POLYMER CONCRETE OVERLAY TEST PROGRAM

USERS' MANUAL

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.

The authors wish to acknowledge the work and assistance of the staff of the Materials and Research Section.

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The purpose of this manual is to provide the reader with sufficient information to successfully place a polyester styrene polymer concrete overlay on a bridge deck. Although the binder is a resin, no detailed knowledge of polymer chemistry is needed to proportion, mix, place, and finish the product.

Attention is directed to the safety instructions which are included for use when handling the chemicals. It is advisable to review them along with the manufacturers' recommendations for storage and handling before chemicals are ordered.

Supplementing the information directed toward polymer concrete overlays for bridge decks, Appendix C provides recommended procedures for using polymer concrete for patching portland cement concrete.

INTRODUCTION

Since the late 1960's, the major concern of bridge maintenance engineers has been bridge deck repairs. Highway departments across the country found bridge maintenance costs soaring as bridge decks deteriorated to an unsound condition. The use of deicing chemicals was identified as the chief cause of the premature deterioration. The corroding effects of these chemicals on unprotected decks caused the reinforcing steel to rust and the concrete to spall. As large potholes developed in the deck surfaces due to spalling, the structural adequacy of the decks diminished to a point where the decks were unsafe. Driving over the rough decks became an additional hazard.

Initial attempts to repair the damaged decks with conventional materials proved unsatisfactory. One major problem was the long curing time required to gain sufficient material strength. The prolonged closure of bridges, or lanes of bridges, while repairs were made was found to be intolerable, especially in metropolitan areas.

As one avenue approaching this bridge deck repair problem, the Federal Highway Administration commissioned the Oregon State Highway Division to investigate the use of a quick setting, high-early strength material called polymer concrete. After four years of development and testing, a polymer concrete has been formulated for use in bridge deck overlay work. The basic components of the system are a polyester-styrene resin and a well graded, high quality aggregate. The material cost for this system is approximately $290 per cubic yard.

To date, two small polymer concrete overlays have been placed on bridge decks in Oregon. The continued monitoring of these overlays has shown generally favorable results.

SELECTION PROCESS

The criteria for selection of a bridge deck for rejuvenation by the application of a polymer concrete overlay is very important. Decks with moderate surface cracking or spalling or decks requiring additional stiffening because of inadequate thickness may be greatly improved by the application of a polymer concrete overlay. Figures 1 and 2 illustrate moderate bridge deck problems. However, decks with extensive map cracking, working cracks, or decks with severe delaminations may be beyond the help of a polymer concrete treatment. A detailed inspection of the deck will be required before an economic study can be made to determine an appropriate course of action. An approximate in-place cost of $30 per square yard can be anticipated for a 1-1/2 inch thick polymer concrete overlay including deck preparation.

Because of its quick curing, high early strength characteristics, polymer concrete overlays may be better suited for use in urban areas where traffic control and highway closures are extremely costly.

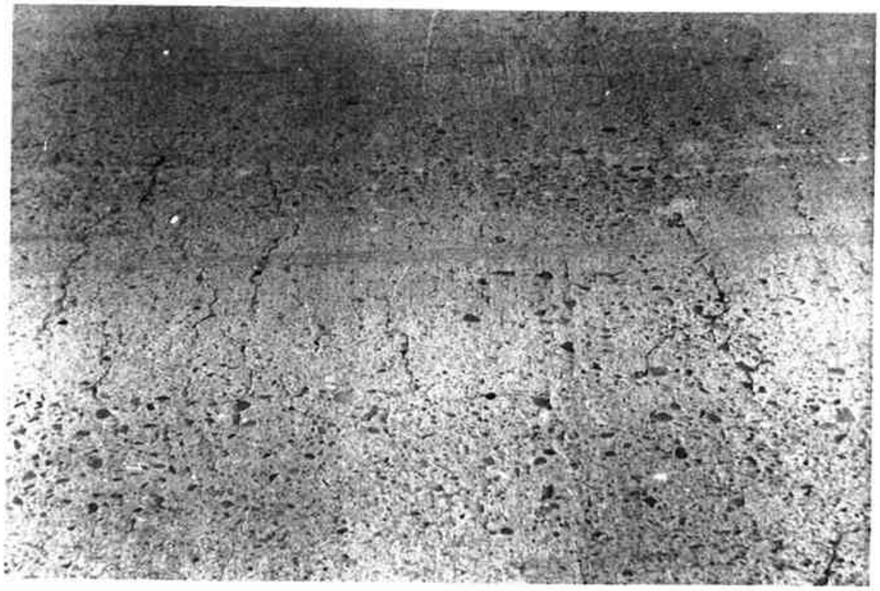


Figure 1. Typical transverse deck cracking.

Figure 2. Typical bridge deck spalling.

DEFINITIONS

The following are definitions of terms used in the implementation manual.

Polymer Concrete: (P.C.)	A composite material consisting of a polyester styrene resin as a binder and a well graded, high quality aggregate as a filler.
Resin (Monomer):	A medium viscosity liquid material which hardens to a solid plastic.
Polymer:	A hard plastic material.
Polymerization:	A chemical reaction by which the molecules of a monomer are cross-linked to form a polymer.
Initiator:	A substance added to the resin in small quantities to cause the resin to harden.
Promoter:	A substance added to a resin which, in combination with an initiator, causes polymerization at ambient temperatures.
Cure Time:	Time required for the liquid resin to harden and reach a strength capable of performing its intended function.
Inhibitor:	A substance added to resin to slow down or prevent curing.

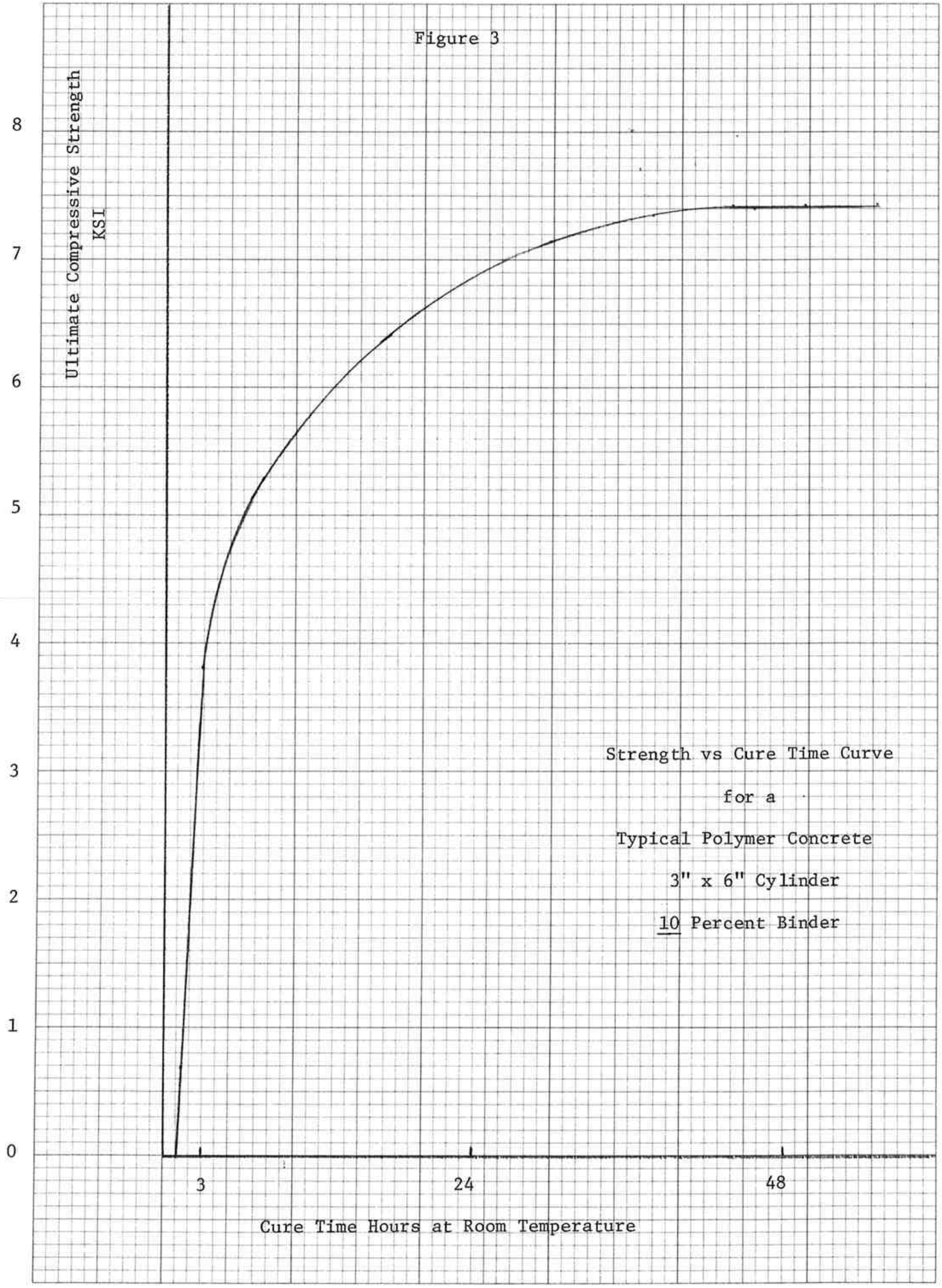
Work Time:	Allowable length of time the resin may be worked without destroying the cross-linking internal bonds. This work time is measured from when the initiator is added to the promoted resin.

MATERIALS

Although several monomer systems have been used in the production of polymer concrete, polyester styrene was chosen for development and use on this project because of its moderate cost, ease in obtaining a variety of formulations, and the excellent polymer concrete properties it produces. By purchasing individual components of resin, initiator, promoter, inhibitor, and aggregate, a polymer concrete can be designed to satisfy individual project parameters while being priced competitively with the other structural overlay systems currently being used. Polymer Concrete, as noted in the definitions, consists of a resin binder and an aggregate filler. Initially, the resin is a liquid but becomes a solid through a process called polymerization. The type of polymerization is classified as a free radical mechanism. Although there are several methods available to induce polymerization, the initiator-promoter system is most commonly used in the production of polymer concrete because it permits curing at ambient temperatures. The rate of polymerization, or rate of cure, is dependent on many factors such as temperature, humidity, and ultra-violet rays of the sun in addition to the amounts of chemical additives of initiator, promoter, and inhibitor that are used in the formulation. As with most chemical reactions, the higher the temperature, the faster the reaction.

The properties of polymer concrete which make it attractive as a structural overlay material are the excellent high early compressive strength and the superior bonding strength. Figure 3 shows ultimate compressive strength versus cure time for a typical polymer concrete formulation.

Figure 3



Strength vs Cure Time Curve
for a
Typical Polymer Concrete
3" x 6" Cylinder
10 Percent Binder

The monomer (resin) that was used in two bridge deck overlay projects was purchased from the Hatco Polyester Division of W. R. Grace Company under the designation GR 11044. It is marketed as an unpromoted semi-flexible polyester casting resin containing between 36 and 40 percent styrene. This material is light yellow in color and has a viscosity of 150 to 200 centipoise at 77 F. It has a consistency of a light syrup. The resin properties are found in Appendix B of this report. Other manufacturers produce similar resins.

The initiator recommended for use with GR 11044 resin is Hi-Point 180 (methyl ethyl ketone peroxide), manufactured by Witco Chemical Company. This material decomposes to form free radicals which chemically induce the cross-linking of the monomer molecules to produce polymers.

To accelerate this chemical reaction and thereby reduce the curing time, two promoters are incorporated into the resin formulation. These accelerators are a 12 percent cobalt octoate solution and dimethyl aniline. Both promoters can be added to the resin in advance of construction without altering the shelf life.

Due to the fact that free radical polymerization of polyester styrene resin occurs naturally, a chemical inhibitor is added to the resin at the time it is produced. This inhibitor is a free radical scavenger which prolongs the shelf life. Since the potency of the inhibitor is time dependent and can be expended, its effectiveness should be checked periodically, especially if the resin is to be stored for a time exceeding the manufacturer's recommendations.

During construction, an inhibitor is needed to delay the polymerization if a reasonable work time is to be available. This is especially true after the initiator is added to a promoted resin. A 20 percent solution of tert-butyl hydroquinone in ethyl alcohol has been used both as the inhibitor during construction and to prolong the shelf life during storage. Recommended proportions of the chemical components are listed in the Resin Formulation section.

In order to improve the bonding characteristic of the resin tack coat, an organic-silane ester has been included in the tack coat formulas only. This material acts as a coupling agent between the resin and the silica in the aggregate. The silane bonding agent recommended for use is A-174 marketed by Union Carbide.

Any chlorinated hydrocarbon can be used as a cleaning solution for the polyester styrene system. The two recommended for use are either methylene chloride or trichloroethane. Each has been used to satisfactorily clean equipment and tools.

A well graded, high quality aggregate is necessary to produce a durable polymer concrete. The aggregate should have a moisture content of less than 1/2 percent to ensure good bonding between the resin and the aggregate. Both natural gravels and crushed aggregate have been used in laboratory and field work with good results. A dry, well graded aggregate can be purchased from most companies which produce bagged concrete mixes. This aggregate is normally uncrushed sand and gravel. Another source of dry, graded aggregate is from asphalt concrete plants. It is essential however, to prevent the aggregate from being contaminated with asphalt. This can be done by cleaning the interior of the drier with several batches of clean aggregate prior to drying the polymer concrete aggregate. The aggregate will have to be cooled to ambient temperature before use.

Care must be exercised to prevent aggregate segregation if the grading is attempted at the plant. The blending of the coarse and fine aggregate by weight or volume at the job site can eliminate much of the segregation problem.

Dry storage must be provided for the aggregate to ensure a negligible moisture content when the aggregate is needed for polymer concrete batching. The temperature of the aggregate at the time of use should not be higher than 90 F. Aggregate that was stored in the beds of 5 cubic yard dump trucks inside a building required 7 days to cool from 230 to 85 F.

The gradation of the polymer concrete aggregate has been examined and tested to produce an economical mix. A deficiency of the very fine material has allowed the resin to drain from the mix, resulting in concrete having poor abrasion resistance. An excessive amount of the smaller material has required the use of additional resin to fully coat or wet all the surface areas, thereby increasing the cost of the mix and increasing shrinkage.

The gradation found to be most acceptable closely follows the 3/8 inch minus Fuller's maximum density curve. The design gradation tolerance limits are as follows:

Sieve Size	Percent Passing
1/2	100
3/8	100-86
1/4	85-71
#10	47-40
#40	23-18
#200	8-6

Fine material passing the #200 sieve can be supplemented by adding portland cement, cottrell flour, or pozzolan, if necessary.

DECK PREPARATION

As with any structural overlay, surface preparation is of great importance. To ensure good bonding, it is essential the polymer concrete be placed only on dry, sound, and clean concrete. To attain a suitable surface, the top 1/4 inch of surface mortar should be removed by scarification. This will remove any oil, asphalt, or other contaminants which could prevent the penetration of the resin tack coat into the concrete substrate.

On large overlay projects, scarification equipment manufactured by CMI, Galion, or Tennant could be used to produce a desired surface. On small projects, decks can be prepared satisfactorily by using a MacDonald scabbler. Figure 4 shows the scabbler in use.

After scarification is completed, an inspection of the deck is required to ensure all loose and unsound concrete has been removed in accordance with good construction practice.

In addition to scarification, the deck may require sandblasting if the overlay is delayed and the surface is contaminated by traffic or construction equipment. Figure 5 shows sandblasting in progress. The entire deck area should also be air blasted to remove dust and debris just prior to polymer concrete placement.

RESIN FORMULATION

The importance of proportioning the chemical components precisely cannot be overstated. For this reason and because of the potential hazards involved in handling some of the chemical components in concentrated form, the formulation of the monomers with inhibitor, promoter, and initiator should be performed by, or under the supervision of, persons with a knowledge of general chemistry. Adequate cleaning materials such as soap, water, solvents, and towels should be provided at the blending site to allow instant clean-up should an accident occur. The site of the blending activities must have adequate ventilation to prevent monomer and solvent vapor build-up. It may be necessary to provide respirators with organic solvent canisters.

On the day preceding the overlay, much of the resin formulation can be performed. The temperature and weather conditions during the overlay will influence the proportion of initiator, promoter, and inhibitor to be used. By obtaining the weather forecast beforehand, the approximate maximum and minimum temperature can be predicted.

Figure 4. Deck preparation by scabbling.

Figure 5. Final deck cleaning by sandblasting.

Figure 6. Mixing components into barrels of resin.

TABLE 1

RESIN FORMULATIONS FOR SEVERAL AMBIENT TEMPERATURE RANGES

	Temperature Range	Approximate Work Time Minutes	Initiator	Promoters		Inhibitor	Silane
			Hi-Point 180 * Percent	12% Cobalt Octoate * Percent	Dimethyl Aniline * Percent	Tert-butyl Hydroquinone PPM *	A-174 * Percent
Polymer Concrete	60-70	30	1.50	0.25	0.20	100	-
	70-80	30	1.25	0.25	0.20	100	-
	80-90	30	1.00	0.25	0.20	200	-
Tack Coat	60-70	15	1.25	0.25	0.20	100	2.0
	70-80	15	1.00	0.25	0.20	100	2.0
	80-90	15	0.80	0.25	0.20	200	2.0

* Component concentrations are percent of the resin by weight.

The procedure of adding the chemical components to the resin, with the exception of the initiator, in advance of the overlay has worked well. The promoters and inhibitors can be added directly into the barrels of resin through the bung. A thorough mixing is required by using either a long shaft hook or paddle powered by a spark-proof drill, or by stirring by hand with long rods. Figure 6 illustrates the method of mixing resin with rods. Since the work time begins when the initiator is added to a promoted resin, this must be delayed until just prior to the mixing of the polymer concrete. Table 1 presents formulations for various temperature ranges which will provide a minimum work time of 30 minutes.

In addition to the polymer concrete resin, a special tack formulation should be prepared. The silane coupling agent can be added ahead of time to the resin to be used for the tack coat. A 15 mil coverage can be assumed for the purpose of calculating the required quantity of tack coat resin. Painting T.C. on the tack coat containers will reduce the chance of misuse. The same procedure of adding initiator to the tack coat resin just prior to application must be followed.

MIXING POLYMER CONCRETE

Polymer concrete has been mixed in both conventional rotating drum and paddle type mortar mixers. The mortar mixer has been the most satisfactory because it mixes thoroughly without segregation, it mixes faster, and is easier to clean. Although there was some material build-up on the blades, the walls of the mixer were generally wiped clean. An average mixing time for polymer concrete containing a 10 percent to 12 percent resin content in the mortar mixer was three minutes. The disadvantages of using the mortar mixer are the difficulty in locating large mixers and the reduced mixing capacity due to the stiffness of the mix. A 60 percent reduction in rated capacity is a good rule of thumb.

The use of a rotating drum mixer is best used with a low resin content (8 percent) polymer concrete. The suggested mixing time for this system is seven minutes minimum. In order to achieve satisfactory mixing, the drum should be in a horizontal position during mixing to provide greater tumbling action. The advantage of using the rotating drum mixers is they are more readily available in larger sizes. A disadvantage is the possiblity of segregation of the aggregate and build-up of fines on the drum walls.

The method of consolidation will influence the amount of resin that will be required to produce a desirable surface and acceptable density. If lightweight finishing equipment is used, the resin content required will be between 10 and 12 percent. If heavy finishing equipment such as a Bidwell dense concrete finisher is used, a reduction of resin content to about 8 percent would be expected.

If the mixers are to charged by hand, the storage of the aggregate at the mixing site should be such as to minimize handling. Predetermined amounts of aggregate should be added to the mixer along with an appropriate amount of resin. This can be accomplished by weight or by volume. The use of precalibrated containers, such as five gallon cans, greatly reduces the batching time when measuring resin quantities.

The following mixing sequence is recommended:

1. Withdraw promoted and inhibited resin from drum in pre-calibrated containers. (Figure 7)
2. Add precise amount of initiator and stir thoroughly. (Figure 8)
3. Charge mixers with aggregate. (Figure 9)
4. Add resin to mixers.
5. Allow mixing to continue until all particles appear fully coated (three minutes minimum for mortar mixer and seven minutes minimum for rotating drum).
6. Discharge polymer concrete into an appropriate vehicle for transfer to bridge deck. (Figure 10) Depending upon the size of the project and the distance between mixing site and placement area, different transportation vehicles are available. These include wheelbarrows, gasoline powered concrete buggies, or front-end loaders.

It is essential that precautions are taken to ensure that uninitiated resin is not mistakenly added to the aggregate as polymerization will not occur. A method of tagging the resin once the initiator has been added or placing the initiated resin in one specified location can help reduce the chance of serious error. Only designated personnel should be allowed to handle the initiated resin and then only after careful instruction.

When polymer concrete mixing commences, both initially and after each cleaning cycle, the resin content must be increased slightly. This additional resin is needed to replace the amount lost on the mixer walls. The mixer may be "buttered" directly by the addition of a quart of resin before mixing begins.

Figure 7. Withdrawing resin into pre-calibrated containers.

Figure 8. Adding initiator to resin.

Figure 9. Adding aggregate into mixers.

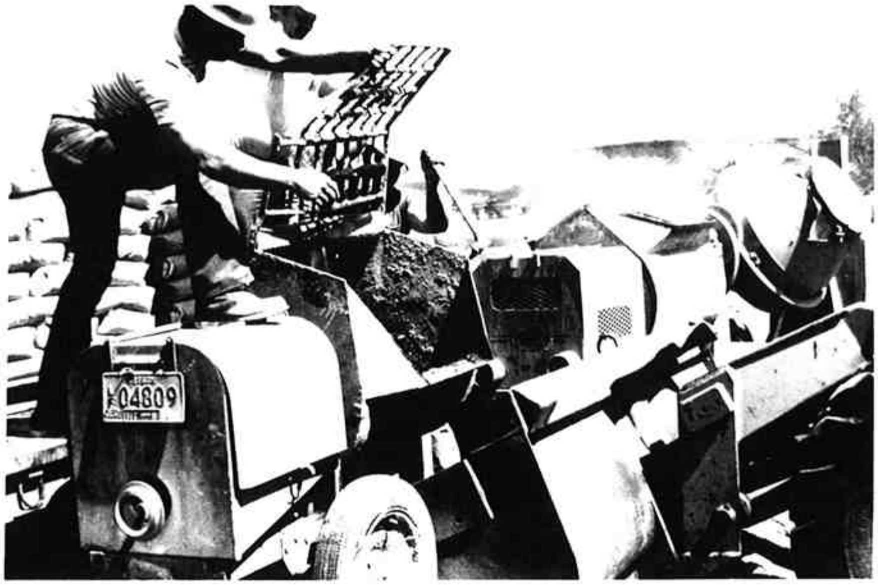


Figure 10. Discharging polymer concrete from mixer.

Direct communication between the mixing site and placement area is necessary to ensure a continuous placing and finishing operation, and to prohibit a prolonged waiting time between mixing and placing. Portable hand-held, two-way radios can be used to great advantage. This communication system can also aid in the application of the tack coat at optimum times.

The cleaning of the mixers and transportation vehicles is an important activity during the construction sequence. The frequency of cleaning will depend on the rate of material build-up, but should not exceed 45 minute intervals. This may require a complete work stoppage.

The method used to clean the mixers during the construction phase is simple and fast. Approximately two gallons of a suitable solvent such as methylene chloride or trichloroethane and twenty pounds of large aggregate can be added to the mixer for a five minute agitation cycle. The solvent and the aggregate can then be discharged into a five gallon can for reuse during the next cleaning break. A cover will reduce or prevent solvent evaporation from the can. Any remaining build-up on the mixer can be removed by chipping with a pointed hammer.

The cleaning of the transportation vehicle can be accomplished by applying solvent to the hopper by paint brush or rags. The solvent will dissolve residue and soften remaining polymer concrete. A sharp blow with a pointed hammer or similar object should loosen any remaining material.

The equipment and tools used in placing and finishing the polymer concrete on the bridge deck should also be cleaned during this pause. Care must be exercised not to contaminate the deck with cleaning solvent. Personnel in direct contact with the resin or cleaning solvent should be provided with eye protection, organic filter masks and impermeable rubber gloves.

PLACING AND FINISHING POLYMER CONCRETE

The placing and finishing of a polymer concrete overlay requires careful coordination if the operation is to proceed smoothly. The activities during this phase of construction are listed in the following steps.

1. Set screed rails.
2. Apply resin tack coat.
3. Transport and deposit polymer concrete.
4. Screed and consolidate polymer concrete.

Before construction can begin, screed rails must be set on the bridge deck. This can occur immediately after the deck has been cleaned by high pressure air. The type of screed selected for use will determine the type of rail needed. If a steel H beam or similar section is chosen for the screed, timber 2 x 4s or light steel channels can serve as rails. If a heavy duty deck finishing machine is used, appropriate adjustable pipe rail will be required. The method of using 2 x 4s for screed rails directly on a scarified deck has produced only a fair riding surface even on a short span. A new grade line should be established to eliminate any existing irregularities on the deck. The screed elevation should be set 1/4 inch high to allow consolidation for a 1-1/2 inch thick overlay.

The masking of deck drains, catch basins, and deck joints can also be done at this time.

TACK COAT APPLICATION

The integrity of a structural overlay depends upon the bonding of the new material to the existing substrate. Because of this, the application of a resin tack coat is a key factor in the successful placement of a polymer concrete overlay. Both the introduction of the initiator and the timing of the application critically affect the performance of the tack coat. A major problem can develop if the tack coat "sets-up" prematurely. When this happens, poor or not bonding results. Care must be taken therefore to reduce the time interval between the addition of the initiator into the tack coat resin and the placement of the polymer concrete overlay. The proportioning of the initiator is also important since an excessive quanitity will greatly shorten the work time.

The person applying the tack coat should have a supply of resin on the deck containing all components except the initiator. By knowing the amount of polymer concrete that will be batched and delivered to the deck during each cycle, the required quantity of resin tack coat per batch can be calculated. Only this relatively small quantity of resin tack coat per batch should be initiated to gain maximum work time. Figure 11 shows initiator being added to tack coat resin at job site. Since only a small quantitiy is needed during each application, precise initiator measuring is essential. A plastic graduated cylinder can be used with good results.

If a delay should occur between the time the initiator is added to the tack coat resin and the polymer concrete is to be placed, the tack coat should

Figure 11. Adding initiator to tack coat resin.

Figure 12. Tack coat application.

be wasted. If a delay occurs after the tack coat is placed on the deck, a new coat should be applied just before the polymer concrete is placed. The allowable working time for the tack coat can be tested before construction begins by applying it to the deck and observing its reaction time. Adjustments in the initiator concentration can be made to attain the needed work time. The tack coat will normally polymerize faster than the resin in polymer concrete with the same chemical components for two reasons. First, the lack of aggregate to absorb heat, second, the exposure of a thin resin film to direct sunlight.

The method of application of the tack coat on small projects has been the use of medium nap paint rollers. Figure 12 illustrates a tack coat application. One difficulty associated with the application is the constant need to clean the rollers before polymerization occurs. This can be accomplished by having a container of solvent near the work area for roller soaking purposes. Several roller assemblies are needed to provide a continuous application. Some of the rollers can be soaking while the others are in use.

A spray delivery system which would enable initiator and resin mixing at the nozzle would simplify tack coat application. This would be especially helpful on large projects. The ability to apply the tack coat quickly and the elimination of preblending of the initiator would solve much of the tack coat problem.

For design and estimating purposes, a 15 mil resin tack coat is recommended.

As the polymer concrete is delivered to the work area, it should be deposited quickly and as evenly as possible over the deck that is to be covered (Figure 13). Additional spreading can then be done by raking and shoveling. An attempt to spread the polymer concrete to an elevation slightly above the bottom of the screed will reduce material removal during the screeding. A long-handled asphalt rake can effectively move large quantities of material just ahead of the screed (Figure 14). If a steel H beam is used as the screed, eye bolts can be utilized to attach pulling ropes. The screed should span at least one lane width and be of such weight as to allow maneuverability.

As the screed is moved along the rails, sufficient polymer concrete must be maintained at the front edge to ensure a smooth finished surface. If a defect in the surface is found as the screeding proceeds, the screed must be immediately returned to the defective location for corrective action. It is far easier to repair a substandard area before compaction takes place.

As soon as the screeding has progressed sufficiently to allow freedom of movement, the consolidation of the polymer concrete overlay should begin. The compaction of the overlay can be accomplished by use of a light 600 pound roller or by a vibrating plate asphalt compactor such as a Wacker Packer (Figure 15). The quality of the surface will depend upon the ability of the operator. No sudden turns should be allowed because shoving and tearing of the overlay will result. Two passes by either compactor will normally be all that is required to produce adequate compaction. As soon as the compaction is completed, the equipment must be removed from the overlay surface to avoid disturbing the polymer concrete as polymerization occurs. A moveable transverse deck platform may be used to eliminate the need to walk on the freshly placed polymer concrete.

Figure 13. Polymer concrete deposited on deck.

Figure 14. Spreading polymer concrete before screed.

If possible, the use of a heavy duty deck finishing machine such as the Bidwell shown in Figure 16 is strongly recommended. Although only limited testing has been done, the surface quality and apparent compaction of polymer concrete finished with a Bidwell appeared excellent. The two major obstacles seen in using this type of machine are the necessity to clean the screeds periodically and the requirement to keep a sufficient quantity of polymer concrete in front of the machine for a continuous finishing operation.

The curing time required for the polymer concrete to develop sufficient strength to allow the resumption of traffic will depend on several factors as mentioned earlier. As a rule of thumb, traffic can be allowed over the polymer concrete overlay approximately 1-1/2 hours after a peak exotherm is generated during polymerization. This peak exotherm is the maximum heat produced by the chemical reaction within the polymer concrete. It can be measured by a thermocouple or thermistor probe. The peak exotherm, for the formulations recommended in this text, will generally occur within one hour after blending. This means the bridge deck can be opened for traffic approximately 2-1/2 hours after the final polymer concrete batch has been placed and finished.

If time permits, there are several advantages to providing a polymer concrete mix having a longer work time and in providing a longer cure time. By delaying the polymerization, there is a better opportunity to place and compact the overlay before the chemical reaction is initiated. This should result in a smoother riding surface. Also, the increased work time makes cleaning the mixers and finishing equipment much easier. The material does continue to gain strength for several days, thus, longer cure times offer a stronger concrete.

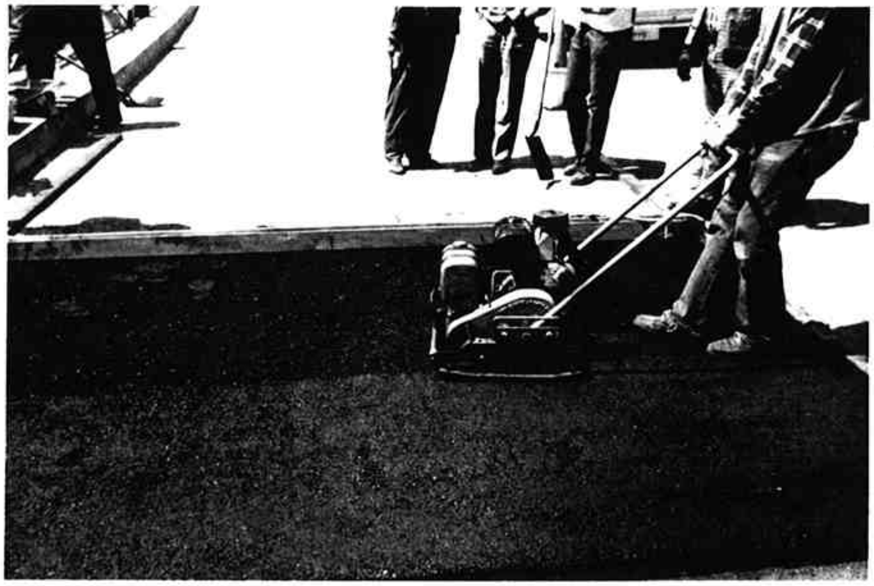


Figure 15. Consolidating polymer concrete.

Figure 16. Bidwell finishing machine.

SAFETY

Many of the chemicals used in the production of polymer concrete are toxic, flammable, and volatile. However, with a minimum amount of care, these chemicals will not present a problem. The manufacturers of the chemicals provide recommendations for safe storage and handling. They should be studied before any chemical is ordered and handled.

Provisions must be made to store initiator and promoter separately and to prevent them from coming into contact with one another in a pure form. When mixing the components, the initiator should be added to the resin only after all other ingredients are in and well mixed. Continued mixing of the resin while the initiator is being added will prevent a high concentration build-up.

STORAGE AND HANDLING

RESIN

The polyester styrene resin can be stored in the drums in which it comes. However, the drums should be stored out of direct sunlight and in an area with adequate ventilation to prevent a build-up of vapor. Cool storage increases the shelf life of the resin. The polyester styrene is flammable and must be kept away from heat, sparks or other fire hazards. In case of fire, use only dry chemical extinguishers.

For personnel safety, avoid breathing resin vapors and resin contact with eyes, skin, or clothing because of potential irritation.

PROMOTERS

Two promoters are used to accelerate the chemical reaction in the polyester styrene resin. The cobalt octoate solution needs no special care except storing in a closed container. The dimethyl analine, on the other hand, is extremely hazardous. Intoxication can occur from inhalation, ingestion, or cutaneous absorption. This material must be stored in an airtight container out of direct sunlight. Avoid contact with either vapor or liquid as both are rapidly absorbed through the skin.

INITIATOR

The methyl ethyl ketone peroxide initiator must be stored in a closed container in a cool area, out of direct sunlight and away from any fire hazard. It must not be contaminated with any foreign material and never allowed to come in direct contact with a metal surface. The initiator must never be mixed directly with the promoters as this will result in an explosive decomposition and fire. Also, contact with eyes and skin should be avoided.

INHIBITOR

The tert-butyl hydroquinone-alcohol solution inhibitor should be stored in a closed container to prevent the evaporation of the alcohol. This solution should be kept out of direct sunlight also.

SOLVENT

Methylene chloride vapor is somewhat hazardous and can cause death if too much is inhaled. Adequate ventilation is therefore required to eliminate vapor build-up. Prolonged or repeated breathing of the vapor and contact with the skin should be avoided.

All personnel handling chemicals in the production of polymer concrete should be thoroughly trained and familiar with the manufacturer's safety recommendations. Personnel blending the chemicals should be provided with eye protection, impervious gloves and aprons, and respirators equipped with chemical filters. Personnel mixing and placing the polymer concrete must be aware of the fire hazard. No smoking signs should also be posted to alert visitors of potential danger.

APPENDIX A

Illustrative Problem

Sample Calculations

Assume	1.	Deck	30' x 120'	(10m x 40m)
	2.	Resin Content	10% by weight of the aggregate	
	3.	Aggregate Content	130 lbs/cf	(2082.4 kg/m^3)
	4.	1-1/2 Inch Polymer Concrete Overlay		(38.1mm)

Required Quantities

Polymer Concrete	30' x 120' x 0.125' = 450 cubic feet (12.74m^3)
Aggregate	450 cf x 130 lbs/cf = 58,500 lbs (26,535 kg)
Resin	58,500 x 0.10 = 5,850 (2,653 kg)

Design Mix per cubic foot

Assume ambient temperature 75 F (23.9C)
See Table 1 for appropriate proportions

Aggregate 130 lbs (58.96 kg)
Resin (GR 11044) 130 lbs x 10% = 13.0 lbs (5.90 kg)
MEKP (Hi Point 180) 13.0 x 0.0125 = 0.1625 lbs (73.71 gms)
12% Cobalt Octoate 13.0 x 0.0025 = 0.0325 lbs (14.75 gms)
Dimethyl Aniline 13.0 x 0.0020 = 0.0260 lbs (11.80 gms)
Tert-butyl Hydroquinone $13.0 \times \frac{100}{10^6} = 0.0013$ lbs (0.59 gms)

APPENDIX B

Specificatications and Potential Suppliers for Required Chemicals

Polyester Styrene Resin (GR 11044)

This resin is an unpromoted semi-flexible casting resin containing between 36 and 40 percent styrene. Below are some pertinent specifications.

Liquid Resin	Viscosity 77 F., cps. - 20 RPM	140-200
	Pounds per gallon	9.2 to 9.3
	Specific gravity @ 77 F.	1.13 to 1.17
	Stability in dark @ 77 F.	6 months minimum
1/8" Casting	Tensile Strength psi minimum	2500 psi
	Elongation percent	40%
	Shore "D" Hardness	70

Curing Properties @ 77 F.
0.2% CoO 12%
0.1% DMA + 1% MEk Peroxide

Gel Time (minutes)	5 to 7
Peak Exotherm (F)	260 to 280
Total Time to Peak (minutes)	6 to 8

Potential Supplier:

Polyester Division-Marco
W. R. Grace & Co.
1605 West Elizabeth Ave.
Linden, New Jersey 07036

Cobalt Octoate or Napthenate

Purity	12% Cobalt Napthenate in Mineral Spirits
Specific gravity	1.020 to 1.060

Potential Suppliers:

Interstab Coating Product
500 Jersey Avenue
P.O. Box 631
New Brunswick, N.J. 08903

Cordano Chemical Co., Inc.
3322 N.W. 35th Avenue
Portland, Oregon 97210

Tenneco Chemical
P.O. Box 365
Picataway, N.J 08854

N,N, Dimethyl Aniline (DMA) - Mono Free

Formula	$C_6H_4N(CH_3)_2$
Purity	99%
Formula Weight	121.18
Melting Point	2 to 4 C
Boiling Point	192 to 193 C
Density	0.9557 g/cc

Potential Suppliers:

Mallinckroot Chemicals
P.O. Box 5439
St. Louis, MO 63160

Matheson, Coleman, Bell
Headquarters:
Norwood, Ohio 45212
Chemical Centers throughout
the United States

Eastman Kodak
Eastman Organic Chemicals
Rochester, N.Y. 14650
Chemical Centers throughout
the United States

Methyl Ethyl Ketone Peroxide (Hi Point 180)

Purity	60% MEKP in Dimethyl Phthalate
Density	1.13 g/cc

Potential Suppliers:

Witco Chemical
U.S. Peroxygen Division
850 Morton Avenue
Richmond, California 94804

T-Butyl Hydroquinone

Formula	$2\text{-}(CH_3)_3CC_6H_3 - 1_14\text{-}(OH)_2$
Purity	97%
Molecular Weight	166.22
Melting Point	125 to 128 C
Density	0.80 g/cc

Potential Suppliers:

Lab Products
1940 N. Jantzen Ave.
Portland, Oregon 97217

Aldrich Chemical
Milwaukee, Wisconsin 53233
Chemical Centers throughout
the United States

APPENDIX C

Polymer concrete can be used effectively as a patching material for portland cement concrete bridge decks and highway pavements. The flexibility in altering the curing characteristics to suit various temperatures has proven to be very useful. Patching has been accomplished at temperatures as low as 40 F and as high as 95 F with excellent results. In each case, traffic was allowed over the polymer concrete patches in less than two hours after the work was completed. These patches required only small quantities of material, which reduced the time needed to mix and place to less than 15 minutes.

Much of the procedure in polymer concrete patching is similar to that used in applying a polymer concrete overlay. The same chemicals are used but normally in different concentrations because of the different requirements.

Patching with polymer concrete involves four basic steps.

1. Determine size of patch and amount of material required.
2. Detour traffic.
3. Remove damaged concrete and prepare hole.
4. Mix and place polymer concrete.

The size and type of repair will determine the required work time that must be provided to produce a successful patch. For small defects requiring only one to one and one-half cubic feet of material, the work time can be reduced to 15 minutes or less. This amount can normally be mixed in one batch in a wheelbarrow or concrete mixer. For deep patches requiring larger quantities of polymer concrete, more work time is needed to allow a monolithic patch. If a relatively thin but large patch is needed which requires several batches. a short work time can still be utilized providing work is completed on each section of the patch before its allowable work time expires.

During preparation and placement of a patch, it will be necessary to detour traffic from the work area and traffic lane. This will require warning flashers, cones, and signs well in advance of the patching site. The equipment and supplies including the mixer, compressor, aggregate and resin can be located within the closed work area.

It is important to prepare the area to be patched so that the polymer concrete is placed against dry, sound and clean concrete. This may require the use of jackhammers and sandblasting equipment to remove loose or marginal material (Figure 17). All concrete contaminated by asphalt or oil should be completely removed to assure good bond with the polymer concrete. If possible, concrete should be removed from around rebar in several locations to create a keying action.

The resin needed for the repair may be formulated at the job site (Figure 18). If the promoters and inhibitors are added in advance to the resin brought to the job, only the initiator will need to be added at the site. Table A provides recommended component concentrations for an approximate 15 minute allowable work time at various temperatures. If longer work times are needed, less initiator can be used. Refer to Table 1 for longer work times.

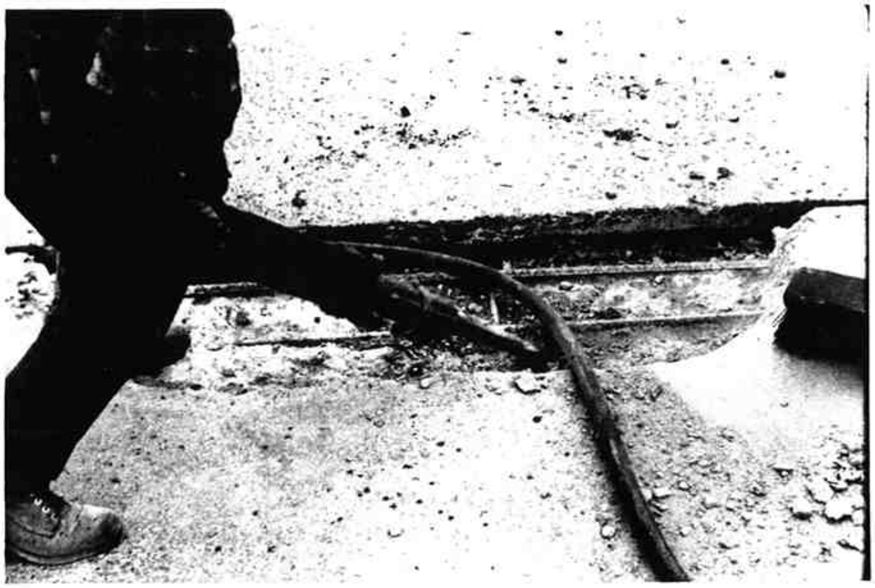


Figure 17. Removal of unsound concrete.

Figure 18. Resin formulation at job site.

A convenient method of dispersing the resin from a 55 gallon drum is through the use of a molasses type gate. The resin can be easily discharged off the end of a truck into a 5 gallon can for measuring or weighing. A list of recommended tools and equipment is included in this text.

When short working times are acceptable, the same component concentrations can be used for both the polymer concrete and tack coat. Depending on the aggregate gradation, a 10 percent to 12 percent resin content by weight of the aggregate will generally produce a workable mix.

Once the deteriorated area has been prepared, mixing of the polymer concrete can begin. The initiator should not be added to the promoted resin until the moment it is required in the mixer. Because of the short allowable work time, several activities should occur simultaneously. As the polymer concrete is mixing, the tack coat may be applied to the bottom and sides of the repair area. This may be done effectively by paint brush (Figure 19).

After a 3 to 5 minute mixing cycle, the polymer concrete may be deposited in the hole. To consolidate the mix, tamping with a metal plate or timber post will produce a dense concrete (Figure 20). The finished surface may then be screeded with a 2 x 4 to achieve a smooth patch.

The polymer concrete patch shown in Figure 21 was located at a joint on a bridge deck. A 3/4 inch piece of plywood was used as a form in the joint. The plywood was coated with an automotive wax which prevented bonding and made removal easy. Traffic was allowed on this patch one hour after placement.

The following tools, equipment and supplies are recommended for polymer concrete patching projects.

Equipment

- Air Compressor
- Jackhammer
- Concrete Mixer (paddle type preferred over rotating drum)
- Paint Brushes or Roofing Brushes (2)
- Broom (1)
- Shovels (2)
- Wheelbarrow
- Traffic Control Equipment (as required)
- 100 pound Weighing Scale
- Measuring Tape
- 50 pound Tamper (6 inch square steel plate with handle)
- Screeding Device (wood or metal)

Supplies

- Polymer Resin (including initiator, promoter, inhibitor, and silane)
- Cleaning Solvent (Methylene chloride)
- Aggregate (coarse, fine)
- Portland Cement (if aggregate needs more fines)
- Cleaning Rags
- Gloves
- Five-gallon Cans (5) (mixing and measuring)

TABLE A

RESIN COMPOSITION FOR POLYMER CONCRETE PATCHING

	Temperature Range	Approximate Work Time Minutes	Initiator	Promoters		Inhibitor	Silane
			Hi-Point 180 * Percent	12% Cobalt Octoate * Percent	Dimethyl Aniline * Percent	Tert-butyl Hydroquinone PPM *	A-174 * Percent
Polymer Concrete & Tack Coat	40-60	15	2.0	.5	.2	100	2.0
	60-70	15	1.75	.5	.2	100	2.0
	70-80	15	1.50	.5	.2	100	2.0
	80-90	15	1.00	.5	.2	150	2.0

* Component concentrations are percent of the resin by weight.

Figure 19. Tack coat application.

Figure 20. Placing and compacting polymer concrete patch.

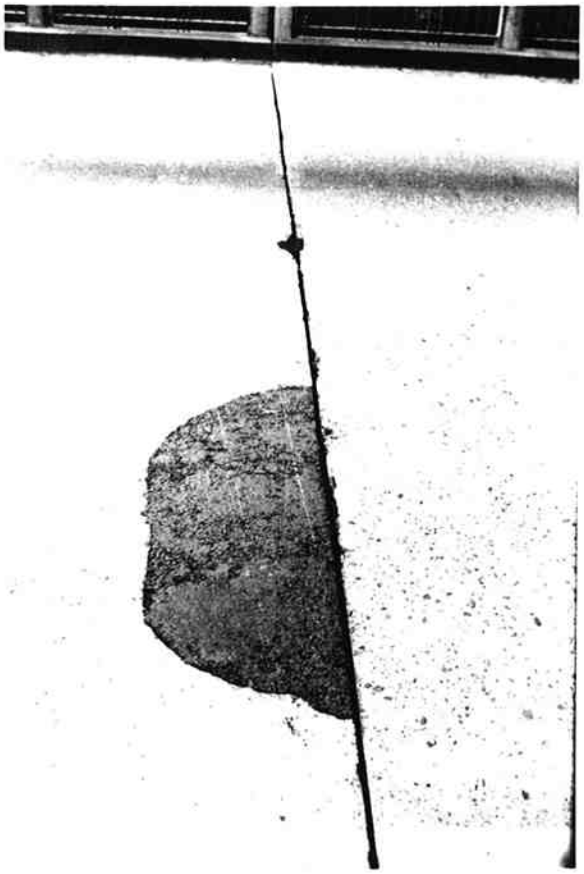


Figure 21. Polymer concrete patch.