Polyester Overlays for Portland Cement Concrete Surfaces

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The use of thermosetting polyester resins in protective coatings for portland cement concrete (PCC) surfaces is described. Specific reference is made to the use of polyester-aggregate systems as coatings on PCC bridge decks.

Two polyester overlay systems are examined. One uses ordinary seal coat application methods in which polyester resin is sprayed directly onto a carefully cleaned PCC surface. Stone chips are added for skid resistance. The second system uses a polyester-sand mortar applied as a ¼-in. overlay. This type of system also acts as a leveling course which allows readjustment of irregular wearing surfaces to a desired grade.

Selective gradation of the aggregate and proper proportioning of the graded aggregate with polyester resin give a dense impermeable mortar overlay. The variation of compressive strength with aggregate grading is demonstrated.

The properties of selected polyester mortars are examined in the laboratory. The mortar is shown to reach 80 percent of its ultimate compressive strength in less than 24 hr. The completed mortar is also shown to be resistant to hydrocarbon solvents.

Methods used for surface preparation and for applying the polyester overlays are examined. Special construction equipment is described. Both overlay systems have been shown to be effective in several large-scale field tests.

• MILLIONS of dollars are being spent annually for the maintenance and repair of badly spalled and deteriorated portland cement concrete (PCC) bridge decks. This problem is particularly acute in northern areas of the United States where the infiltration of brine, which results from the use of de-icing salts, together with a large number of freeze-thaw cycles are the major causes of rapid deterioration of concrete. Degradation also occurs on bridge decks subjected to vibration from heavy truck traffic. Often deterioration of wearing surfaces is severe enough to require removal of the PCC sections.

The New York State Thruway Authority launched in 1958 a 4-yr, $3,000,000 rehabilitation program to seal and waterproof over 300 of their bridges (1). Estimates based on private discussions indicated over 120,000,000 sq yd of PCC decks in the United States are in need of resurfacing. For example, 8,500 bridges need to be recoated in one southern State alone. Another 2,200 PCC decks require resurfacing in a midwestern State.

This paper describes two overlay systems using polyester resin. One method is based on ordinary seal coat application techniques. A second method involves the use of a polyester-sand mortar. Both the mortar and its method of application are claimed in patent applications now pending before the U. S. Patent Office.

These polyester materials provide a tough, impermeable, fuel-resistant coating of approximately ¼-in. thickness. The thermosetting nature of polyester resins allows

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the coatings to harden quickly and thus reduces considerably "out-of-service" time.

EXISTING OVERLAY SYSTEMS

One of the most common methods for resurfacing PCC bridge decks is with 1 to 2 in. of asphalt concrete (AC). This method can be expensive when the cost of raising existing expansion joints and gutters and changing drainage outlets and bridge approaches are considered. In addition, AC overlays increase the dead weight of the bridge. This increase alone is sometimes sufficient to preclude the use of AC as a resurfacing material for PCC bridges.

Recently, latex-modified cement (LMC) mortars have been introduced in several States as overlays for PCC decks (2). Despite improved compressive, tensile, flexural, and bond strengths claimed for LMC when applied as a ½-in. coating over ordinary PCC, State highway officials and research engineers have had only limited success with LMC (3). In particular, long curing times are required with the LMC mortars.

A third type of coating, epoxy road surfacings, was first introduced in 1954 (4, 5). Both skid-resistant seal coat applications and epoxy asphalt concrete (EAC) mixes were extensively tested in the laboratory and in the field (4, 6, 7, 8). Once correct methods for surface preparation and bonding of the overlays to pavements were developed, epoxy coatings proved quite successful (9). Epoxy resin, like polyester resin, is a thermosetting material that allows the rapid formation of a tough protective surface coating. These coatings have good chemical resistance, can withstand severe weather cycles, and are wear resistant. Of the two, polyester resin is less expensive and currently costs about one-half the price of most epoxies (10).

DEVELOPMENT OF POLYESTER SYSTEMS

Seal Coat

Ordinary seal coat methods were used in the early experiments with polyester resins as protective coatings (11). Aggregate chips were bonded to a cleaned PCC surface with polyester resin. Figure 1 (11) shows the condition of two seal coat sections after 2½ yr of heavily loaded truck traffic. Since the time of taking the photograph an addi-

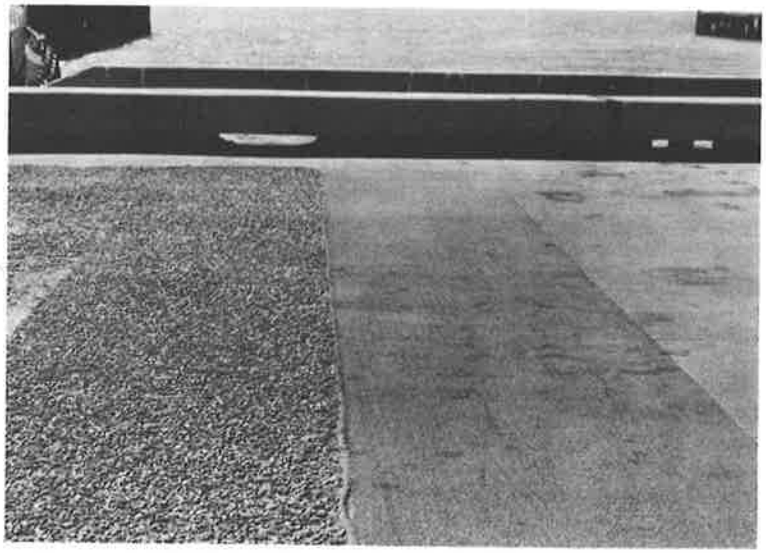

Figure 1. Condition after $2\frac{1}{2}$ yr of service of large and small aggregate seal coats bonded directly to PCC with polyester resin.

tional year of traffic has passed over these sections with little sign of wear. This type of application is designed for new concrete surfaces or for relatively undamaged PCC decks where a protective coating is desired.

The seal coat is not acceptable for rough and deteriorated PCC surfaces which require grade correction. These decks need a coating that can "smooth out" the riding surfaces as well as protect the remaining sound concrete. Studies were carried out in the laboratories to develop a suitable polyester-aggregate mortar for this condition also.

Mortar Overlay

A promising mortar was field tested for the first time on a heavily traveled bridge in the Richmond Refinery of the Standard Oil Company of California. Initially, a high impact rigid polyester resin was used to prime the PCC deck prior to applying the ¼-in. mortar overlay. A high impact rigid polyester was also used as the binder in the mortar. Failures appeared in the form of cracks in the overlay and bond failures between the overlay and PCC surface. These failures were attributed to either a higher modulus of elasticity in the overlay than in the concrete base or the inability of the rigid resin to withstand stresses set up during the curing of the overlay or during thermal cycling.

In the next field trials, a more flexible, high impact polyester resin was substituted for the high impact rigid polyester in the primer and in the mortar. In addition, better surface preparatory methods and a more efficient prime coat system were used. The sections were placed during April 1962 on a smaller PCC bridge on the same access road as the first trials in the Richmond Refinery. Both sandblasting and acid etching were tried as surface preparatory methods. Although no significant difference was found from bond tests (4) on the acid-etched vs the sandblasted sections of the study area, acid etching has been shown to be more effective for epoxy surfacings (4). However, the type and condition of the concrete surface can significantly affect test results (4). After 9 months' service, there are no signs of cracking or bond failures. The condition of one of these sections is shown in Figures 2 and 3. These photographs were taken after 4 months' service, and since then there has been no difference in appearance. The rippled surface texture shown in Figure 2 was caused by the use of a polyethylene film in the compacting process. Apparently, slippage of the film when

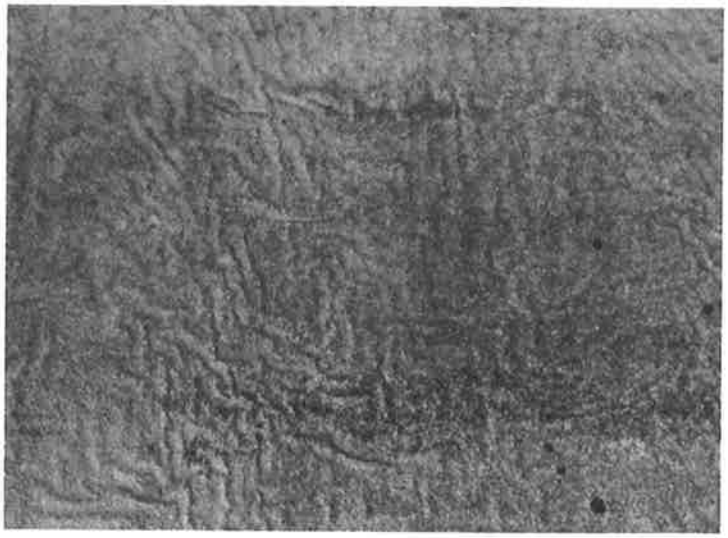

Figure 2. Polyester mortar overlay on PCC surface.

passed between the compacting roller and mortar is responsible for the rippled appearance in the mortar's surface. Placing techniques are discussed in more detail later in the paper. The core holes in Figure 3 are the result of in-place tensile tests which are also discussed later. Additional field trials are being conducted on publicly traveled bridges.

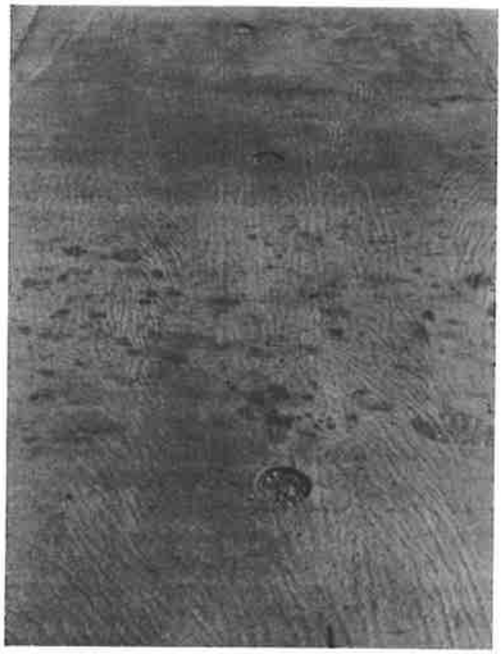

Figure 3. Condition of polyester mortar section after 4 months' service.

AGGREGATE GRADING IN MORTAR FORMULA

A critical range of aggregate gradation must be met to attain maximum strength in the mortar. Previously, Andreasen and Anderson (12) showed in their analyses of aggregate grading curves that they can be represented by

$$y = CK^q \qquad (1)$$

in which

y = percent aggregate passing a sieve of size K;
q = slope of plot of log percent passing each sieve vs log of sieve size; and
C = a constant.

This equation was later plotted on a double-logarithmic scale by Wilhelmi (13).

Nijboer (14) subsequently found that the voids in mineral aggregate for use in AC mixes can be determined graphically. He showed that a slope q of the plot of log percent passing various sieves vs log of sieve size is 0.45 for an aggregate gradation having minimum voids or maximum density.

When thermosetting polyesters were considered as a possible component for the preparation of sand mortars for use in paving work, their particular nature made prediction of the properties of the ultimate cured overlay virtually impossible.

It was also found in an extensive series of tests that a superior mortar is obtained by selective grading of the aggregate according to

$$\log Y = a \log X + b, \qquad (2)$$

in which Y is the percent by weight of the aggregate that will pass through the maximum sieve opening of X inches, and a and b are constants ranging from about 0.35 to about 0.55 and from about 2.30 to about 2.65, respectively. By choosing these critical proportions of the so-graded aggregate and polyester resin, one obtains a mortar that will set to an overlay having greatly improved properties, in particular, the compressive strength, as compared with previously proposed PCC and AC mixes.

The relationship of the percent of aggregate passing various sieve sizes, shown as line B in Figure 4, was developed for a No. 8 mesh maximum size sand. During construction, it is often necessary to modify the preceding grading to improve the workability of the mix. Moreover, other maximum size aggregate mortars may be desired. For these reasons, lines A and C in Figure 4 are included as reasonable limits to the ideal grading.

Four sand fractions are used in the mortar formula. The grading of each fraction is given in Table 1. When combined as 40.6 parts coarse sand, 16.3 parts medium sand, 24.4 parts fine sand, and 18.7 parts filler, the grading of line B in Figure 4 is closely approximated.

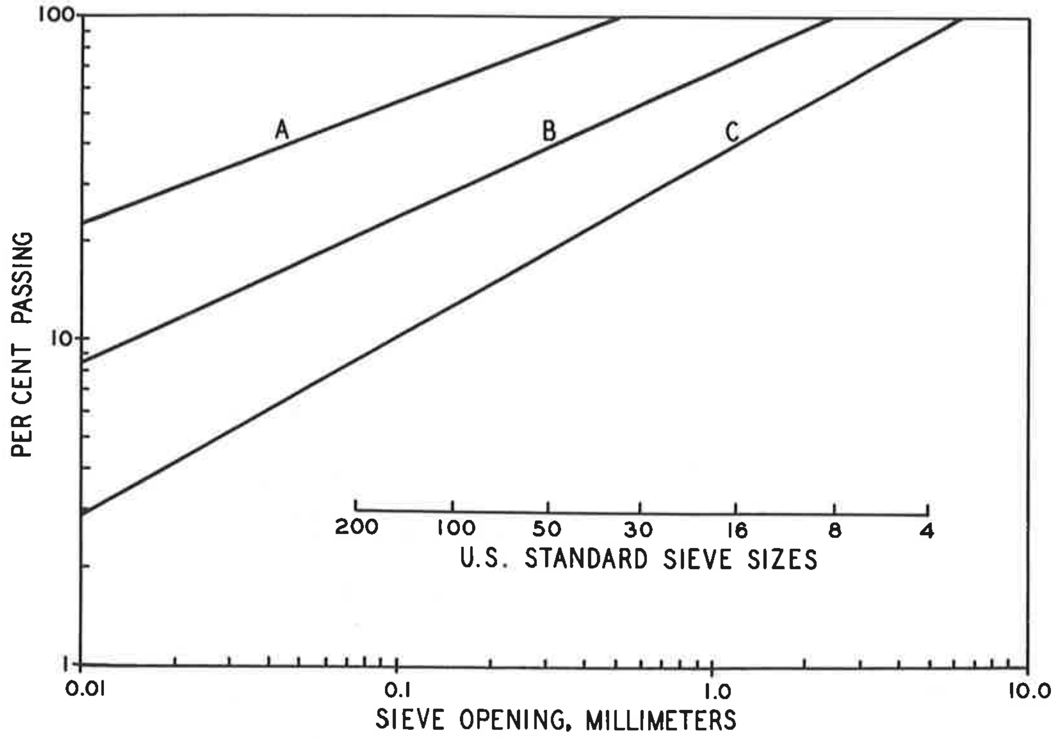

Figure 4. Aggregate grading curve and allowable limits for maximum compressive strength of polyester mortar.

TABLE 1

GRAIN SIZE DISTRIBUTION DATA FOR MORTAR OVERLAY AGGREGATE

ASTM Sieve Designation	Square Opening (mm)	Cumulative Percent Passing by Weight			
		Coarse Sand	Medium Sand	Fine Sand	Filler
No. 8	2.380	100.0			
No. 12	1.680	78.0	--		
No. 16	1.190	26.0	100.0		
No. 20	0.840	2.0	81.0		
No. 30	0.590	--	23.0	--	
No. 40	0.420		4.0	100.0	
No. 50	0.297		1.0	99.5	
No. 70	0.210		--	93.8	
No. 100	0.149			58.2	
No. 140	0.105			21.2	
No. 200	0.074			5.0	--
No. 270	0.053			1.3	100.0
--	0.040			--	99.0
--	0.030				94.0
--	0.020				73.0
--	0.010				39.0
--	0.005				18.0

The resin content to be used in the mortar is estimated graphically using the method previously discussed for determining the voids in the mineral aggregate. The resin content selected is equal to or slightly higher than the calculated voids so that the resultant mortar is voidless.

The importance of aggregate grading is further shown by the compressive strength values given in Table 2. Two-inch cube specimens prepared from the mortar were tested according to ASTM procedure C 306-60 (Method of Test for Compressive Strength of Resin-Type Chemical-Resistant Mortars (C 306-60), 1961 Book of ASTM Standards, Part 4, p. 447) with the exception that the speed of testing was 0.05 in. per min, and an accelerated cure was used. The curing periods were 140 F for 1 hr and 325 F for 3 hr. The samples were then allowed to cool to room temperature for 1.5 hr before testing. The polyester used in these samples is of the high impact rigid type. A high impact flexible polyester mortar would give somewhat lower compressive strengths due to the longer time required for the flexible resin to reach its ultimate strength.

LABORATORY PROPERTIES OF POLYESTER MORTAR

The mortar formula found to be the most satisfactory from the laboratory and field studies was examined for compressive strength, modulus of elasticity, tensile strength, air permeability, and solvent resistance. The sand proportions and resin concentration used in this mortar are given in Table 3. The higher resin concentration shown in Table 3 vs Table 2 is due to the difference in specific gravities of high impact rigid and high impact flexible polyester resins. Results of physical tests are given in Tables 4 and 5.

TABLE 2

AGGREGATE GRADING INFLUENCES COMPRESSIVE STRENGTH OF POLYESTER MORTAR

Proportions (parts per hundred)					Compressive Strength (psi)
Coarse Sand	Medium Sand	Fine Sand	Filler	High Impact Rigid Polyester Resin	
90.9	0	0	0	9.1	5,150
72.7	18.2	0	0	9.1	5,270
45.5	45.4	0	0	9.1	5,570
27.3	63.6	0	0	9.1	4,750
0	90.9	0	0	9.1	4,900
63.6	0	27.3	0	9.1	8,650
27.3	36.3	27.3	0	9.1	7,780
27.3	18.2	45.4	0	9.1	5,400
54.5	18.2	18.2	0	9.1	7,200
45.4	27.3	18.2	0	9.1	8,720
54.5	9.1	27.3	0	9.1	8,750
45.4	18.2	27.3	0	9.1	9,040
36.3	27.3	27.3	0	9.1	8,600
54.5	0	36.4	0	9.1	8,350
36.3	18.3	36.3	0	9.1	8,190
44.5	17.8	26.8	1.8	9.1	8,470
37.6	15.0	22.6	15.7	9.1	10,070
36.9	14.8	22.2	17.0	9.1	10,930[a]

[a] Aggregate grading corresponds to line B in Fig. 4.

The compressive strength and modulus of elasticity values represent an average of three tests on 2-in. cube samples made according to ASTM procedure C 306-60 with slight modifications in curing methods and testing speed. The mortar's tensile strength is an average of four results on samples prepared by ASTM procedure C 307-61 (Method of Test for Tensile Strength of Resin-Type, Chemical-Resistant Mortars (C 307-61), 1961 Book of ASTM Standards, Part 4, p. 452) with similar modifications. Both compression and tension samples were cured for 24 hr at room temperature (70 F) before testing. The testing speed in both instances was 0.05 in. per min. The air flow rate through 2-in. diameter by ¼-in. thick mortar plugs recovered from one of the field trials was measured in the laboratory with the air permeability apparatus (17). The retention of strength after immersion in various hydrocarbon solvents was measured on samples air cured at ambient temperature for 24 hr before the soaking period began.

TABLE 3

COMPOSITION OF POLYESTER MORTAR OVERLAY

Material	Proportions (parts per hundred)
Coarse sand	37.5
Medium sand	15.0
Fine sand	22.5
Filler	15.0
High impact flexible polyester resin	10.0

TABLE 4

PHYSICAL PROPERTIES OF POLYESTER MORTAR COMPARED WITH PORTLAND CEMENT CONCRETE

Properties	High Impact Flexible Polyester Mortar	Portland Cement Concrete (16, 17)
Compressive strength (psi)	4,900 ± 100	2,000 - 5,000
Modulus of elasticity (psi)	$7.1 \times 10^5 \pm 2.9$	$2.4 - 4.9 \times 10^6$
Tensile strength (psi)	556 ± 69	200 - 500
Average air flow rate[1] (ml/min)	2.28 ± 0.72	--

[1] Two-inch diameter area, pressure differential 1.00 in. water.

TABLE 5

SOLVENT RESISTANCE OF POLYESTER MORTAR

Soaking Time at 70 F (hr)	Compressive Strength (psi)		
	After Soaking in Jet Fuel, Type A-1[a]	After Soaking in Auto Gasoline	After Soaking in Aviation Hydraulic Fluid
0	4,900	4,900	4,900
5	4,690	4,675	4,725
24	3,375	3,625	5,125
96	4,840	5,390	5,350

[a] ASTM Designation D 1655-61T.

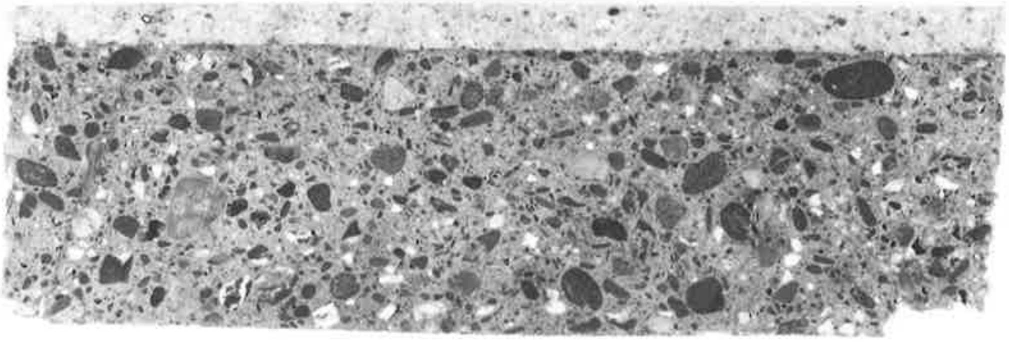

Figure 5. Polyester mortar tightly bonded to PCC section with polyester prime coats.

The effect of temperature variation on the bond strength of the mortar overlay was studied on the sliced section shown in Figure 5. This ¼-in. thick sample was heated to 425 F and immediately placed in a 39.2 F bath. Microscopic inspection showed no signs of bond separation. A similar sample was fractured with a hammer after this test. In no case did the fractured pieces show failure at the overlay-concrete interface.

The polyester mortar when properly prepared can attain high compressive strengths in a relatively short time. Once the accelerator and catalyst have been added to the polyester resin, a chemical reaction begins. Curing time of the resin can be readily adjusted from a few minutes to several hours. The resins used in the field trials were designed to set in about 1 hr at normal room temperature. The increase in mortar strength with curing time is shown in Figure 6. The mortar is shown to reach 80 percent of its ultimate compressive strength within 24 hr at ambient temperature and in 17 hr is stronger than most fully cured PCC (15). This high early strength allows coated PCC surfaces to be opened to traffic shortly after construction.

CONSTRUCTION OF POLYESTER OVERLAYS

PCC surfaces are prepared in a similar way for both seal coats and the mortar system. All deteriorated concrete is first removed to expose sound surfaces. A solvent wash is used to remove asphalt and oil spots. This is necessary for best adhesion and because most asphalts have a retarding effect on polyester cure. The surface is then prepared for the overlay by sandblasting or by etching with a dilute acid solution. The method used is largely dependent on the condition of the PCC. In the case of an acid etch, the deck is flushed with water and must be thoroughly dried before applying polyester resin because water also affects the wetting out, adhesion, and cure of the resin.

The conventional seal coat is constructed by imbedding suitable chips into an appropriate amount of polyester resin. The resin rate and aggregate size and type are selected for the final surface texture desired.

The mortar overlay is bonded to the concrete base with a combination of two polyester prime coats. The first primer

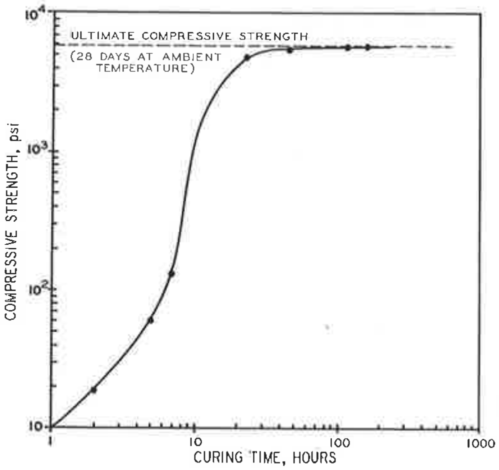

Figure 6. Increase of compressive strength of mortar with curing time.

is lower in viscosity and designed to penetrate and seal off the voids in the PCC surface, thus providing "in-depth" adhesion for the mortar to the concrete. The next prime coat is the same resin as that used in the mortar formula and acts as the major bonding medium between the mortar and concrete. The blended and catalyzed mortar is next roughly troweled or screeded to the desired thickness over the freshly primed surface. Compacting the mortar to maximum density completes the placing process.

To prevent sticking of the polyester mortar to the compacting roller used on the relatively small size field trials, a plastic film was passed between the roller and mortar. After compaction the film is peeled from the mortar leaving a slightly rippled surface texture. These ripples are probably caused by slippage of the film under the roller.

Additional skid resistance is imparted to the overlay by brooming the surface just as the mortar begins to cure (Fig. 7). The final texture of a broomed surface is shown in Figure 8. A still rougher texture is obtained by rolling a liberal coating of angular chips into the uncured mortar. Excess chips are swept from the surface after the mortar has hardened. Such a surface texture is shown in Figure 9.

SELECTION OF MATERIAL AND APPLICATION RATES

The seal coat overlay can be designed to give any desired type of surface. If a fairly rough textured surface is needed, the seal coat is made with $^3/_8$-in. chips. For a fine textured overlay, No. 20 or No. 30 mesh grits are bonded to the PCC deck with ap-

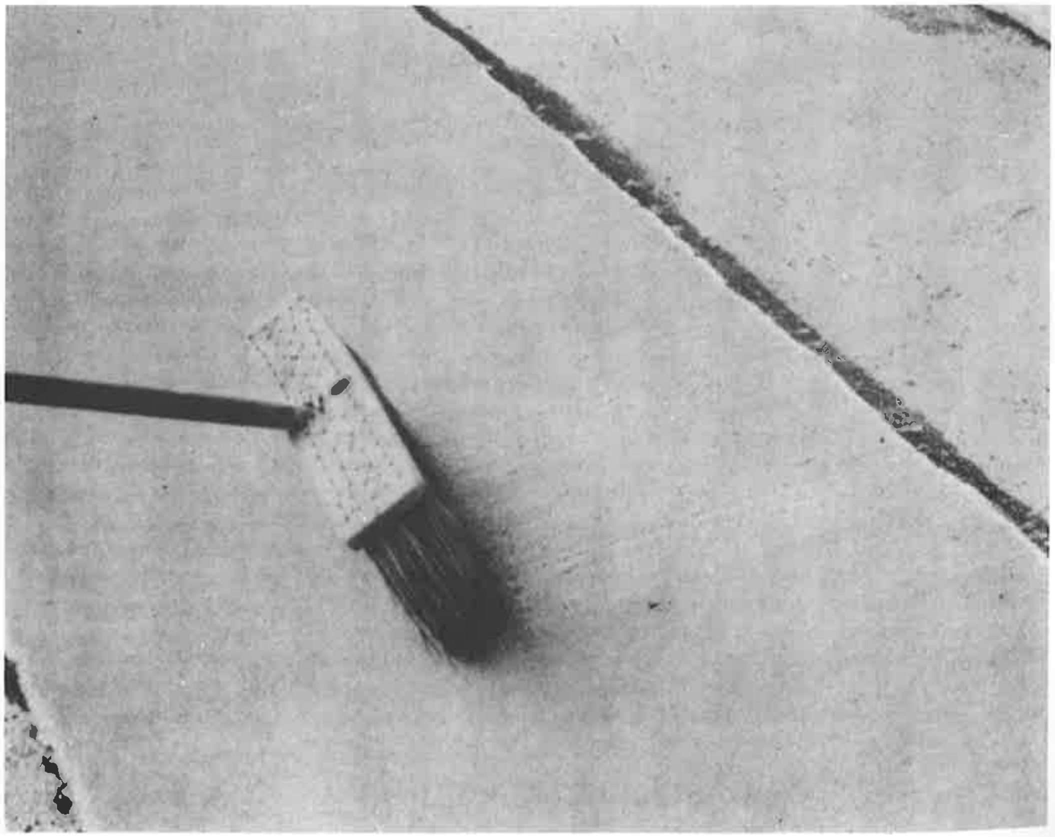

Figure 7. Brooming just before cure to give polyester mortar toughened skid-resistant surface.

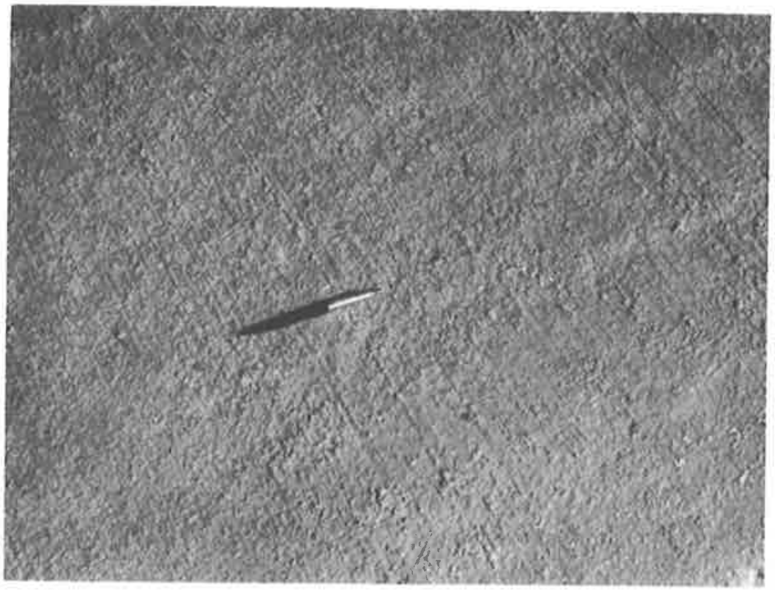

Figure 8. **Final surface texture of broomed mortar section.**

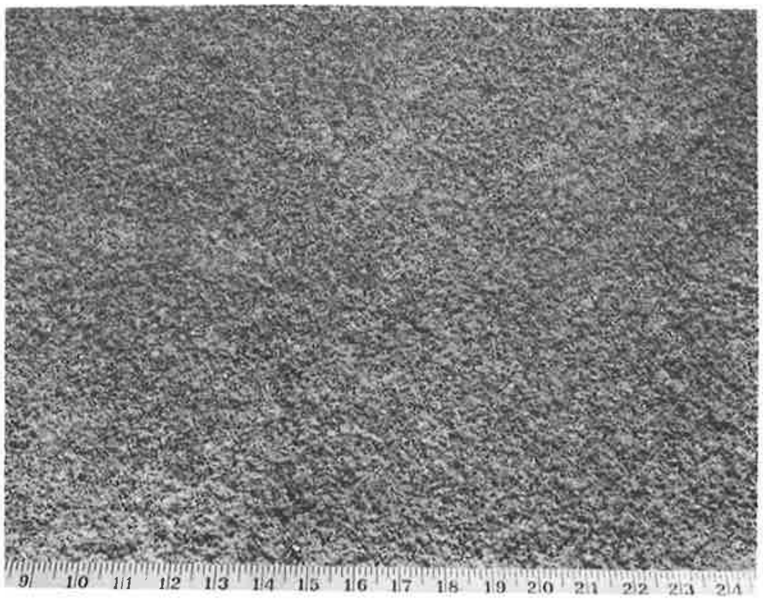

Figure 9. Stone chips in mortar overlay to increase skid resistance.

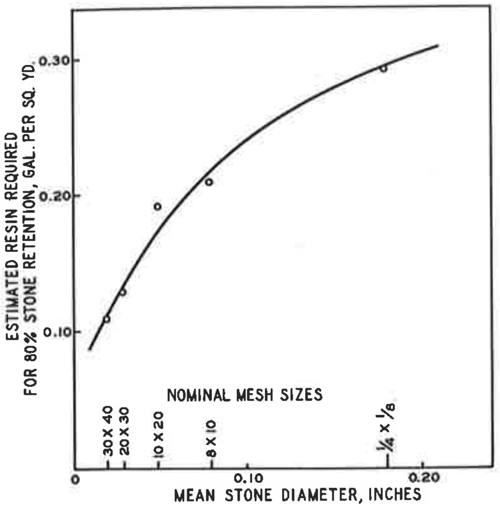

Figure 10. Relation between resin requirements and stone size for 80 percent stone retention after 3 yr of service on PCC surface.

proximately 0.13 gal of resin per sq yd (1.14 lb per sq yd). Typical application rates for maximum stone retention, based on the field studies, are shown in Figure 10. These rates are included only as guides because the porosity of the PCC surface will often dictate resin requirements.

The aggregate used in the mortar overlay system is controlled by the desired thickness of the coating. For ¼-in. overlays, a No. 8 mesh sand is chosen as the maximum size aggregate. The recommended maximum size aggregate is one-half the thickness of the desired overlay.

The application rates for the prime coats used with the mortar overlay range from 0.06 to 0.08 gal per sq yd (0.53 to 0.70 lb per sq yd). This is again dependent on the porosity of the PCC surface and the viscosity of the priming resin.

CONSTRUCTION EQUIPMENT

Readily available equipment can be used for the major construction of polyester seal coats. For limited areas, the resin can be sprayed on by hand or with a self-propelled spray rig (11). Where larger sections are to be coated, a dual spray bar unit equipped with multiple spray heads may be used. Stone chips may be spread by tail gating from a truck or with commercially available chip spreaders.

The prime coats used with the mortar overlay system can be sprayed on with the methods described for seal coats. A 40-in. long, 12-in. diameter hand steel roller weighing 35 lb per linear in. was used to compact the mortar placed in the field trials. For full-scale construction, any suitable self-propelled unit may be used.

PERFORMANCE OF POLYESTER OVERLAYS

As discussed earlier in this paper, the polyester seal coat installations have performed well under heavily loaded truck traffic for over 3 yr. The high impact flexible polyester mortar overlay trials in the Richmond Refinery are also in excellent condition after 9 months of traffic.

In-place tensile tests (5) were run to evaluate the bond strength of polyester mortar overlays. All the tensile tests on high impact rigid polyester mortars resulted in adhesive bond failures at the concrete-overlay interface. When a high impact flexible resin was used in the mortar, the bond strength increased but still showed up as partial cohesive failure in the concrete and partial adhesive failure at the bond line. In both sections only one prime coat was used. For a high impact flexible polyester mortar bonded with multiple prime coats, tensile tests gave even higher bond strengths with complete cohesive failure in the concrete. Figure 11 shows this type of failure. Test results are shown in Figure 12. The tensile values reported represent an average of at least three tests. The comparison of results just described is for an acid-etched PCC surface.

Similar tests were run on sandblasted areas on the same PCC deck (Fig. 12). This particular concrete surface was in good condition, but conceivably poorer PCC surfaces would show marked differences between acid etching and sandblasting as surface preparatory methods.

RELATED USES OF POLYESTER SYSTEMS

Seal coat applications of polyester and stone will be beneficial wherever corrosion

Figure 11. Typical cohesive bond failure in concrete.

control or maintenance of PCC surfaces is a problem. Thus, in addition to highway use, seal coats of this type may find use as coatings on commercial floors, wharf decks, and storage reservoirs.

The mortar overlay also has numerous potential uses as a protective coating. Its benefits as an impermeable solvent-resistant overlay for bridge decks have been demonstrated. In addition, the mortar may find use on PCC surfaces subjected to severe deterioration by wave action or turbulent flow. The mortar could be applied to buckets and faces of spillways, the upper face of concrete dams, bridge piers, or the interior of concrete canals.

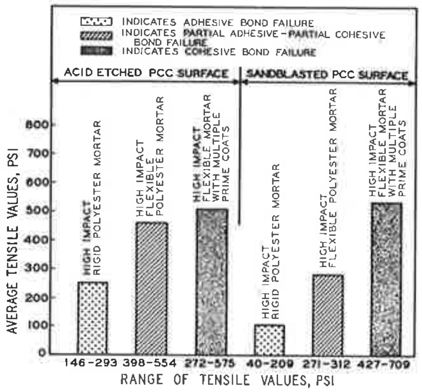

Figure 12. Tensile test results showing effect of resin-type and surface preparatory methods.

CONCLUSIONS

Polyester seal coats have demonstrated their use as durable protective coatings under heavy vehicles. The texture of the seal coat surface can be controlled by proper selection of aggregate particles.

Initial field trials have shown polyester mortar overlays to be a promising material for protecting PCC surfaces from environmental deterioration. When properly designed and applied, the mortar provides the following qualities:

1. An impermeable surface which prevents infiltration of water, solvents, and de-icing salts into the concrete base.
2. A thin coating which is essential in resurfacing bridges where additional dead weight must be kept to a minimum.
3. A leveling material which allows for the realignment of irregular or deteriorated PCC surfaces without significantly raising the grade.
4. Fast curing which eliminates "out-of-service" traffic delays. The mortar has been shown to develop strengths greater than most concretes in less than 20 hr.

5. A light-colored overlay that can be pigmented for any desired effect.
6. Antiskid properties for highway safety.

Although the initial cost of polyester resins is high compared to those of cement and asphalt, the savings in maintenance and repair of PCC surfaces may far offset the difference. Moreover, thermosetting resins, like polyester, provide strength, chemical-resistant, and wear-resistant properties superior to existing bridge coatings.

ACKNOWLEDGMENTS

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Discussion

H. B. BRITTON, New York State Department of Public Works—The author is to be congratulated for the excellent manner in which he has developed his subject. The details and graphic description contained in this paper could only result from an intimate knowledge based on experience.

It is interesting to note the influx of new and sophisticated materials for the purpose of protecting, restoring or developing concrete in order that its serviceable life might be increased.

The paper presented outlines two methods of employing polyester resin as an overlay protective system for portland cement concrete. These have been designated as a seal coat and a mortar overlay.

It is recommended that the seal coat be used only on new concrete or on concrete that is relatively free of surface deterioration. It is not definitely stated, but it is inferred, that the seal coat is established by a single application of the polyester resin on which chips of a gradation commensurate with the finish desired are spread. This procedure might well raise the question as to whether the final product had produced a truly impermeable material inasmuch as of necessity the wetting out of the chips could cause a reduction in the final mil thickness of the resin. Because it has been demonstrated that a prime coat of polyester resin enhances the properties of the mortar overlay, it would appear reasonable to expect the same results if this procedure was used when applying the seal coat.

In the development of the mortar overlay, the rigid polyester resin was replaced with a flexible polyester resin. The author presents a choice as to the reasons for the failure of the mortar overlay made with the rigid polyester resin. It might have been helpful if some definite conclusion could have been drawn relative to the failure.

The gradation and percentages of the aggregates for use in the mortar overlay, though possible to attain in the laboratory, might be impossible to realize under field conditions except at elevated or prohibitive cost. The proportions given in Table 3 are predicated on a perfect nesting of each successive graded aggregate into the interstices of its predecessor. This ideal of void satisfaction is difficult to accomplish because particle shape is as much a factor as particle size.

It would also appear from the proportions in Table 3 that the ratio of filler to the resin is too high; in fact, it could possibly result in robbing the complete system of its resin requirement.

From the indicated air flow rate in Table 4 it is obvious that the mortar overlay is porous in nature. This may be due in part to the observations previously noted.

This indicated porosity would preclude the use of the mortar overlay in a great many of the States where the incidence of freeze-thaw cycles is high.

Considerable detail was given to the description of methods of placement and equipment; however, no mention is made of the equipment required to produce the mortar. It is assumed that conventional concrete mixing equipment can be used.

The two systems outlined in this paper show considerable promise and should be given the opportunity to demonstrate their ability to perform under various construction conditions. One such condition should be on new construction and the other as a maintenance operation.

When utilized in new construction, the designer should be cognizant of this fact and note on his plans the desired finish texture of the concrete best suited to the polyester application.

Under maintenance operations, surface conditions should be attained as recommended in the author's paper. Under maintenance conditions deteriorated concrete must necessarily be removed, and the paper has demonstrated the practical advantages of choosing the mortar overlay as a leveling course. It would then appear that the best results would be obtained by limiting the use of the mortar overlay for this purpose and follow with a complete application of the seal coat. This would then provide a system that would make possible a 100 percent runoff of water or solution from the top surface without the possibility of migration into or through the system.

Because compaction of the mortar is recommended by the author and a relatively smooth riding surface area is desirable, would it be possible to provide polyethylene sleeves for the rollers to overcome the slippage encountered in the use of the plastic sheet?

It would be most helpful if a time interval would be indicated for the successive applications of the resin. On this time differential will depend the type of bond obtained between succeeding coats of resin. If the time interval between succeeding coats is in the area of one to four hours, there is a good possibility that the bond could be effected by copolymerization. If the time interval between succeeding coats is in excess of a day it could be that the bond produced will be mechanical.

The indication that both the mortar and its methods of application are claimed in patent application now pending before the U. S. Patent Office is the only disturbing statement contained in the paper. This might develop a reluctance on the part of many end users to investigate the potential of this apparently desirable material.

In presenting this formal discussion the writer is playing the role of the second guesser and anything contained herein should not be interpreted as intending to detract from this very fine work done by the author.

L. E. SANTUCCI, Closure—The author wishes to thank Mr. Britton for his very appropriate comments on the paper. He has brought out several points about the paper which require further clarification or re-emphasis at this time.

First, the author would like to emphasize the fact that both the polyester seal coat and the mortar overlay discussed in the paper are completely impermeable to water. Several field tests were conducted in which a 4-in. diameter glass tube was tightly bonded to the overlay surface. Water was then added to the tube to an initial height of 6 in. After three days of standing, no measurable drop in the water height was noted. Furthermore, the permeability results reported in this paper are air permeability values, measured under a pressure differential of 1 in. of water. The fact that an absolutely zero value vs the reported value of about 2.3 ml per min was not obtained is probably due to the limitations of the air permeability device to measure completely impermeable samples.

In measuring air flow rate, the sample, whether it be an asphalt concrete core or a $\frac{1}{4}$-in. thick plug of the mortar overlay, is placed in a "core adapter" described in "A Method for Measuring the Air Permeability of Asphalt Concrete Pavements," ASTM Special Tech. Publ. 294 (1960). The adapter consists of a rubber membrane which is collapsed around the circumference of the sample. Often, with highly impermeable samples, the air flow rate obtained may be the result of a leak around the edge of the sample rather than passage of air through the specimen.

In answer to the question on the choice of reasons for failure of the high impact rigid polyester sections, the author was actually unable to isolate either of these reasons as being the major cause of failure on this test section. However, it is felt that there is a better than 50 percent chance that failure was caused by excessive stresses set up in the rigid polyester resin during the curing cycle. Nevertheless, dropping the modulus of elasticity slightly below that of concrete will reduce the chance of failure by cracking.

The aggregate gradation of the mortar given in Table 3 is actually the grading used in all the field installations. No particular difficulty was encountered in placing the material. However, it should be recognized that the mortar is a relatively dry mix and does require more than simple troweling.

The proportion of filler to resin used in the mortar may be expressed in another way. For example, the filler to binder (F/B) ratio, in this case the polyester resin, is 0.59 on a volume basis. This value falls within the recommendations of Nijboer (14) in his asphalt concrete mix design method. Nijboer suggests a desirable range of F/B ratio of 0.3-0.6. Because the polyester resin acts essentially as an asphalt in bonding aggregate particles together, there is no reason for not accepting these recommended proportions.

The author wishes to apologize for not including the type of equipment used in preparing the mortar. Actually, Mr. Britton's assumption is correct in that typical paddlewheel type of mixer was used to blend the graded aggregate and catalyzed polyester resin before applying it to the test surface.

TABLE 6

ESTIMATED COST IN PLACE OF POLYESTER SEAL COAT AND MORTAR OVERLAY

Types of Costs	Polyester Seal Coat		Polyester Mortar Overlay	
	$/lb	$/Sq Yd	$/lb	$/Sq Yd
Resin:				
As bond coat, 2.0 lb/sq yd	0.35[a]	0.70		
As primer, 1.1 lb/sq yd			0.35[a]	0.39
In mortar, at 2.6 lb/sq yd			0.35[a]	0.91
Sand:				
(10 by 20 mesh) At 18 lb/sq yd	0.01	0.18		
Special Calresearch sand Blend, 23 lb/sq yd			0.01	0.23
Miscellaneous[b]:		1.57		1.72
Total cost		2.45		3.25

[a] Based on average current polyester resin cost, Chem. and Eng. News, Quarterly Report on Resin Prices (May 7, 1962).

[b] Including surface preparation, equipment and labor, profit, and contingencies.

As to the use of polyethylene sleeves on the roller, the author conducted several small-scale field tests in which various release compounds such as silicone and plastic coated rollers were tried. None of the release materials prevented sticking of the mortar to the steel wheel. Teflon- and polyethylene-coated rollers showed no sticking of mortar to the roller for one or two passes. After this, however, small pieces were picked up which quickly snowballed into a major pickup of material. This problem was not solved by adding a scraper bar to the roller. The use of a polyethylene film as a physical barrier between the compacting roller and the fresh mortar has proved to be the most successful approach. Because the mortar surface will most likely be roughed by brooming or adding stone chips, the author has not been concerned with the rippled surface pattern caused by slippage of the polyethylene sheet under the roller.

The question on the time intervals for successive applications of the resin is a very good one. The diluted polyester prime coat is first applied to the cleaned PCC surface. Shortly thereafter, approximately 5 to 10 min, the second polyester prime coat is placed on the deck. The blended and catalyzed mortar is immediately spread over the uncured prime coats. As a result, there is no time delay in waiting for one layer of application to set up before the next phase of the overlay system is added.

The author feels certain that Mr. Britton understands the author's position regarding patent applications. As a producer of new products or novel ways for using existing products, it is often necessary to protect the proprietory position of such an invention by patent coverage. It is only fair to inform end users that patent applications on both the mortar and its method of application are pending before the U. S. Patent Office.

As a result of several questions on the estimated cost of the two polyester overlay systems described in the paper, the author refers to Table 6. The costs in the table are given as estimates only, and it should be realized that variations in the quoted figures can result from (a) the condition of the PCC surface to be coated and, hence, the amount of surface preparation required, (b) the porosity of the PCC surface, (c) local labor costs, (d) the availability of locally suitable aggregate, and (e) the type and current prices of the polyester resin selected for the mix.