

Electrically Conductive Polymer-Concrete Overlays

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ABSTRACT

The use of cathodic protection to prevent the corrosion of reinforcing steel in concrete structures has been well established. Application of a durable, skid-resistant electrically conductive polymer-concrete overlay would advance the use of cathodic protection in highway engineering. Laboratory studies indicate that electrically conductive polymer-concrete overlays with conductive fillers, such as calcined coke breeze, in conjunction with polyester or vinyl ester resins have resistivities of 1 to 10 ohm-cm. Both multiple-layer and premixed mortar-type overlays have been made. Shear bond strengths of the conductive overlays to concrete substrates vary from 600 to 1,300 psi; the bond strengths of the premixed overlays are 50 to 100 percent higher than those of the multiple-layer overlays.

Of major concern to highway structural and maintenance engineers is the rapid deterioration of concrete bridge decks and structural members such as beams, girders, columns, and piers. Although several factors contribute to the deterioration of concrete, the primary cause is corrosion of the reinforcing steel. The heavy winter use of deicing salts releases critical quantities of chloride ions that penetrate to the reinforcing-steel level and, in the presence of moisture and oxygen, initiate the corrosion process. The corrosion products increase the volume of the reinforcing steel, thereby creating tensile stresses in the surrounding concrete. When these stresses exceed the tensile strength of the concrete, it cracks and eventually spalls or delaminates.

The repair of spalls and delaminations in concrete is a common practice in highway engineering. At times all the delaminated or deteriorated concrete to the level of the reinforcing steel is removed and replaced in an effort to extend the service life of a bridge deck. In addition, the repaired decks are covered by low-slump concrete, latex-modified concrete, or polymer-concrete (PC) overlays to prevent further intrusion of chloride or moisture into the concrete. However, neither extensive patching nor overlaying of chloride-contaminated concrete has been successful in stopping the corrosion process. The only methods available to date are the removal and replacement of all chloride-contaminated concrete or the use of cathodic protection (CP). Although the removal of chloride-contaminated concrete is technically feasible, it is often prohibitively expensive. Cathodic protection, however, is not only reliable but is considered to be economically feasible.

The use of cathodic protection to prevent the corrosion of reinforcing steel in chloride-contaminated concrete bridge decks has been well documented in the literature (1-4). In the early CP systems developed for bridge deck applications, an electrically conductive asphaltic-concrete overlay was used that performed well but required significant changes in elevations and increases in dead load (5). The Office of Research of FHWA has conducted its own research program and sponsored others to improve the highway engineer's understanding of CP systems (6-8). In addition, FHWA has applied for a patent for an electrically conductive PC mortar and overlay system (9). On the basis of this work, CP systems have been

installed on 11 bridges throughout the United States by utilizing electrically conductive PC mortar in slots cut into the bridge deck surface. Approximately 1 linear foot of slot is required for every square foot of the bridge deck surface. This type of installation is tedious and costly; thus FHWA sponsored research at Brookhaven National Laboratory (BNL) to further develop an electrically conductive PC overlay that would simplify the installation of CP systems on concrete bridge decks (10).

Considerable research has been done at BNL to develop a thin sand-filled resin overlay system for use on concrete bridge decks (11-13). The overlay, consisting of three to four layers of resin and aggregate, is impermeable to water and chlorides and is considered to provide a good skid-resistant surface. This type of overlay can be made electrically conductive by replacing the silica sand in the first two or three layers with an electrically conductive filler.

LABORATORY EVALUATIONS

Test Procedures to Measure Properties of Electrically Conductive Composites

The test methods used to evaluate the electrical, physical, and mechanical properties of the overlay systems are described in the following sections.

Electrical Resistivity Test

Electrical resistivity values were determined by means of one of two methods: resistivity constant and the test circuit. In the preferred, test-circuit method, a known resistance is connected in series with the conductive composite to be measured and a current is passed through the circuit. The voltage drop across the unknown composite is compared with the voltage drop across the known resistance:

$$R_C = V_C R_K / V_K \quad (1)$$

Thus, the resistivity of the composite is

$$\rho_C = V_C R_K A_C / V_K L \quad (2)$$

where

ρ_C = resistivity of the composite,
 V_C = voltage drop across the composite,
 R_K = resistance of known resistor,
 A_C = cross-sectional area of the composite,
 V_K = voltage drop across the known resistor, and
 L = length of the conductor across which the V_C is measured.

A diagram of the test specimens and test circuitry is shown in Figure 1.

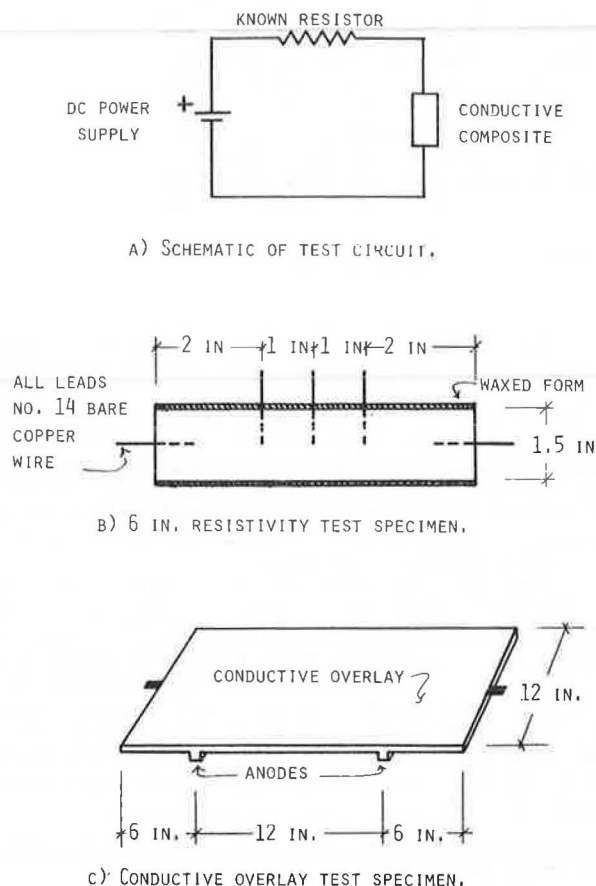


FIGURE 1 Resistivity test specimens and test circuit.

Shear Bond Strength Tests

Shear bond strengths were measured on 3-in.-diameter cores taken from overlaid portland cement concrete slabs. The bond strength is measured in direct shear by using a fixture as shown in Figure 2.

Freeze-Thaw Durability Tests

The freeze-thaw durability characteristics of electrically conductive PC overlays were evaluated according to ASTM C666 (Resistance of Concrete to Rapid Freezing and Thawing), Procedure A, and ASTM C672 (Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals). The samples used for ASTM C666 were 3-in.-diameter cores taken from overlaid slabs, whereas the samples used for ASTM C672 were 9.5 x 8.5 x 3.625-in.-thick overlaid concrete slabs. Evaluations of the overlays in both cases were based on visual examinations and shear bond strengths.

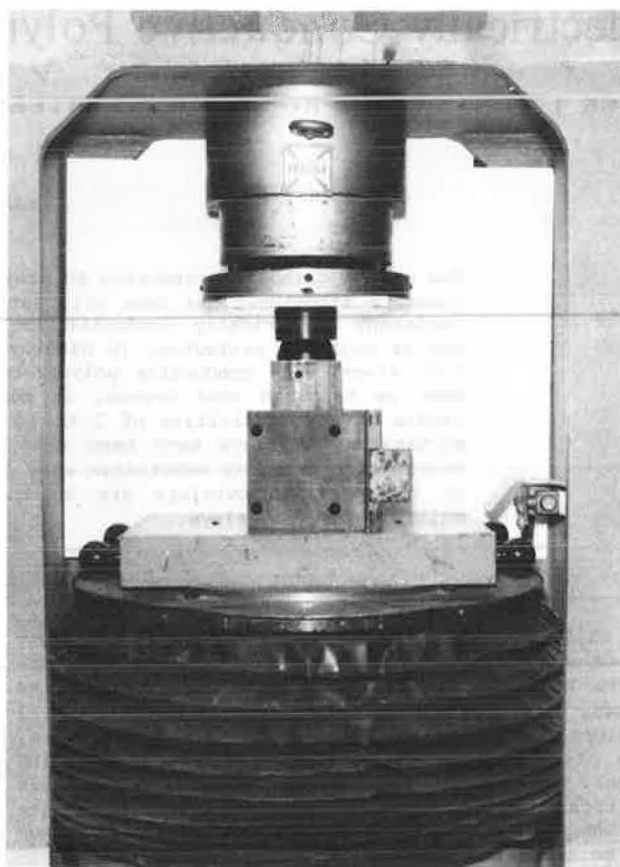


FIGURE 2 BNL shear bond strength test.

Thermal Coefficient of Expansion

The thermal coefficient of expansion was measured with a Dupont 990 Thermal Analyzer and a 943 Thermalmechanical Analyzer.

Evaluation of Electrically Conductive Composites

Conductive Fillers

The electrical conductivity of PC composites was evaluated by using all the commercially available conductive fillers and resins listed in Tables 1 and 2.

One resin, LB183-13, an orthophthalic polyester, was used to make premixed mortars with all 16 fillers. The mix proportions of filler to resin were varied for each system to obtain a smooth, workable mix in each case. The electrical resistivity of all the samples was measured and the data are summarized in Table 3.

The Shamokin coke breeze, the Asbury calcined coke breeze, and the Loresco calcined coke breeze all produced composites with electrical resistivity values of <5 ohm-cm. The calcined coke breeze composites had electrical resistivity values of 0.59 to 1.01 ohm-cm. Although the Magnamite graphite fibers also produce a conductive composite, the fibers would be considered as an additive to the coke breeze systems rather than as a filler.

Because the Loresco SWK coke breeze has a particle-size distribution of +1/4 to +No. 200, it was considered impractical for built-up or thin premixed

TABLE 1 Summary of Resins Evaluated

Resin	Manufacturer	Description	Viscosity cP (centipoise at 24° C)	Initiator/Promoter (% at 24° C)
Orthophthalic polyesters				
LB183-13	U.S.S. Chemical Company	Low-viscosity, highly resilient general-purpose resin	100-150	1.2 MEKP/0.5 CoN
MR11044	U.S.S. Chemical Company	Semiflexible casting resin	140-200	1.2 MEKP/0.5 CoN
LB802-6	U.S.S. Chemical Company	Flexible resin formulated for use as a protective coating on roads	110-135	2.0 BPO/prepromoted by supplier
MR15031-I	U.S.S. Chemical Company	Low-viscosity general-purpose resin	255	1.2 MEKP/0.5 CoN
Polylite 90-570	Reichhold Chemical Company	Low-viscosity general-purpose resin	160	1.2 MEKP/0.5 CoN
Hetron 197A	Ashland Chemical Company	Low-viscosity thixotropic resin with good resistance to acids and chlorine gas	500	1.2 MEKP/prepromoted by supplier
Isophthalic polyesters				
Polylite 98-507	Reichhold Chemical Company	Low-viscosity flexible resin	140	1.2 MEKP/prepromoted by supplier
Aropol 7532	Ashland Chemical Company	Resilient low-viscosity chemical resistant resin	450-600	1.2 MEKP/0.5 CoN
Dural 370	Dural International Corporation	Flexible low-viscosity resin	120	1.2 MEKP/0.5 CoN
Quick Deck	ODI, Inc.	Specially modified resin for bridge deck wearing surfaces	700-1,000	1.2 MEKP/prepromoted by supplier
Vinyl esters				
Epocryl DPV-701	Shell Chemical Company	Highly resilient low-viscosity resin with good chemical resistance	80-140	2.4 MEKP/0.4 CoN, 0.1 DMA
Derakane 411-C50	Dow Chemical Company	Low-viscosity casting resin with good corrosion resistance	80-160	1.8 MEKP/0.4 CoN, 0.1 DMA
Derakane XD-8084-05	Dow Chemical Company	Experimental resin with good corrosion and impact resistance	460	1.0 MEKP/0.2 CoN, 0.05 DMA
Epoxies				
Duralith	Dural International Corporation	Low-temperature high-modulus high-strength epoxy	500-1,000	2 parts base/1 part hardener
Flexolith	Dural International Corporation	Low-temperature low-modulus high-early-strength epoxy	700-1,000	2 parts base/1 part hardener
Duralcast Conductive	Dural International Corporation	Conductive epoxy binder of thin-set terrazzo floors	>1,000	4 parts base/1 part hardener
Others				
60% MMA, -35% PMMA, -5% TMPTMA	Blended at BNL	Low-viscosity methyl methacrylate-based system	225	4.7 BPO/1.0 DMA, 0.05 DMT
55.5% Sty, -4.5% PSty, -40% TMPTMA	Blended at BNL	Low-viscosity styrene-based system	10-15	2.5 BPO, 0.5 AIBN/ 1.0 DMA (oven cured at 90° C)

Note: MEKP = methyl ethyl ketone peroxide, CoN = cobalt naphthenate, BPO = benzoyl peroxide, DMA = dimethyl aniline, DMT = dimethyl-p-toluidine, AIBN = azobis (isobutyronitrile), MMA = methyl methacrylate, PMMA = poly(methyl methacrylate), TMPTMA = trimethylolpropane trimethacrylate, Sty = styrene, Psty = polystyrene.

TABLE 2 Summary of Conductive Fillers Evaluated

Filler	Manufacturer
Carbon blacks	
Statex 160	Cities Service Company
Statex M 568	Cities Service Company
Statex MT	Cities Service Company
Conductex SC	Cities Service Company
Ketjenblack EC	Armack Company
Coke breeze	
Shamokin coke breeze	Shamokin Filler Company
Calcined coke breeze	
Asbury 4335	Asbury Graphite Mills
Loresco DW1	Catholic Engineering Equipment
Loresco DW2	Catholic Engineering Equipment
Loresco SWK	Catholic Engineering Equipment
Acetylene black	
Shawinigan acetylene black	Shawinigan Products
Gulf acetylene black-50	Gulf Oil Chemicals Company
Fibers	
Magnamite graphite fibers, Type AS, 1/4 in. and 0.44 in. long	Hercules, Inc.
Others	
Austin Black 325 bituminous fine black	Slab Fork Coal Company
Silicon carbide grit, 150RA	Union Carbide
Graphite powder (grade 38)	Fischer Scientific

TABLE 3 Resistivity Test Results for Various Filler Systems

Filler	Mix Proportions (wt%)		Resistivity (ohm-cm)
	Resin ^a	Filler	
Carbon blacks			
Statex 160	76	24	18,500
Statex M 568	72	28	3,360
Statex MT	55	45	>20,000,000
Conductex SC	85	15	1,480
Ketjenblack EC	95	5	2,970
Coke breeze			
Shamokin	33	67	3.02
Calcined coke breeze			
Asbury 4335	26	74	0.85
Loresco DW1	30	70	0.99
Loresco DW2	30	70	1.01
Loresco SWK	30	70	0.59
Acetylene black			
Shawinigan	88	12	310
Gulf-50 compression	95	5	2,500
Fibers			
Magnamite graphite fibers, type AS, 1/4 in.	94	6	2.48
Others			
Austin Black 325, bituminous fine black	55	45	>20,000,000
Silicon carbide grit, 150RA	31	69	>20,000,000
Graphite powder (grade 38)	63	37	1,510

^aLB183-13 polyester with 1.2 wt% MEKP initiator and 0.5 wt% CoN promoter.

overlays and was eliminated from further consideration in this program. The Loresco DW2 was basically the same as the DW1 except that it was designed for pumping applications, so it also was eliminated. Therefore, it was decided to evaluate the Asbury 4335 and the Loresco DW1 calcined coke breezes as the primary electrically conductive fillers.

Resin Systems

A total of 18 resins, described in Table 1, were used in conjunction with Asbury 4335 calcined coke breeze to make electrically conductive composites. A mix proportion of 30 percent by weight of resin and 70 percent by weight of filler was used wherever possible to make the conductive composites. The test results are summarized in Table 4.

The electrical resistivity values varied from 0.70 to 65.71 ohm-cm, with 12 of the 18 systems exhibiting resistivity values of <5 ohm-cm. The Polylyte 90-570 orthophthalic polyester resin had the lowest resistivity at 0.70 ohm-cm. In general, all the polyesters and vinyl esters that were tested, with the exception of LB802-6, can be used to make electrically conductive polymer concrete with a resistivity of <5 ohm-cm.

Evaluation of Multiple-Layer Conductive Overlay Systems

Determination of Layers Required for Conductive Overlays

Resistivity tests were performed to determine the optimum number of layers of conductive filler required to make an electrically conductive overlay. Two resins were used in this study: LB183-13 polyester and the DPV-701 vinyl ester. Each overlay consisted of five applications of Asbury 4335 calcined coke breeze and resin; the resistivity was measured after the placement of each successive layer. The overlays were allowed to cure for a mini-

TABLE 4 Resistivity Test Results for Various Resin Systems

Resin	Mix Proportions (wt%)		Resistivity ^b (ohm-cm)
	Resin	Filler ^a	
Orthophthalic polyesters			
LB183-13	30	70	0.87
MR11044	30	70	0.97
LB802-6	30	70	9.26
MR15031-I	30	70	0.87
Polylyte 90-570	30	70	0.70
Hetron 197A	30	70	2.14
Isophthalic polyesters			
Polylyte 98-507	30	70	1.37
Aropol 7532	30	70	2.02
Dural 370	30	70	0.79
Quick Deck	37	63	2.00
Vinyl esters			
Epocryl DPV-701	30	70	1.20
Derakane 411-C50	30	70	1.12
Derakane XD-8084-05	30	70	1.14
Epoxies			
Duralith	30	70	30.62 ^c
Flexolith	30	70	50.78 ^c
Duralcast Conductive	27	73	14.34 ^c
Others			
MMA-based system ^d	30	70	65.71 ^c
Styrene-based system ^d	30	70	— ^e

^aAsbury 4335 calcined coke breeze.

^bResistivity measured by using test circuit method unless otherwise noted.

^cResistivity = resistance (ohms) \times 2.1 cm (resistivity constant).

^dRefer to Table 1 for monomer formulation.

^eToo high to be measured with available test equipment.

mum of 4 hr before the resistivity was measured. The results are graphically presented in Figure 3. The test results indicate that the resistivity values of the overlay made with LB183-13 are fairly constant beyond two layers of conductive filler. The vinyl ester DPV-701, on the other hand, is slightly more variable and it appears that at least three layers are necessary for adequate performance as a conductive overlay.

Evaluation of Multiple-Layer Conductive Overlays by Using Asbury 4335 or Loresco DW1 Calcined Coke Breeze

In the initial studies, conductive PC mortars made with Asbury 4335 or Loresco DW1 calcined coke breeze had essentially the same resistivity values. Studies were made with both fillers in multiple-layer overlays. The overlays were made by using the LB183-13 polyester and the DPV-701 vinyl ester. The results, as shown in Figure 4, indicate that the resistivities of overlays made with the Asbury 4335 calcined coke breeze are slightly lower than those made with the Loresco DW1 calcined coke breeze. Therefore, the rest of the work in this program was done with the Asbury 4335 calcined coke breeze.

Electrical Resistivity Values of Several Multiple-Layer Overlay Systems

The original resistivity tests were made on premixed mortars by using various resins. Evaluations of similar systems were made on multiple-layer overlays. In general, each overlay consisted of three layers of Asbury 4335 calcined coke breeze and two layers of No. 2 silica sand to provide a skid-resistant surface for the overlay. Resistivity values were obtained after each layer had cured for a minimum of 4 hr. The test results are summarized in Table 5. The resistivities of five of these systems varied from 0.86 to 2.81 ohm-cm: LB183-13, MR11044, Polylyte

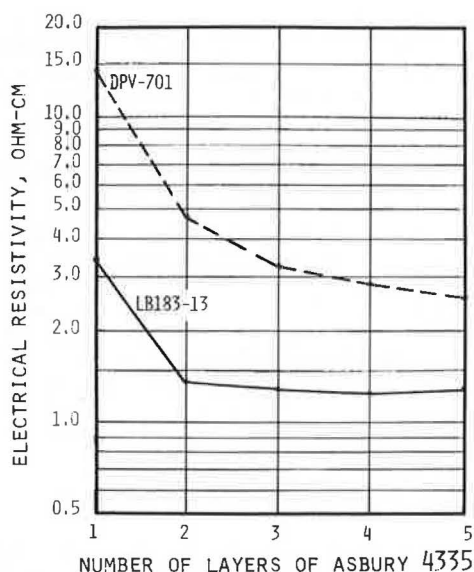


FIGURE 3 Variation of electrical resistivity with number of layers of Asbury 4335 calcined coke breeze.

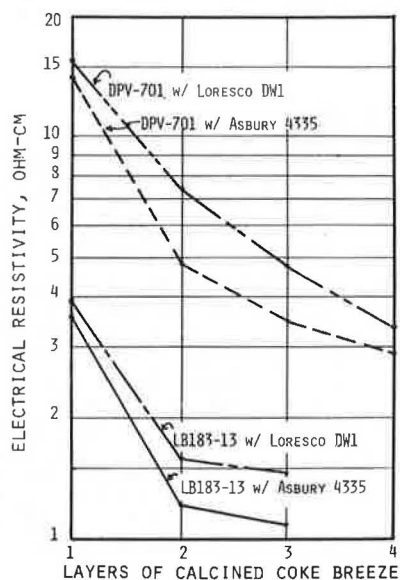


FIGURE 4 Electrical resistivity values of overlays made with Asbury 4335 and Loresco DW1 calcined coke breeze.

TABLE 5 Resistivity Test Results for Various Built-Up Systems

Resin	Electrical Resistivity (ohm-cm) by Layer ^a				
	1	2	3	4	5
Orthophthalic polyesters					
LB183-13	3.62	1.22	1.01	1.32	1.26
MR11044	1.33	1.16	0.94	1.02	1.01
Polylite 90-570	2.17	1.32	1.23	1.49	1.46
Isophthalic polyesters					
Polylite 98-507	11.13	6.86	6.46	21.03	27.27
Aropol 7532	1.53	0.88	0.89	0.88	0.86
Dural 370	21.08	3.97	6.98	25.54	66.69
Vinyl esters					
Epocryl DPV-701	14.15	4.69	3.25	2.93	2.81
Derakane XD-8084-05	18.86	22.64	5.53	8.21	7.58

^aFirst three layers were placed by using Asbury 4335 calcined coke breeze. The fourth and fifth layers were placed by using No. 2 silica sand.

90-570, and Aropol 7532 polyesters and the DPV-701 vinyl ester. The resistivity of the Derakane XD-8084-05 vinyl ester was 7.58 ohm-cm, and those of the Polylite 98-507 and Dural 370 vinyl esters were 27.27 and 66.99 ohm-cm, respectively. Both the Polylite 98-507 and the Dural 370 polyesters are difficult to fully cure in thin layers, which is probably why their resistivities were so high.

Evaluation of Premixed Electrically Conductive Mortars

Resistivity Versus Resin Content

Electrically conductive PC mortars were made with Asbury 4335 calcined coke breeze and LB183-13 polyester resin. The resin content was varied from 75 to 25 percent by weight for the total mix. The results presented in Table 6 indicate that resin contents of 25 to 40 percent by weight all produce conductive composites with resistivities of <5 ohm-cm. The recommended mix is 30 percent by weight of resin and 70 percent by weight of filler; these proportions produce a workable mixture that does not show any excess resin upon curing.

TABLE 6 Variation of Electrical Resistivity with Resin Content

Mix Proportions (wt%)		
Resin ^a	Filler ^b	Resistivity (ohm-cm)
100	0	>19,000,000
75	25	>19,000,000
60	40	>19,000,000
55	45	47.31
50	50	8.17
40	60	1.34
35	65	1.17
32	68	0.83
30	70	0.80
28	72	0.54
25	75	0.89

^aLB183-13 polyester.

^bAsbury 4335 calcined coke breeze.

Resistivity of Mixed Filler Systems

Although calcined coke breeze filler composites have excellent electrical resistivity properties, their physical properties are poor. To improve their physical properties without destroying their electrical properties, studies were made on mixed filler systems. Silica sand was used to replace a portion of the calcined coke breeze and these composites were tested for both compressive strength and electrical resistivity. The test results of the blended filler systems are summarized in Table 7 and in Figure 5.

Test results indicate that the higher the coke breeze content, the lower the electrical resistivity. Coke breeze contents of >40 percent by weight are required to obtain resistivity values of <5 ohm-cm. Compressive strengths of ~4,300 psi were measured for coke breeze contents up to 60 percent, whereas compressive strengths for composites containing more than 60 percent coke breeze average only 3,500 psi.

On the basis of these results, a filler system containing 50 percent by weight of Asbury 4335 calcined coke breeze and 50 percent by weight of blended silica sand was selected for further evaluation as a conductive overlay.

TABLE 7 Electrical Resistivity Test Results for Composites Made with Blended Filler Systems

Filler Content (wt%)		
Sand	Coke Breeze ^a	Resistivity (ohm-cm)
100	0	>19,000,000
90	10	>19,000,000
80	20	>19,000,000
75	25	186.54
70	30	23.78
60	40	6.81
52	48	3.32
50	50	2.39
40	60	1.90
30	70	1.40
20	80	1.05
0	100	0.80

Note: Composite consists of 30 wt% LB183-13 polyester and 70 wt% blended filler.

^aAsbury 4335 calcined coke breeze.

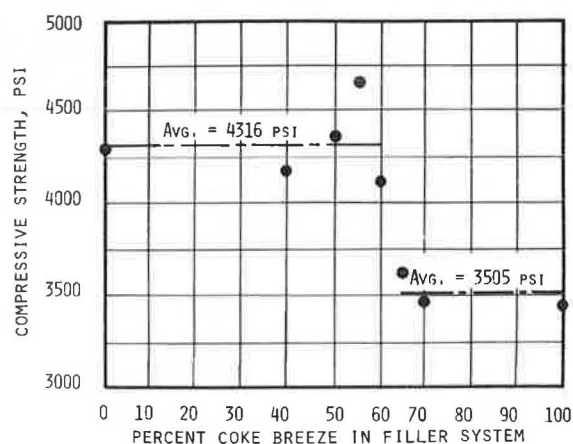


FIGURE 5 Compressive strengths of premixed mortars.

Evaluation of Electrical Resistivity of Premixed Mortars with Various Resins

Tests were done to evaluate the electrical resistivity of premixed mortar systems made with various resins. The mortar generally contained 20 percent by weight of resin and 80 percent by weight of blended filler. The blended filler used consisted of 50 percent by weight of Asbury 4335 calcined coke breeze and 50 percent by weight of blended silica sand. The test results are summarized in Table 8.

TABLE 8 Electrical Resistivity Values of Premixed Conductive Mortars

Resin	Resin Content (wt%)	Electrical Resistivity (ohm-cm)
Orthophthalic polyesters		
LB183-13	20	4.7
MR11044	20	4.0
Polylite 90-570	20	4.4
Isophthalic polyesters		
Polylite 98-507	20	3.4
Aropol 7532	30	2.0
Dural 370	20	3.7
Vinyl esters		
DPV-701	20	10.5
XD-8084-05	22	4.2

Note: Filler consisted of 50 wt% Asbury 4335 calcined coke breeze, 50 wt% blended silica sand, 2.0 wt% TiO₂ colorant.

The resistivities of the mortars varied between 2.0 and 10.5 ohm-cm, with the Aropol 7532 polyester composite exhibiting the lowest resistivity and the DPV-701 vinyl ester composite exhibiting the highest.

Evaluation of Electrical and Mechanical Properties of Multiple-Layer and Premixed Overlays

A series of tests was made to evaluate multiple-layer and premixed electrically conductive PC overlays with six different resin systems. Properties that were measured include electrical resistivity, shear bond strength, freeze-thaw durability, flexural modulus of elasticity, thermal coefficient of expansion, and the compressive strength of the premixed mortars. The test results are presented in Tables 9-11.

Electrical Resistivity

The electrical resistivities of the multiple-layer overlays varied from 2.3 to 66.7 ohm-cm; the LB183-13 resin was the lowest and the Dural 370 resin was the highest.

The electrical resistivities of the premixed overlays varied between 3.4 and 10.5 ohm-cm. The DPV-701 vinyl ester had the highest resistivity, and the Polylyte 98-507 isophthalic polyester had the lowest.

Shear Bond Strength

The shear bond strength of overlays measured at the interface of the concrete substrate and the overlay should be higher than the shear strength of the base concrete (400 to 500 psi) if the overlay is to perform satisfactorily.

The shear bond strengths for the multiple-layer overlays varied between 392 and 691 psi, whereas the bond strengths of the premixed overlays varied from 928 to 1,370 psi. The bond strengths exhibited by the premixed overlays were all 50 to 100 percent higher than those of the multiple-layer overlays. This is because the coke breeze filler in the multiple-layer overlays is physically much weaker than the blended filler system used in the premixed overlay. Also, the filler in the premixed system "wets out" better and is more uniformly distributed; thus it attains better bonding characteristics.

Freeze-Thaw Durability

Freeze-thaw durability was evaluated according to ASTM C666 and ASTM C672. Generally, the rapid freeze-thaw cycling of ASTM C666 will show greater bond strength reductions than the slow cycling of ASTM C672.

The multiple-layer overlays made with Polylyte 98-507 and the Dural 370 polyesters and the XD-8084-05 vinyl ester exhibited the best durability characteristics. Of the premixed overlays, the XD-8084-05 vinyl ester also exhibited the best durability characteristics.

Flexural Modulus of Elasticity

With one exception, the flexural modulus of elasticity of the multiple-layer overlays was lower than that of the premixed overlays. The modulus varied from 112,000 psi for the Dural 370 polyester to 1,442 psi for the XD-8084-05 vinyl ester in the multiple-layer overlays. In the premixed overlays,

the PolyLite 98-507 polyester had the lowest modulus, 243,000 psi, which compares with a high of 734,000 psi for the DPV-701 vinyl ester.

In general, lower-modulus overlays have had a better history of not disbonding from concrete bridge decks owing to their ability to flex with the deck itself under moving traffic loads.

Thermal Coefficient of Expansion

The coefficient of expansion of portland cement concrete varies from 5.0 to 6.0×10^{-6} in./in. ($^{\circ}\text{F}^{-1}$). The coefficient of expansion of the electrically conductive PC overlays studied varies from 11.3 to 22.4×10^{-6} in./in. ($^{\circ}\text{F}^{-1}$). The multi-

TABLE 9 Properties of Built-Up and Premixed Electrically Conductive Overlays: Orthophthalic Resins

Property	LB183-13		PolyLite 90-570	
	Built Up	Premixed	Built Up	Premixed
Electrical resistivity (ohm-cm)	2.3	4.7	3.3	4.4
Shear bond strength (psi)	598	1,724	691	1,370
Freeze-thaw durability bond strength (psi)				
After 100 rapid cycles	411	—	—	—
After 200 rapid cycles	464	—	—	—
After 25 slow cycles	—	—	—	—
After 50 slow cycles	433	—	495	—
Flexural modulus of elasticity (psi)	437,700	702,800	447,200	628,800
Thermal coefficient of expansion [in./in. ($^{\circ}\text{F}^{-1}$)]	19.4×10^{-6}	13.3×10^{-6}	17.0×10^{-6}	14.8×10^{-6}
Compressive strength (psi)				
Initial	—	7,917	—	6,783
After 100 rapid cycles freeze-thaw	—	8,132	—	7,013

Note: Built-up overlays consist of two to three layers of Asbury 4335 calcined coke breeze and two to three layers of sand. The premixed overlays, with two exceptions, consisted of 20 wt% resin and 80 wt% blended filler. Aropol 7532 overlays consisted of 30 wt% resin and 70 wt% blended filler and the XD-8084 overlays consisted of 22 wt% resin and 78 wt% blended filler. All values presented in this table are averages for all the data collected for each overlay system throughout the program and, as a result, may vary with data reported for specific tests.

TABLE 10 Properties of Built-Up and Premixed Electrically Conductive Overlays: Vinyl Ester Resins

Property	Epocryl DPV-701		Derakane XD-8084-05	
	Built Up	Premixed	Built Up	Premixed
Electrical resistivity (ohm-cm)	7.8	10.5	7.6	4.2
Shear bond strength (psi)	677	945	680	1,016
Freeze-thaw durability bond strength (psi)				
After 100 rapid cycles	553	—	—	—
After 200 rapid cycles	607	—	—	—
After 25 slow cycles	—	—	581	1,066
After 50 slow cycles	577	—	667	1,247
Flexural modulus of elasticity (psi)	267,000	734,200	1,442,000	632,000
Thermal coefficient of expansion [in./in. ($^{\circ}\text{F}^{-1}$)]	14.8×10^{-6}	12.2×10^{-6}	11.3×10^{-6}	15.6×10^{-6}
Compressive strength (psi)				
Initial	—	6,313	—	6,713
After 100 rapid cycles freeze-thaw	—	6,544	—	7,719

Note: Built-up overlays consist of two to three layers of Asbury 4335 calcined coke breeze and two to three layers of sand. The premixed overlays, with two exceptions, consisted of 20 wt% resin and 80 wt% blended filler. Aropol 7532 overlays consisted of 30 wt% resin and 70 wt% blended filler and the XD-8084 overlays consisted of 22 wt% resin and 78 wt% blended filler. All values presented in this table are averages for all the data collected for each overlay system throughout the program and, as a result, may vary with data reported for specific tests.

TABLE 11 Properties of Built-Up and Premixed Electrically Conductive Overlays: isophthalic Resins

Property	PolyLite 98-507		Dural 370	
	Built Up	Premixed	Built Up	Premixed
Electrical resistivity (ohm-cm)	27.3	3.4	66.7	3.7
Shear bond strength (psi)	495	980	392	928
Freeze-thaw durability bond strength (psi)				
After 100 rapid cycles	—	—	—	—
After 200 rapid cycles	—	—	—	—
After 25 slow cycles	497	898	407	747
After 50 slow cycles	492	831	432	785
Flexural modulus of elasticity (psi)	199,000	243,000	112,000	393,000
Thermal coefficient of expansion [in./in. ($^{\circ}\text{F}^{-1}$)]	17.5×10^{-6}	15.0×10^{-6}	22.4×10^{-6}	16.3×10^{-6}
Compressive strength (psi)				
Initial	—	4,117	—	4,175
After 100 rapid cycles freeze-thaw	—	4,438	—	4,494

Note: Built-up overlays consist of two to three layers of Asbury 4335 calcined coke breeze and two to three layers of sand. The premixed overlays, with two exceptions, consisted of 20 wt% resin and 80 wt% blended filler. Aropol 7532 overlays consisted of 30 wt% resin and 70 wt% blended filler and the XD-8084 overlays consisted of 22 wt% resin and 78 wt% blended filler. All values presented in this table are averages for all the data collected for each overlay system throughout the program and, as a result, may vary with data reported for specific tests.

ple-layer overlays generally had a higher coefficient of expansion than the premixed overlays. This is generally because the resin content of multiple-layer overlays is higher than that in premixed overlays.

Compressive Strength of Premixed Overlays

The compressive strength of the premixed mortars used to make the electrically conductive overlays varied from 6,300 to 7,900 psi. None of the mortars tested showed any reductions of strength after being subjected to 100 freeze-thaw cycles.

Multiple-Layer Conductive Overlays in Active CP Systems

Two multiple-layer overlays were placed on reinforced-concrete slabs 4 ft x 4 ft x 8 in. thick. The slab and overlay configurations are shown in Figure 6. Each slab contained two anode slots and two mats of reinforcing steel, each of which was welded to ensure positive electrical connections.

Multiple-layer overlays with LB183-13 polyester resin and DPV-701 vinyl ester resin with Asbury 4335 calcined coke breeze were placed on the slabs. The mortar mix for the anodes consisted of 24 percent by weight of resin, 38 percent by weight of Asbury 4335 calcined coke breeze, and 38 percent by weight of blended silica sand. The primary anode wire was 0.031-in.-diameter copper-core wire clad with niobium platinum. Copper plate electrodes were incorporated into each overlay to facilitate the measurement of the electrical resistivity of the overlays. Power was supplied to each system by using a constant-current variable-voltage power supply.

The CP systems were operated for 1 year, during which time current density, operating voltage, "instant off" electrical potentials, electrical resistivity, and shear bond strengths were measured periodically to evaluate the performance characteristics of each overlay. The data are summarized in Tables 12 and 13.

The CP systems were initially activated at a current density of 2.9 mA/ft² of concrete surface area or 5.2 mA/ft² of reinforcing-steel surface

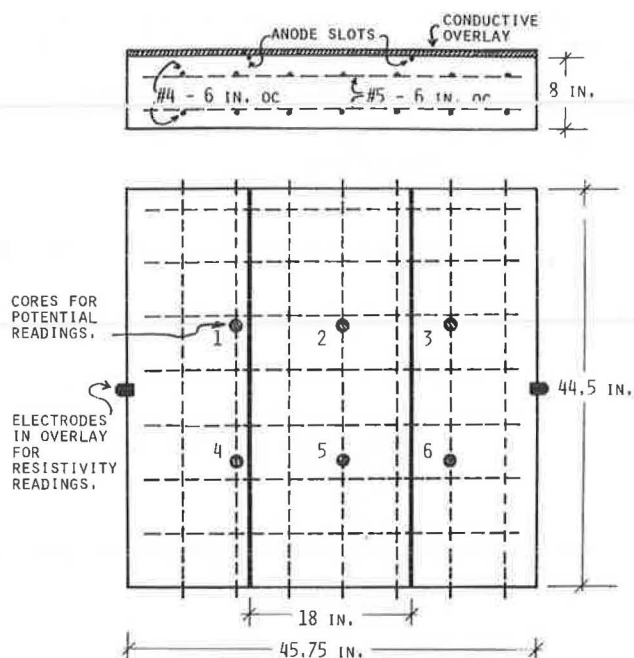


FIGURE 6 Large-scale test slabs.

area. Over the first 6 weeks, the current density was reduced to 2.12 mA/ft² of concrete surface area to keep the shift in rebar potential essentially constant.

Cores were taken periodically to measure any change in overlay bond strength. After 1 year of active operation, the bond strengths of both overlays were reduced by 32 percent. Visual examination of the LB183-13 overlay at the end of the year did not reveal any disbondment or deterioration. The overlay made with the DPV-701, however, had delaminations over ~2 percent of its surface area. These delaminations were characterized by a black discoloration at the overlay surface. In addition, coke breeze layers with the delaminated regions appeared to be partially disintegrated.

TABLE 12 Large-Scale Overlay Test: Slab EC356

Total Operating Time	Operating Current (mA)	Operating Voltage (V)	Avg "Instant Off" (V) ^a	Electrical Resistivity (ohm-cm)	Bond Strength (psi)	Ambient Temperature (°F)
0	—	—	-0.142	2.4	523	43
48 hr	40 ^b	26.6	-0.545	—	—	53
2 wk	40	17.7	-0.618	—	—	48
3 wk	35 ^c	13.9	-0.619	—	—	48
4 wk	35	8.0	-0.609	2.5	—	58
5 wk	30 ^d	11.1	-0.605	—	—	49
6 wk	30	9.1	-0.607	2.5	436	53
CP system shut down for 30 days, then restarted						
7 wk	30	5.6	-0.586	2.1	—	63
8 wk	30	2.8	-0.573	—	—	70
12 wk	30	4.0	-0.594	2.6	—	78
14 wk	30	4.3	-0.593	—	—	75
18 wk	30	3.3	-0.589	3.7	—	85
22 wk	30	3.6	-0.604	—	—	76
6 mo	30	7.5	-0.625	2.8	400	63
9 mo	30	11.2	-0.672	3.2	210	34
1 yr	30	6.5	-0.700	3.8	357	39

Note: Overlay made by using LB183-13 polyester and consisting of two noncompacted layers of Asbury 4335 calcined coke breeze and two noncompacted layers of No. 2 silica sand.

^aPotentials measured in reference to CSE half-cell.

^b40 mA = 2.90 mA/ft² of concrete surface area.

^c35 mA = 2.48 mA/ft² of concrete surface area.

^d30 mA = 2.12 mA/ft² of concrete surface area.

TABLE 13 Large-Scale Overlay Test: Slab EC357

Total Operating Time	Operating Current (mA)	Operating Voltage (V)	Avg "Instant Off" (V) ^a	Electrical Resistivity (ohm-cm)	Bond Strength (psi)	Ambient Temperature (°F)
0	—	—	-0.124	8.0	583	43
48 hr	40 ^b	24.0	-0.541	—	—	53
2 wk	40	16.4	-0.610	—	—	48
3 wk	35 ^c	12.2	-0.609	—	—	48
4 wk	35	6.6	-0.628	7.9	—	58
5 wk	30 ^d	8.7	-0.616	—	—	49
6 wk	30	7.3	-0.610	7.3	474	53
CP system shut down for 30 days, then restarted						
7 wk	30	5.0	-0.580	7.4	—	63
8 wk	30	2.6	-0.550	—	—	70
12 wk	30	3.8	-0.596	7.6	—	78
14 wk	30	4.3	-0.593	—	—	75
18 wk	30	3.3	-0.581	6.9	—	85
22 wk	30	3.7	-0.595	—	—	76
6 mo	30	8.2	-0.622	8.2	509	63
9 mo	30	12.0	-0.662	9.3	514	34
1 yr	30	7.0	-0.667	8.9	392	39

Note: Overlay made by using DPV-701 vinyl ester and consisting of three noncompacted layers of Asbury 4335 calcined coke breeze and two noncompacted layers of No. 2 silica sand.

^aPotentials measured in reference to CSE half-cell.

^b40 mA = 2.90 mA/ft² (31.3 mA/m²) of concrete surface area.

^c35 mA = 2.48 mA/ft² (26.9 mA/m²) of concrete surface area.

^d30 mA = 2.12 mA/ft² (22.9 mA/m²) of concrete surface area.

CONCLUSIONS AND RECOMMENDATIONS

Multiple-layer electrically conductive PC overlays have been made by using conductive fillers. Resistivity of such overlays varies from 1 to 8 ohm-cm depending on the type of resin used and the number of conductive layers applied. Studies of such overlays with an operating CP system indicate that the bond strength of the overlay to the concrete substrate is reduced by 32 percent within 1 year of operation.

On the basis of physical and mechanical properties, three resin systems show the greatest promise for use in multiple-layer overlays. These resins are LBL83-13 and PolyLite 90-570 polyesters and DPV-701 vinyl ester. The electrical resistivities of these overlays average 2.3 to 7.8 ohm-cm with initial bond strengths of 600 to 700 psi.

The major disadvantage of multiple-layer conductive overlays appears to be the inherent weakness of the calcined coke breeze. In addition, the calcined coke breeze appears to be subject to deterioration due to oxidation from the gases emitted during operation of the CP system.

The premixed electrically conductive PC overlays appear to be more promising at this time. They exhibit bond strengths that are 50 to 100 percent higher than those of multiple-layer overlays. In addition, they appear to have better freeze-thaw durability and more reliable curing characteristics. The filler particles are coated better in premixed systems and therefore should be less subject to deterioration due to off-gassing of the concrete when it is under an operating CP system. Although the electrical resistivities (3 to 10 ohm-cm) of premixed conductive overlays are slightly higher than those of multiple-layer overlays, they are still low enough to operate in CP systems.

The major emphasis of this study was on multiple-layer overlays, and it is believed that additional research work is necessary to obtain such information on premixed overlays as curing shrinkage, placement techniques, skid resistance, and performance under actual traffic conditions.

The two resin systems that would be recommended for premixed overlays are PolyLite 90-570 polyester and XD-8084-05 vinyl ester. In addition, both the

PolyLite 98-507 and Dural 370 isophthalic polyesters should also be considered for premixed conductive overlay systems.

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Bridge Deck Rehabilitation by Using Cathodic Protection with a Low-Slump Concrete Overlay

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ABSTRACT

The design and construction of a state-of-the-art cathodic protection system for a reinforced-concrete bridge deck by the Minnesota Department of Transportation is described. The bridge selected was the 42nd Street Bridge (Bridge 9616) over I-35W in South Minneapolis. The system selected was a distributed-anode system with a low-slump concrete overlay as a wearing surface. The system was constructed in the summer of 1983. The cathodic protection system has primary and secondary anodes for current distribution. A primary anode system of platinized niobium wire placed transversely across the bridge feeds a secondary anode system of carbon strands placed longitudinally on the bridge. Both the wire and the strands are covered with conductive polymer concrete. Power from a rectifier is supplied to the anodes through a conduit running along the north crash rail of the bridge. Rehabilitation of the bridge was completed in 30 working days, and the system was activated in December 1983.

In 1982 the Minnesota Department of Transportation decided to pursue the design and construction of a state-of-the-art cathodic protection system for a bridge deck rehabilitation. This project was to be undertaken with the participation of the Demonstration Projects Division of FHWA as part of Demonstration Project 34, Cathodic Protection.

Minnesota had previously placed an early design of cathodic protection. This system was placed in 1975 on the Duluth Street Bridge on Trunk Highway (T.H.) 100 (Bridge 27002) in Golden Valley. This system utilized a conductive coke breeze layer stabilized with asphalt and containing the cathodic protection hardware covered by an asphalt overlay as a wearing surface (Figure 1). Because of the instability of the conductive coke layer, the asphalt wearing surface showed distress and was reconstructed in 1981 by cold milling off 1 in. of the original overlay and replacing that with 2 in. of new material. By 1983 the wearing surface once again exhibited surface distress. Although the cathodic protection system had functioned satisfactorily, it was

believed that an updated design might provide a more stable wearing surface.

After an investigation of bridges slated for rehabilitation, it was decided to contract for the design and construction of a cathodic protection system on the 42nd Street Bridge over I-35W in South Minneapolis. The designer selected was Kenneth Clear of Kenneth C. Clear, Incorporated. The rehabilitation contract was awarded to the low bidder, Arcon Construction Company of Mora, Minnesota. Egan McKay Electric of Minneapolis was the subcontractor.

It was decided to use a distributed-anode cathodic protection system on the bridge with a low-slump concrete overlay for the wearing surface.

BACKGROUND

The 42nd Street Bridge (Bridge 9616) over I-35W in South Minneapolis was constructed in 1964. The bridge is a precast concrete beam span made up of four spans