.0	A	2.0	0.5	–	250	2.0	Compression
103	10.0	A	2.0	0.5	–	250	2.0	Compression

(1) See Appendix A for resin blends and abbreviations.
** The Radgrout resin contained an unknown amount of promoter.

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CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %	PURPOSE OF TEST
104	10.0	A	2.0	0.5	–	200	2.0	Compression
105	10.0	A	2.0	0.5	–	200	2.0	Compaction Study
106	10.0	F	2.0	0.5	–	500	2.0	Compression
107	10.0	G	2.0	0.5	–	450	2.0	Compression
108	10.0	A	2.0	0.5	–	450	2.0	Compression
109	10.0	A	2.0	0.5	–	250	2.0	Compression
110	12.0	A	2.0	0.5	–	250	2.0	Compression
111	11.0	A	2.0	0.5	–	250	2.0	Compression
112	10.0	K	2.0	0.5	–	400	2.0	Overlay
113	8.5	A	2.0	0.5	–	400	2.0	Overlay
114	8.5	A	2.0	0.5	–	400	2.0	Overlay
115	10.0	A	2.0	0.5	–	450	2.0	Compression
116	10.0	A	2.0	0.5	–	200	2.0	Compression
117	10.0	A	2.0	0.5	–	200	2.0	Compression
118	10.0	A	1.5	0.5	–	200	2.0	Compression
119	10.0	A	1.0	0.5	–	200	2.0	Compression
120	10.0	A	2.0	0.5	–	200	2.0	Compression
121	10.0	A	1.0	0.5	–	200	2.0	Compression
122	8.5	A	2.0	0.5	–	200	2.0	Compression
123	10.0	A	2.0	0.5	–	200	2.0	Compression
124	10.0	A	2.0	0.5	–	200	2.0	Compression
125	10.0	A	2.0	0.5	–	200	2.0	Compression
126	10.0	A	2.0	0.5	–	200	2.0	Compression
127	8.5	A	2.0	0.5	–	200	2.0	Compression
128	10.0	A	2.0	0.5	–	200	2.0	Compression
129	10.0	A	1.0	0.5	–	200	2.0	Compression
130	10.0	A	2.0	0.5	–	100	2.0	Compression
131	10.0	A	1.0	0.5	–	100	2.0	Compression

(1) See Appendix A for resin blends and abbreviations.

APPENDIX B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	ADDITIVE PROPORTIONS(1) (by wt of total resin)						PURPOSE OF TEST
			Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %		
132	10.0		2.0	0.5	–	200	2.0		Compression
133	10.0		1.5	0.5	–	200	2.0		Compression
134	10.0		1.0	0.5	–	200	2.0		Compression
135	17.0		2.0	0.5	–	200	2.0		Compression
136	17.0		2.0	0.5	–	200	2.0		Compression
137	10.0		2.0	0.5	–	200	2.0		Density (slab)
138	10.0		2.0	0.5	–	400	2.0		Compression
139	8.5		2.0	0.5	–	200	2.0		Compression
140	17.0		2.0	0.5	–	200	2.0		Density (slab)
141	10.0		2.0	0.5	–	200	2.0		Density (slab)
142	10.0		2.0	0.5	–	–	2.0		Compression
143	8.5		2.0	0.5	–	200	2.0		Freeze-Thaw
144	10.0		2.0	0.5	–	200	2.0		Freeze-Thaw
145	8.5		2.0	0.5	–	400	2.0		Modulus of Elasticity
146	10.0		2.0	0.5	–	400	2.0		Modulus of Elasticity
147	10.0		1.5	0.5	–	400	2.0		Modulus of Elasticity
148	10.0		1.5	0.5	–	400	2.0		Compression
149	10.0		1.5	0.5	–	200	2.0		Compression
150	10.0		2.0	0.5	–	400	2.0		Penetration Test (Cure)
151	10.0		2.0	0.5	–	200	2.0		Compression
152	10.0		1.0	0.5	–	200	2.0		Density (slab)
153	10.0		1.5	0.5	–	200	2.0		Compression
154	10.0		2.0	0.5	–	200	2.0		Compression
155	10.0		2.0	0.5	–	200	2.0		Compression
156	10.0		2.0	0.5	–	200	2.0		Compression
157	10.0		2.0	0.5	–	200	2.0		Compression
158	10.0		2.4	0.5	–	450	–		Compression
159	10.0		2.4	0.5	–	450	–		Compression

(1) See Appendix A for resin blends and abbreviations.

A P P E N D I X   B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %	PURPOSE OF TEST
160	10.0	A	2.4	0.5	–	450	1.0	Compression
161	10.0	A	2.4	0.5	–	450	1.0	Compression
162	8.5	A	2.4	0.5	–	450	0.0	Compression
163	8.5	A	2.4	0.5	–	450	1.0	Compression
164	10.0	A	2.0	0.5	–	200	2.0	Compression & Splitting Tensile
165	8.5	A	2.0	0.5	–	200	2.0	Compression
166	10.0	A	2.0	0.5	–	200	1.0	Compression
167	8.5	A	2.0	0.5	–	200	0.0	Compression
168	10.0	A	2.0	0.5	–	200	2.0	Compression
169	10.0	A	1.5	0.5	–	400	0.0	Permeability
170	8.5	A	1.5	0.5	–	300	0.0	Bond
171	10.0	A	2.0	0.5	–	200	2.0	Compression
172	10.0	I	2.0	0.5	–	200	–	Splitting Tensile
173	10.0	I	2.0	0.5	–	200	–	Splitting Tensile
174	10.0	A	2.0	0.5	–	200	2.0	Splitting Tensile
175	10.0	A	1.5	0.5	–	200	–	Compression
176	10.0	A	1.5	0.5	–	200	ℯ	Compression
177	10.0	A	2.0	0.5	–	200	Vary	Compression
178	10.0	A	2.0	0.5	–	200	Vary	Compression
179	10.0	A	2.0	0.5	–	200	Vary	Compression
180	10.0	D	2.0	0.5	–	200	–	Compression
181	10.0	D	2.0	0.5	–	200	2.0	Splitting Tensile
182	8.5	A	2.0	0.5	–	200	2.0	Splitting Tensile
183	10.0	A	2.0	0.5	–	200	2.0	Flexure & Compression
184	8.5	A	2.0	0.5	–	200	2.0	Flexure & Compression
185	10.0	A	2.0	0.5	–	200	2.0	Flexure & Compression
186	10.0	A	2.0	0.5	–	200	–	Cure Study
187	10.0	A	2.0	0.5	–	100	–	Cure Study

(1) See Appendix A for resin blends and abbreviations.

APPENDIX B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	ADDITIVE PROPORTIONS(1) (by wt of total resin)					PURPOSE OF TEST
			Initiator MEKP %	Promoters Co Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174	
188	10.0	A	1.5	0.5	–	100	–	Cure Study
189	10.0	A	1.5	0.5	–	100	–	Compression
190	10.0	A	2.0	0.5	–	200	1.0	Overlay & Compression
191	10.0	H	2.0	0.5	–	200	1.0	Compression
192	10.0	A	2.0	0.5	–	200	1.0	Compression
193	12.0	A	1.5	0.5	–	–	2.0	Compression
194	10.0	H	1.5	0.25	–	200	1.0	Modulus of Elasticity & Flex.
195	10.0	J	1.5	0.25	–	200	1.0	Modulus of Elasticity
196	10.0	A	2.0	0.5	–	100	1.0	Gel Study
197	10.0	A	2.0	0.5	–	100	1.0	Gel Study
198	10.0	A	2.0	0.5	–	300	1.0	Gel Study
199	10.0	A	2.0	0.5	–	300	1.0	Gel Study
200	10.0	A	2.0	0.5	–	200	1.0	Gel Study
201	12.0	A	2.0	0.5	–	200	1.0	Overlay & Compression
202	12.0	A	2.0	0.38	–	200	1.0	Compression
203	10.0	L	1.5	0.5	–	100	–	Compression
204	10.0	L	2.0	0.5	–	200	1.0	Bond
205	10.0	L	2.0	0.5	–	200	2.0	Modulus of Elasticity & Flex.
206	12.0	L	1.5	0.25	–	200	1.0	Flexure
207	10.0	L	2.0	0.5	–	200	2.0	Splitting Tensile
208	12.0	A	1.0	0.25	–	100	–	Density
209	10.0	A	1.0	0.25	.25	–	–	Compression
210	12.0	A	2.0	0.5	–	100	–	Polymer Patch
211	12.0	A	1.0	0.25	–	–	–	Shrinkage
212	12.0	A	1.5	0.25	–	100	–	Bond
213	12.0	A	1.5	0.25	–	100	–	Bond
214	12.0	A	1.5	0.25	–	–	–	Field Patch

(1) See Appendix A for resin blends and abbreviations.

APPENDIX B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	Initiator MEKP %	Promoters Co.Oc %	DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %	PURPOSE OF TEST
215	12.0	A	1.5	0.25	–	200	–	Bond
216	12.0	A	1.5	0.25	–	200	–	Bond
217	12.0	A	1.5	0.25	–	200	–	Bond
218	12.0	A	1.5	0.25	–	200	–	Bond
219	12.0	A	1.5	0.25	–	200	–	Bond
220	12.0	A	1.5	0.25	–	200	–	Bond
221	12.0	A	1.5	0.25	–	200	–	Bond
222	12.0	A	1.5	0.25	–	200	–	Bond
223	12.0	A	1.5	0.25	–	200	–	Bond
224	12.0	A	1.5	0.25	–	200	–	Bond
225	12.0	A	1.5	0.25	–	200	–	Bond
226	12.0	A	1.5	0.25	–	200	–	Bond
227	12.0	A	1.5	0.25	–	75	–	Overlay
228	12.0	A	1.5	0.25	–	200	–	Shrinkage
229	10.0	A	1.5	0.25	–	400	–	Shrinkage
230	12.0	L	1.5	0.25	–	200	–	Shrinkage
231	12.5	L	1.5	0.25	–	200	–	Shrinkage
232	12.0	A	2.0	0.5	–	200	–	Workability & Compression
233	9.3	A	2.0	0.5	–	200	–	Workability & Compression
234	9.8	A	2.0	0.5	–	200	–	Workability & Compression
235	9.4	A	2.0	0.5	–	200	–	Workability & Compression
236	9.7	A	2.0	0.5	–	200	–	Workability & Compression
237	14.0	L	2.0	0.5	–	200	–	Workability & Compression
238	12.0	A	2.0	0.5	–	200	–	Workability & Compression
239	12.0	L	2.0	0.5	–	200	–	Workability & Compression
240	12.0	A	2.0	0.5	–	200	–	Density
241	12.0	A	2.0	0.5	–	200	–	Compression
242	12.0	A	2.0	0.5	–	200	–	Compression

(1) See Appendix A for resin blends and abbreviations.

APPENDIX B

CHEMICAL COMPONENTS AND PROPORTIONS OF TEST MIXES

TEST NO.	POLYMER CONTENT (% by wt of aggregate)	RESIN(1)	Initiator MEKP %	Promoters Co Oc %	Promoters DMA %	Inhibitor HQ ppm	Silane Coupling Agent A-174 %	PURPOSE OF TEST
243	12.0	A	2.0	0.5	—	200	—	Compression
244	12.0	L	2.0	0.5	—	200	—	Shrinkage
245	12.0	L	2.0	0.5	—	200	—	Shrinkage
246	12.0	L	2.0	0 5	—	200	—	Shrinkage
247	12.0	L	2.0	0.5	—	200	—	Shrinkage
248	12.0	L	2.0	0.5	—	200	—	Density
249	12.0	L	2.0	0 5	—	200	—	Modulus of Elasticity & Comp.
250	12.0	L	2.0	0.5	—	200	—	Compression
251	10.0	L	2.0	0.5	—	200	—	Shrinkage
252	10.0	L	2.0	0.5	—	200	—	Shrinkage
253	14.0	L	2.0	0.5	—	200	—	Shrinkage
254	14.0	L	2.0	0.5	—	200	—	Shrinkage
255	12.0	L	2.0	0.5	—	200	—	Thermal Coefficient
256	12.0	L	1.5	0.5	—	200	—	Overlay
257	12.0	L	1.5	0.125	—	200	—	Overlay
258	14.0	L	1.5	0.125	—	400	—	Overlay
259	20.0	L	1.5	0.125	—	200	—	Field Patch
260	12.0	L	2.0	0.125	—	200	—	Field Patch
261	12.0	L	2.0	0.5	—	200	—	Bond
262	12.5	L	1.5	0.25	.2	200	—	Density
263	10.0	L	2.0	0.25	.2	100	—	Workability & Compression
264	12.0	L	2.0	0.25	.2	100	—	Workability & Compression
265	12.0	L	2.0	0.25	.2	100	—	Workability & Shrinkage
266	12.0	L	2.0	0.5	.2	100	—	Field Patch
267	12.0	L	2.0	0.5	.2	100	—	Field Patch
268	14.0	L	1.5	0.125	.2	200	—	Compression
269	11.0	L	1.0	0.25	.20	100	—	Overlay & Compression
270	12.0	L	1.0	0.25	.20	100	—	Overlay
271	10.0	L	1.0	0.25	.20	100	—	Overlay

ADDITIVE PROPORTIONS (1) (by wt of total resin)

(1) See Appendix A for resin blends and abbreviations.

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