

POLYMER CONCRETE OVERLAY TEST PROGRAM

USERS' MANUAL

by

J. C. Jenkins, G. W. Beecroft, and

W. J. Quinn

OREGON STATE HIGHWAY DIVISION
Salem, Oregon 97310

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D.C. 20590

December, 1977

P R E F A C E

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.

T A B L E O F C O N T E N T S

| | |
|--|----|
| Introduction | 1 |
| Selection Process | 3 |
| Definitions | 5 |
| Materials | 7 |
| Deck Preparation | 12 |
| Resin Formulation | 13 |
| Mixing Polymer Concrete | 17 |
| Placing and Finishing Polymer Concrete | 23 |
| Tack Coat Application | 24 |
| Safety | 31 |
| Storage and Handling - Resin | 31 |
| Promoters | 32 |
| Initiator | 32 |
| Inhibitor | 32 |
| Solvent | 32 |
| Appendix A | 34 |
| Appendix B | 35 |
| Appendix C | 37 |

L I S T O F T A B L E S

| | | |
|---------|---|----|
| Table 1 | Resin Formulations for Several Ambient Temperature Ranges | 16 |
| Table A | Resin Composition for Polymer Concrete Patching | 42 |

L I S T O F I L L U S T R A T I O N S

| | | |
|-----------|---|----|
| Figure 1 | Typical Transverse Deck Cracking. | 4 |
| Figure 2 | Typical Bridge Deck Spalling. | 4 |
| Figure 3 | Strength vs Cure Time Curve. | 8 |
| Figure 4 | Deck Preparation by Scabbling. | 14 |
| Figure 5 | Final Deck Cleaning by Sandblasting. | 14 |
| Figure 6 | Mixing Components into Barrels of Resin. | 15 |
| Figure 7 | Withdrawing Resin into Pre-calibrated Containers. | 20 |
| Figure 8 | Adding Initiator to Resin. | 20 |
| Figure 9 | Adding Aggregate into Mixers. | 21 |
| Figure 10 | Discharging Polymer Concrete From Mixer. | 21 |
| Figure 11 | Adding Initiator to Tack Coat Resin. | 25 |
| Figure 12 | Tack Coat Application. | 25 |
| Figure 13 | Polymer Concrete Deposited on Deck. | 28 |
| Figure 14 | Spreading Polymer Concrete Before Screed. | 28 |
| Figure 15 | Consolidating Polymer Concrete. | 30 |
| Figure 16 | Bidwell Finishing Machine. | 30 |
| Figure 17 | Removal of Unsound Concrete. | 39 |

| | | |
|-----------|--|----|
| Figure 18 | Resin Formulation at Job Site. | 39 |
| Figure 19 | Tack Coat Application. | 43 |
| Figure 20 | Placing and Compacting Polymer Concrete Patch. | 44 |
| Figure 21 | Polymer Concrete Patch. | 44 |

F O R W A R D

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.

I N T R O D U C T I O N

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.

S E L E C T I O N P R O C E S S

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.

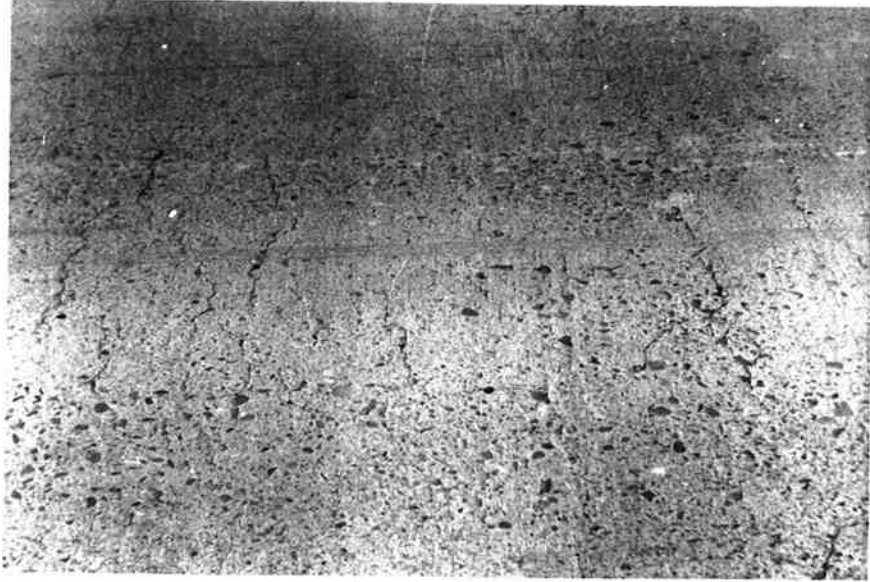


Figure 1. Typical transverse deck cracking.



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:

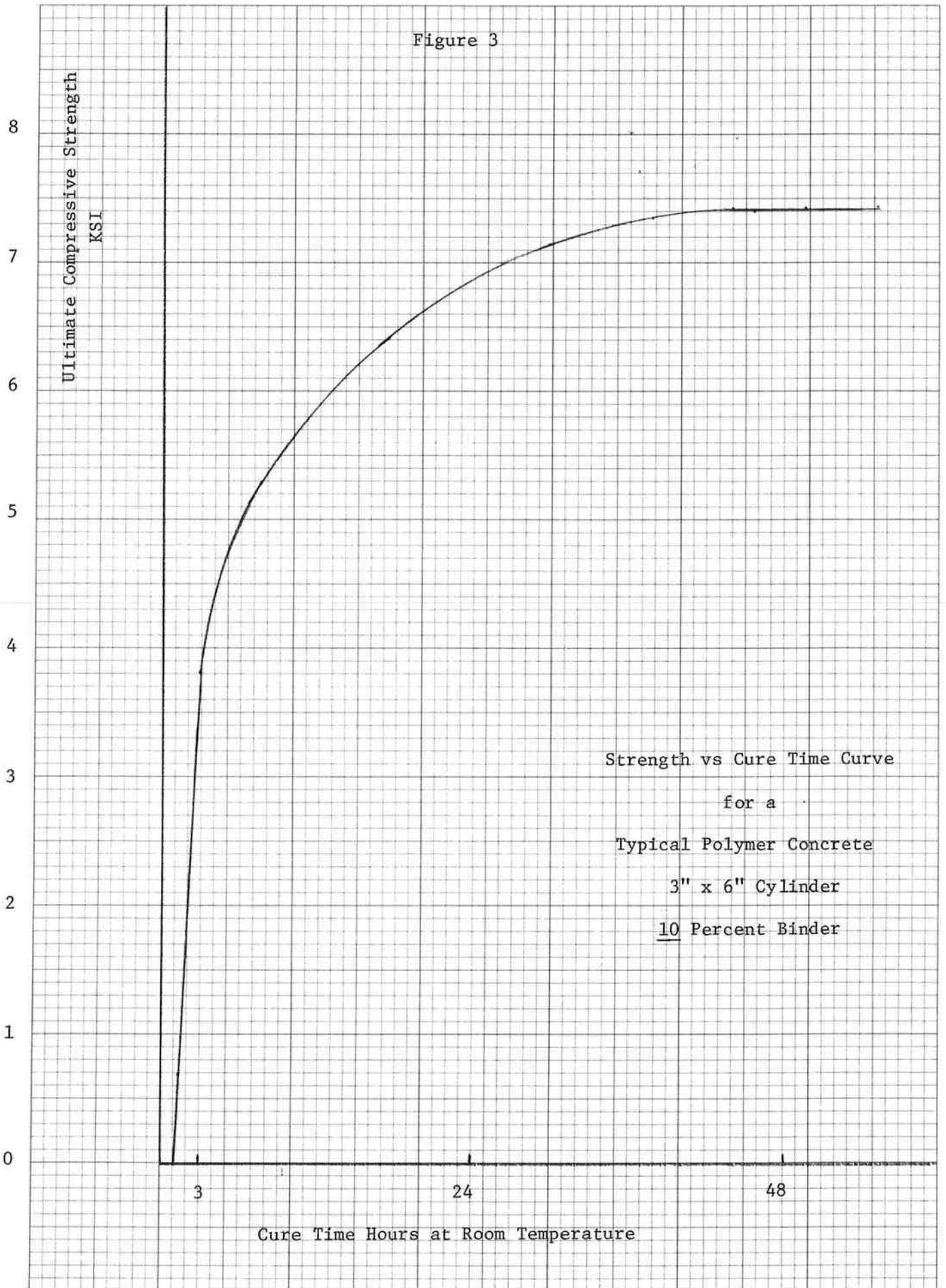
Allowable length of time the resin may be worked without destroying the cross-linking internal bonds. This work time is measured from when the initiator is added to the promoted resin.

M A T E R I A L S

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

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

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.

D E C K P R E P A R A T I O N

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.

R E S I N F O R M U L A T I O N

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 | | | | | |
| 60-70 | 30 | 1.50 | 0.25 | 0.20 | 100 | - | | | | | | | |
| | | | | | | | 70-80 | 30 | 1.25 | 0.25 | 0.20 | 100 | - |
| | | | | | | | | | | | | | |
| 60-70 | 15 | 1.25 | 0.25 | 0.20 | 100 | 2.0 | | | | | | | |
| | | | | | | | 70-80 | 15 | 1.00 | 0.25 | 0.20 | 100 | 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 possibility 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 light-weight 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 be 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 pre-calibrated 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 "battered" 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.

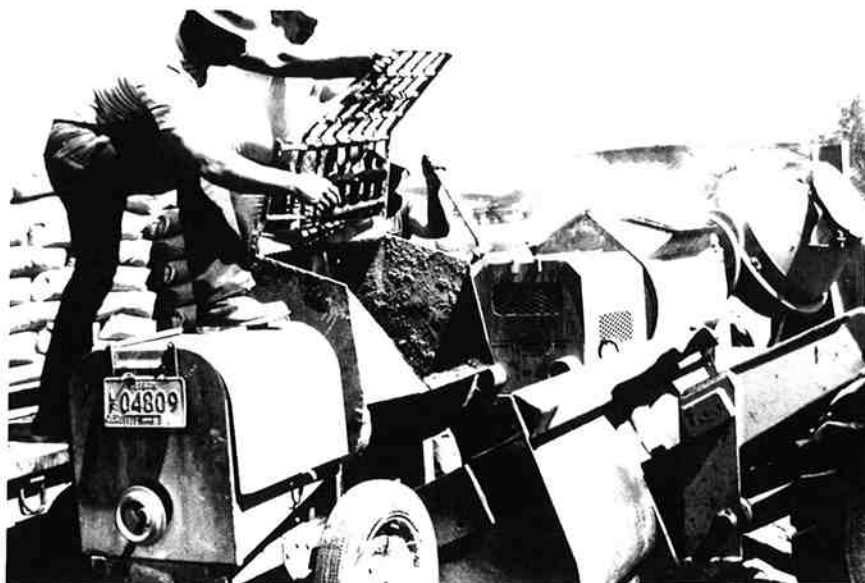


Figure 10. Discharging polymer concrete from mixer.

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