

Laboratory Evaluation of Generic Concrete Sealer and Coating Systems

LUH-MAAN CHANG

Research was conducted to evaluate generic types of sealer and coating systems for use on nonwearing concrete surfaces in Indiana. Although significant variations exist among six generic classes of coating systems subject to accelerated weathering, water absorption and vapor transmission, and rapid chloride ion permeability tests, certain generic chemical formulations of coating systems appear to exhibit comparatively better performance than others. The epoxies were comparatively better barriers to chloride and water absorption but deteriorated and discolored slightly in the accelerated weathering test. The straight penetrants (straight silanes, silicone, and siloxane) were relatively good in terms of their ability to resist water and chloride absorption and showed little sign of deterioration in the weathering test. The materials that were combinations of the above penetrants did not perform as well as the straight penetrants. Masonry coatings were ineffective chloride barriers, but they did have aesthetic qualities. The urethane and methyl methacrylate did not perform consistently across all tests.

The deterioration of concrete structures is accelerated when damaging chemical substances and moisture are allowed to penetrate the concrete. In recent years, attempts to eliminate this problem have been made by applying surface coatings and sealers to the concrete. Although use of sealers and coatings has met with varying degrees of success, it is not uncommon for them to cause earlier failure and uneven discoloration of the concrete surface, thereby degrading the aesthetics of the structure (1,2). In addition, new coating systems emerge on the market almost every day. Many highway engineers continually face the challenge of selecting a proper coating system for construction projects.

Research was conducted at Purdue University to evaluate generic types of sealer and coating systems for use on nonwearing concrete surfaces in Indiana (3). The effectiveness of different surface sealers and coatings when applied on nonwearing concrete surface and subjected to different laboratory experiments was studied. Effectiveness was established by determining if these materials could minimize or prevent the intrusion of chloride ions into the concrete while maintaining structural and aesthetic integrity. The purpose of this paper is to present the research results and methodologies.

The paper will begin with a discussion of the methodology used in the research. Three different types of laboratory ex-

periments will be illustrated. The analysis of the experimental data will be explained, and the results will be presented.

RESEARCH METHODOLOGY

A literature search was completed at Purdue University using *Thomas' Register* and *Sweets Manual* to identify the promising sealers and coatings for experimental tests and testing methods. Information and literature received from the Florida, Illinois, Indiana, Kentucky, Ohio, Tennessee, and Texas state departments of transportation were also reviewed. This review revealed the concrete sealers and coatings currently used by those states. A questionnaire regarding the technical data of concrete sealers was sent to 119 chemical companies. Product information received from 54 suppliers of coatings was analyzed. Of the 54 chemical companies that responded, 42 companies suggested 120 different materials.

After the information and literature received from the departments of transportation and the surrounding states was reviewed, 24 coatings or penetrants were selected from different chemical companies; they generally include all of the generic types of materials in use most widely. The selected materials for evaluation in this project are listed in Table 1. The reader should be aware that solids and ingredients are the same, but different material manufacturers use different names for them. They are the elements of the material composition that are left behind and constitute the dryfilm after drying. There are also differences in definition among sealers, coatings, and penetrants. However, they are used interchangeably here.

These materials were classified into six general groups. The first group includes all of the epoxies. This group contains epoxies with varying percent of solids, ranging from 20 to 100 percent (tests 1–4 and 25). The second group includes all four of the silanes, a silicone, and a siloxane (tests 7–11 and 14). The third group contains the siloxane/silicone mixture, the polysiloxane/hydrophobic-fumed silica, and the blend of many silanes (tests 15, 18, and 21). The fourth group includes all seven of the masonry coatings (tests 16, 19, 20, and 22–24). Test 17 was masonry coating. After trial rapid permeability test, it was removed from the study. The fifth group contains urethanes (tests 5 and 6). The last is methyl methacrylates (tests 12 and 13).

Three laboratory experiments were conducted on the selected penetrants and coatings: water absorption and vapor transmission test, accelerated weathering test, and rapid chlo-

TABLE 1 MATERIALS SELECTED FOR TESTING

Test No.	Chemical Composition	Percent Solids/ Ingredients	Penetrant or Coating
1	Epoxy (polyamine)	50	P
2	Epoxy (polyamine)	20	P
3	Epoxy (polysulfide)	50	P
4	Epoxy (polyamine)	50	P
5	Chemically-Cured Urethane	55	C
6	Moisture-Cured Urethane	30	P
7	Alkyl-Alkoxy Silane	40	P
8	Alkyl-Alkoxy Silane	<20	P
9	Alkyl-Alkoxy Silane	20	P
10	Alkyl-Alkoxy Silane	40	P
11	Silicone	5	P
12	Methyl Methacrylate with Silane Primer	20	P
13	Methyl Methacrylate	30	P
14	Siloxane	20	P
15	Silaxane/Silicone Mixture	10	P
16	Styrene/Acrylic Copolymer	75	C
18	Blend of Silanes	30	P
19	Vinyl Acrylic Latex	58	C
20	Polyester Resin	60	C
21	Poly-Siloxane/Hydrophobic Fumed Silica	7	P
22	Styrene/Acrylic Copolymer	61	C
23	Elastomeric Resin		C
24	Acrylic Resin		C
25	Epoxy	100	C

ride ion permeability test. The procedures for these three experiments are discussed in the following sections.

WATER ABSORPTION AND VAPOR TRANSMISSION TEST

Test Objectives

The objectives of this phase of the project were to evaluate the differences between water and chloride ion absorption for concrete coated with the 24 materials and then soaked in

saltwater solution (15 percent sodium chloride) and the water vapor permeability characteristics of these coated specimens during an air-drying period (4). The following parameters were evaluated: (a) water absorption-vapor transmission characteristics of surface-coated concretes and (b) chloride ion penetration into surface-coated concretes.

The less water absorbed by the concrete, the better the sealing ability of the concrete material. Conversely, the more water the coated concrete absorbed, the worse the sealing ability. In contrast, the more water transmitted out during the drying process the better because less water is trapped inside the concrete. Therefore, the higher the weight loss

or weight gain, the higher the sealing ability of the painted material.

Sample Preparations

Twenty-five 4-in. cubes and two control cubes were cast for testing. The molds for the 4-in. cubes were constructed of steel and were coated with a thin film of oil to allow for easy removal of the concrete cube after an adequate curing period. The fresh concrete was placed in the molds in approximately three equal layers. Each layer was compacted by rodding using 25 strokes with a 3/8-in.-diameter steel rod. The molds were then covered with a sheet of plastic to prevent excess drying on the surface.

The prepared concrete cubes were stored for 24 hr in a laboratory environment. At the end of the 24-hr period, the molds were opened and the samples were placed in lime-saturated water for the next 4 days. Soaking the cubes in the lime-saturated water helped prevent leaching of calcium hydroxide, which breaks down the internal structure and ultimately reduces the strength of the concrete. All six sides of the cubes were lightly sandblasted after the moisture curing period at an age of 5 days to remove any foreign materials that may have been present on the surfaces.

Test Procedures

The 24 cubes were coated at an age of 28 days after an air-drying period of 22 days.

The sealers and coatings were all applied at the rate of 100 ft²/gal. The reason for this was to try to eliminate as many variables as possible from the test in an effort to concentrate on the different paint materials. The amount of material for each cube was calculated using the weight of the material in pounds per gallon, the surface area of the cube, and the 100 ft²/gal coverage rate. The sealers and coatings were applied by brush. The cubes were then stored in a laboratory environment. Two control specimens were prepared with which to compare the coated cubes.

After the drying period for the coatings, the cubes were weighed and immersed in a 15 percent NaCl solution. The cubes were then at the age of 35 days.

All cubes were placed in a plastic container with approximately 6 gal of 15 percent NaCl solution. About an inch cover of the solution was maintained over the tops of the cubes. During the soaking period, the gain in the saturated surface dry cube weight after 3, 6, 9, 12, 15, 18, and 21 days of soaking was determined to the nearest 0.001 lb. Immediately after each weighing, the cubes were returned to the solution. The solution was stirred periodically to eliminate settling. After 21 days of soaking in the solution, each cube was removed from the water bath and moved to a climate-controlled room (70°F and around 65 percent relative humidity). They were stored on steel racks and moved periodically to reduce the effect of variations in air circulation. During the following 24-day air-drying period, the loss in weight at 3, 6, 9, 12, 15, 18, 21, and 24 days was determined by weighing to the nearest 0.001 lb. After the air-drying period, the cubes were moved to another environmentally controlled room for 12 more days (100°F and 20 percent relative humidity). The loss in weight

at 27, 30, 33, and 36 days was determined by weighing to the nearest 0.001 lb.

After the water absorption and vapor transmission testing, powder samples were taken from each of the 24 coated cubes and the 2 untreated control specimens. In order to extract the powder samples, two holes were drilled in opposite sides of each of the cubes. Three powder samples were taken from both of the holes in each cube, for a total of six samples from each cube. The first powder sample was taken at a depth of 1/2 in., the second at 1 in., and the third at 1 1/2 in. All six of the powder samples were tested for chloride content; the values were averaged together and are presented here. The total chloride content was determined using an acid-digestion potentiometric titration procedure.

ACCELERATED WEATHERING TEST

The objective of this test was to determine the influence of 14 weeks of accelerated laboratory weathering on the performance of sealers and coatings when applied to concrete. The performance was judged by making periodical visual observations of the surface conditions by measuring the chloride ion contents in the concrete at the end of the test and by measuring the gloss of the surface with a glossmeter every 2 weeks.

The accelerated weathering method used in this study was similar to the northern climate method described in NCHRP Report 244 (4). This accelerated weathering cycle was designed to expose the slabs to a wide range of environmental factors, including acid, saltwater, thermal heat, ultraviolet exposure, fresh water rinse, and overnight freezing and thawing.

Sample Preparation

Twenty-five concrete slabs and two control slabs were cast in wood frames coated with shellac for easy removal. The test slabs were 4-in. thick and 11-in. square. A dike about 1-in. high was formed on the test surface so that the saltwater could be pounded during testing.

The slabs were covered with a sheet of plastic and allowed to cure for 1 day in a laboratory environment. After curing, the slabs were stripped from their forms and transferred to a moisture curing room for 4 additional days. At the end of this curing period, the slabs were lightly sandblasted to remove any foreign material.

The slabs were allowed to air dry in a laboratory environment for different lengths of time. The sealers and coatings were then applied according to the manufacturers' recommendations. Nine samples were coated at the age of 7 days, 3 at the age of 14 days, 2 at the age of 21 days, and 11 at the age of 28 days. The amount of material for each slab was calculated using the weight of the material in pounds per gallon, the recommended coverage rates, and the surface area of the slabs. The sealers and coatings were applied by brush in a laboratory environment. The second coat, if required, was applied after 24 hr. The slabs were then stored in a laboratory environment for 7 days.

Ultraviolet Light Apparatus

The monthly total for normal ultraviolet radiation (with wave lengths from 2950 to 3950 Å) for winter months in Indianapolis is approximately 2460 W-hr/m²/month. The ultraviolet source used during this phase of the testing consisted of a standard 48-in.-long fluorescent fixture with two 40-W ultraviolet lamps (W-F40BL) on the fixture. Four slabs were positioned 9 in. under two fixtures, which provided 14 to 18 W/m².

By using average values of monthly winter and summer ultraviolet radiation for northern regions along with the average number of hours of daylight per month, 166.7 W-hr/m²/day was calculated to be the approximate normal radiation from the sun for a typical yearly average day. This value was taken from NCHRP Report 244 (4).

The test slabs received 3 hr of ultraviolet exposure per day for 5 weekdays and 66 hr of ultraviolet exposure between 5 p.m. Friday and 8 a.m. Monday. Thus, the slabs received approximately 1,280 W-hr/m²/week for the entire 24-week period. The total cumulative ultraviolet light exposure during the 24-week testing was slightly more than 30,000 W-hr/m², which is roughly equivalent to 185 average northern days of ultraviolet radiation exposure per year.

Northern Climate Test Procedure

This test method was based on a daily cycle, with limited activity extending through the weekends. The following 24-hr cycle was repeated for the 5 weekdays for 24 weeks:

- 15-hr overnight freeze at 0°F; the diked test surface was empty.
- 2-hr thaw at 73 to 83°F; the diked test surface was empty.
- 3-hr exposure to ultraviolet radiation and thermal heat at 95°F (+/- 5°F); the test surface was empty.
- 3-hr soaking period with 15 percent NaCl and 0.02 molar sulfurous acid water solution on the test surface (fresh solution every other day).
- Test solution poured off, slab rinsed with fresh water and drained.
- Slab returned to freezer.

On weekends the specimens were exposed to the ultraviolet radiation and the 95°F temperature. The diked test surface remained empty during weekends.

The northern climate test solution contained a 15 percent NaCl and 0.02 molar sulfurous acid solution component to represent the salts that are spread over the highways throughout the winter and the acids found in the rains and atmosphere in northern industrial regions.

During the 24-week test period, visual inspections, photographs, and notes of the condition of the slabs were recorded biweekly. Glossmeter measurements were also taken to show the loss in gloss of the surfaces during the entire testing period using a 60-degree glossmeter.

Chloride Ion Content Procedure

Following the 24-week testing period, powder samples were taken from each of the 24 coated slabs and the untreated

control slabs. Two holes were drilled in each of the slabs in order to extract the powder samples. Four powder samples were taken from both of the holes in each slab, for a total of eight samples from each slab. The first powder sample was taken at a depth of 1/2 in., the second at 1 in., the third at 1 1/2 in., and the fourth at 2 in. All eight of the powder samples were tested for chloride content, and the values were averaged together and are presented here. The total chloride content was determined using an acid-digestion potentiometric titration procedure. This testing was done at the Indiana Department of Highways (IDOH) Materials and Testing Lab with the help of IDOH personnel.

Glossmeter Data

The glossiness of the test surfaces is one of indexes to the overall appearance of the concrete and can be measured with a glossmeter. Four readings were taken on each surface every 2 weeks and then averaged to obtain a mean value for that particular day.

RAPID CHLORIDE ION PERMEABILITY TEST

The objective of the chloride ion permeability test was to determine the ability of the sealers and coatings to prevent penetration of chloride ions.

It has been shown in recent studies that chloride can be caused to migrate out of a concrete slab quite rapidly by applying an external electric field across the slab (5). This technique can be used as a chloride permeability method if the polarity is reversed by placing a sodium hydroxide solution (+) on one side and a sodium chloride solution (−) on the other. The chloride ions thus migrate into the concrete under the influence of an electric field. As the electrical resistivity of the concrete decreases with the increasing chloride ion concentration, a measure of the increase in current with the time can be correlated with the amount of chloride entering the concrete.

The fresh concrete was placed inside oiled molds 3.75 in. in diameter and 6 in. tall. Three layers were made, and each layer was rodded 25 times with a 3/8-in.-diameter rod.

The cylinders were cured for 24 hr in the molds. They were then removed from the molds and placed in lime-saturated water for 3 days. At the age of 5 days the cylinders were cut into 2-in. disks. The flat surfaces of the cylinders were lightly sandblasted.

The cylinders were allowed to cure until the age of 28 days, at which time 24 disks were coated with the materials. Two control disks remained. The amount of material used to coat all of the cylinders was 100 ft²/gal. All the coated cylinders were allowed to cure for an additional 7 days in a laboratory environment before the testing began.

Concrete Mixture Design

The concrete was designed to meet the requirements of the IDOH specifications for Class A concrete (6). All the concrete specimens were designed to have a water to cement ratio no greater than 0.66, (564 lbs. cement), an air content

between 5 and 8 percent, a ratio of fine aggregate to total aggregate between 35 and 45 percent (by weight), and a slump of 3.0 in.

Source of Errors

Readers should be cautious interpreting the results because of the following several possible sources for errors.

1. No replicates for each individual type of sealer or coating system were made. This could limit the evaluation of validity and reliability of the experimental data obtained from the research. However, many replicates were provided for each generic type of sealer or coating.

were not followed precisely in either the accelerated weathering test or the water absorption and vapor transmission test. Some procedures were adjusted slightly to suit the limited environment.

2. Because of the limitation of testing space and instruments, the procedures discussed in NCHRP Report 244 (4)

3. Each individual type of sealer or coating has its own special formula. Although each was grouped into a certain

generic type, a slightly different ingredient in the formula could make a big difference in performance when applied to the concrete surface.

RESULTS OF INDIVIDUAL TYPE AND DISCUSSION

Water Absorption and Vapor Transmission

The objectives of this phase of the project were to evaluate the differences in water and chloride ion absorption for concrete coated with the 24 materials and soaked in a 15 percent NaCl solution. The subsequent water vapor transmission characteristics were also compared during an air-drying period, which followed the soaking period.

The chloride absorption characteristics and the ratios of weight loss to weight gain for all 24 materials are shown in Table 2. Seven materials exhibited a greater than 80 percent reduction of chlorides compared with the control [two silanes (8 and 10), a silicone (11), a methyl methacrylate (12), a siloxane (14), a siloxane/silicone mixture (15), and a masonry coating (16)]. Materials 8, 10, 11, and 14 all lost more than

TABLE 2 WATER ABSORPTION AND VAPOR TRANSMISSION TEST RESULTS

Generic Type	Test #	Individual Type (% Solids or Ingredients)	AVERAGE CHLORIDE Percent Reduction	WEIGHT GAIN Percent by Weight	WEIGHT GAIN Percent Reduction	Weight Loss Percent by Wt	Wt. Loss Ratio, %
EPOXIES	1	Epoxy (50)	77.28	0.42	80.91(a)	0.95	227.3(b)
	2	Epoxy (20)	79.29	0.42	80.91	1.45	345.5
	3	Epoxy (50)	34.27	0.94	57.27	1.39	248.0
	4	Epoxy (50)	69.72	0.49	77.73	0.83	169.2
	25	Epoxy (100)	74.73	0.29	86.82	0.14	50.0
STRAIGHT PENETRANTS	7	Silane (40)	61.82	0.38	82.73	1.60	420.0
	8	Silane (<20)	85.11	0.30	86.36	1.40	462.5
	9	Silane (20)	40.46	0.53	75.91	1.56	292.9
	10	Silane (40)	81.46	0.27	87.73	1.29	485.7
	11	Silicone (5)	82.79	0.34	84.55	1.55	455.6
	14	Siloxane (20)	85.37	0.34	84.55	1.52	444.4
BLEND OF PENETRANTS	15	Siloxane/Silic (10)	84.73	0.49	77.73	1.62	330.8
	18	Blend of Silanes (30)	76.52	0.49	77.73	1.48	300.0
	21	Poly-Siloxane/Silica (7)	23.25	1.99	9.55	2.40	120.8
MASONRY COATING	16	Styrene/Acrylic Co. (75)	81.19	0.95	56.82	1.65	173.1
	19	Vinyl Acrylic (58)	39.13	1.71	22.27	2.07	121.3
	20	Polyester Resin (60)	63.34	1.34	39.09	2.11	167.7
	22	Styrene/Acrylic Co. (61)	57.18	1.34	39.09	1.97	147.2
	23	Elastomeric Acrylic	17.06	1.91	13.18	1.99	103.8
	24	Acrylic Resin	25.04	1.67	24.09	2.03	121.7
URETHANE	5	Urethane (55)	63.26	0.79	64.09	0.87	104.8
	6	Urethane (30)	-16.64	2.05	6.82	2.05	100.0
METHACRY-LATE	12	Methyl Methacrylate (20)	87.54	0.19	91.36	1.40	740.0
	13	Methyl Methacrylate (30)	73.48	0.87	60.45	1.63	187.0
CONTROL		No Coating	0.00	2.20	0.00	2.54	115.5
(a) (2.2 - 0.42)			2.2 = 80.91,	(b) 0.95	0.42 x 100 % = 227.3 %		

four times the weight that they gained. Five materials were between 70 and 80 percent more effective against chloride intrusion than were the controls [three epoxies (1, 2, and 25), a methyl methacrylate (13), and a blend of silanes (18)]. Materials 2 and 18 both lost more than three times the weight that they gained. Five materials had average chloride content reduction values from 50 to 70 percent of that of the untreated control [an epoxy (4), a urethane (5), a silane (7), and two masonry coatings (20 and 22)]. The silane also lost more than four times what it gained but was only around 61 percent more effective against chloride intrusion.

Accelerated Weathering

The objective of this test was to determine the influence of 24 weeks of accelerated laboratory weathering tests on the performance of the selected sealers and coatings when applied to small concrete slabs. The northern climate test (3) method included an accelerated weathering cycle in which the coated slabs were exposed to a wide range of environmental conditions, including ultraviolet light, high temperatures, acid/salt-water, fresh water rinse, freezing, and thawing.

The performance of the sealers and coatings was judged by making periodical visual inspections of the surface conditions (this included taking photographs), measuring the gloss of the surface with a glossmeter every 2 weeks, and measuring the

chloride ion content in the concrete at the end of the testing period.

All specimens exhibited some degree of surface deterioration or discoloration, except for the chemically-cured urethane and four of the masonry coatings. The epoxy formulations exhibited varying degrees of discoloration and deterioration from the effects of this testing. The 100 percent solids epoxy discolored slightly but did not deteriorate. The 20 percent solids epoxy demonstrated the worst deterioration of all the epoxies. The performance of the epoxy seems to be directly related to the amount of solids present. Only a slight deterioration occurred on the surface of the slabs coated with the penetrants (silane, siloxane, silicone, and combinations of the three). Only one silane (less than 20 percent solids), the combination of siloxane and silicone, and the blend of silanes exhibited significant surface deterioration. The moisture-cured urethane, straight methyl methacrylate, and one of the styrene acrylic copolymers (75 percent solids) also had deep etching over their entire surfaces. The other styrene acrylic copolymer (61 percent solids) exhibited minor surface deterioration, and the methyl methacrylate with the silane primer showed some slight discoloration of the surface coating. The untreated control specimen exhibited uniform deep etching over the entire surface and had many coarse aggregates showing.

The glossmeter values at weeks 0 and 24 of the accelerated weathering test are presented in Table 3. All materials ex-

TABLE 3 GLOSS REDUCTION

Generic Type	Test #	Individual Type (% Solids or Ingredients)	Week 0	Week 24	Percent Reduction
EPOXIES	1	Epoxy (50)	5.95	0.78	86.89
	2	Epoxy (20)	0.75	0.02	97.33
	3	Epoxy (50)	1.55	0.08	94.84
	4	Epoxy (50)	9.53	0.48	94.96
	25	Epoxy (100)	14.20	0.73	94.86
STRAIGHT PENETRANTS	7	Silane (40)	0.23	0.08	65.22
	8	Silane (<20)	0.25	0.00	100.00
	9	Silane (20)	0.13	0.13	0.00
	10	Silane (40)	0.23	0.23	0.00
	11	Silicone (5)	0.15	0.03	80.00
	14	Siloxane (20)			86.30
BLEND OF PENETRANTS	15	Siloxane/Silicone (10)	0.53	0.00	100.00
	18	Blend of Silanes (30)	0.25	0.05	80.00
	21	Poly-Siloxane/Silica (7)	0.55	0.00	100.00
MASONRY COATING	16	Styrene/Acrylic Copolymer (75)	0.58	0.00	100.00
	19	Vinyl Acrylic (58)	1.35	1.15	14.81
	20	Polyester Resin (60)	0.30	0.03	90.00
	22	Styrene/Acrylic Copolymer (61)	1.55	1.05	32.26
	23	Elastomeric Acrylic	1.20	0.93	22.50
	24	Acrylic Resin	0.08	0.70	20.45
URETHANE	5	Urethane (55)	3.93	1.85	52.93
	6	Urethane (30)	1.90	0.10	94.74
METHACRY-LATE	12	Methyl Methacrylate (20)	4.15	1.50	63.86
	13	Methyl Methacrylate (30)	1.88	0.28	85.11
CONTROL			0.20	0.00	100.00

hibited a decrease in their gloss except the slabs coated with silane. The coatings that experienced any deterioration or discoloration also had a subsequent loss of gloss.

The chloride content values for the 24 tested materials and the control specimen are presented in Table 4. The chloride content of the untreated control specimens was extremely high at the end of the test, 0.423 percent by weight of concrete. The two masonry coatings that were based on the styrene acrylic copolymer (samples 16 and 22) actually exhibited higher chloride contents than the control. Five materials that reduced the chloride content by more than 90 percent of that of the untreated control [three silanes (10, 8, and 7), a siloxane, and the blend of silanes]. Six materials were between 80 and 90 percent more effective than the control specimen [a silicone, a silane (9), three epoxies (1, 3, and 25), and the siloxane-silica mixture]. Two of the 24 tested materials were between 50 and 80 percent more effective than the control [an epoxy (4) and a urethane (5)]. Eight materials were less than twice as effective as the untreated control [four masonry coatings (19, 20, 23, and 24), an epoxy (2), a urethane (6), and both methyl methacrylates (12 and 13)].

The rapid chloride ion permeability results for all 24 materials (coated at age 28 days) are shown in Table 5. Two

materials reduced the chloride intrusion by more than 90 percent compared with the control, and one of them (the 100 percent solids epoxy) had a negligible permeability rating. The other material (a chemically cured urethane with a 55 percent solids content) had a low rating. Six of the materials exhibited low permeability values between 58 and 80 percent compared with the control specimens. The last six materials exhibited moderate permeability values between 35 and 54 percent of that of the untreated concrete. The rapid chloride permeability testing is a quick method. In this study, the test took about 8 weeks to complete, whereas a simple water absorption vapor transmission test required 13 weeks to finish and an accelerating weathering test lasted for 24 weeks.

Five of the top seven materials were epoxy formulations. The comparatively best material was the 100 percent solids epoxy. The other four materials were the 50 percent solids epoxies. The next best generic type was the silane. The silanes with the higher solids contents were much more effective than the ones with 20 percent or less solids. Both methyl methacrylates exhibited a reduction of about 77 percent from the uncoated control specimen. Siloxane, silicone, and the combination of the two had permeability values between 65 and 74 percent of that of the untreated concrete. The rest of the

TABLE 4 AVERAGE CHLORIDE CONTENT FOR PONDING SLABS

Generic Type	Test #	Individual Type (& Solids or Ingredients)	Average % Chloride	Percent Reduction
EPOXIES	1	Epoxy (50)	0.075	82.26
	2	Epoxy (20)	0.408	3.64
	3	Epoxy (50)	0.055	86.91
	4	Epoxy (50)	0.125	70.56
	25	Epoxy (100)	0.045	89.39
STRAIGHT PENETRANTS	7	Silane (40)	0.038	91.10
	8	Silane (<20)	0.034	91.75
	9	Silane (20)	0.049	88.26
	10	Silane (40)	0.029	93.02
	11	Silicone (5)	0.044	89.51
	14	Siloxane (20)	0.041	90.19
BLEND OF PENETRANTS	15	Siloxane/Silicone (10)	0.293	30.48
	18	Blend of Silanes (30)	0.031	92.46
	21	Poly-Siloxane/Silica (7)	0.081	80.76
MASONRY COATING	16	Styrene/Acrylic Copolymer (75)	0.482	-14.03
	19	Vinyl Acrylic (58)	0.286	32.34
	20	Polyester Resin (60)	0.289	31.57
	22	Styrene/Acrylic Copolymer (61)	0.528	-24.86
	23	Elastomeric Acrylic	0.292	30.89
	24	Acrylic Resin	0.348	17.71
URETHANE	5	Urethane (55)	0.136	67.78
	6	Urethane (30)	0.295	30.18
METHACRYLATE	12	Methyl Methacrylate (20)	0.230	45.46
	13	Methyl Methacrylate (30)	0.409	3.08
CONTROL			0.422	0.00

TABLE 5 RAPID CHLORIDE PERMEABILITY RESULTS (AASHTO T 277-83I)

Generic Type	Test #	Individual Type (& Solids or Ingredients)	Coulombs Passed	Percent Reduction	AASHTO Designation
EPOXIES	1	Epoxy (50)	661	85.81	very low
	2	Epoxy (20)	1829	60.73	low
	3	Epoxy (50)	467	89.97	very low
	4	Epoxy (50)	546	88.28	very low
	25	Epoxy (100)	66	98.58	negligible
STRAIGHT PENETRANTS	7	Silane (40)	792	82.99	very low
	8	Silane (<20)	1002	78.48	low
	9	Silane (20)	1812	61.09	low
	10	Silane (40)	538	88.45	very low
	11	Silicone (5)	1369	70.60	low
	14	Siloxane (20)	1226	73.67	low
BLEND OF PENETRANTS	15	Siloxane/Silicone			
		Silicone (10)	1623	65.15	low
	18	Blend of Silanes (30)	2521	48.01	moderate
	21	Poly-Siloxane/Silica (7)	2680	42.45	moderate
MASONRY COATING	16	Styrene Acrylic Cop. (61)	1939	58.36	low
	19	Vinyl Acrylic (58)	1788	61.61	low
	20	Polyester Resin (60)	1853	60.21	low
	22	Styrene Acrylic Cop. (75)	2470	46.96	moderate
	23	Elastomeric Acrylic	2255	51.58	moderate
	24	Acrylic Resin	2170	53.40	moderate
URETHANE	5	Urethane (55)	258	94.46	very low
	6	Urethane (30)	3006	35.45	moderate
METHACRY-LATE	12	Methyl Methacrylate (20)	1117	76.01	low
	13	Methyl Methacrylate (30)	997	78.59	very low
CONTROL			4657	0.00	high

materials, all six of the masonry coatings, a blend of silanes, a polysiloxane/silica, and a moisture-cured urethane, had permeability values below 62 percent of that of the control specimen.

RESULTS OF GENERIC TYPE AND DISCUSSION

The results presented in Tables 1-5 are summarized in Table 6. The mean values of percent chloride ion reduction from the three tests indicate that epoxy and straight penetrants consistently stopped chloride ion penetration well. Masonry coatings and blend penetrants were comparatively weak barriers, whereas urethane and methyl methacrylate exhibited mixed results. In the water absorption and vapor transmission

test, epoxy, straight penetrants, and methyl methacrylate had significant moisture reduction value in contrast to blend penetrants, masonry coating, and urethane. The calculation of weight loss to weight gain ratios indicated that straight penetrants, methyl methacrylate, and blend penetrants benefitted the coated concrete substantially more than the epoxy, masonry coating, and urethane. Herein, the epoxy demonstrated that it could block the water out of concrete as well as trap water inside the concrete. It was especially true of the 100 percent solid epoxy. Data on the reduction of gloss after the coated concrete was subjected to 24 weeks of the accelerated weathering test are presented in the last row of Table 6. Combined with the visual inspection, masonry coating and straight penetrants sustained the attack of severe weather better than the other generic types of sealers and penetrants.

TABLE 6 SUMMARY RESULTS FOR GENERIC TYPE

DESCRIPTION OF PROPERTIES COMPARING WITH CONTROL SPECIMEN (uncoated concrete)	EPOXY	STRAIGHT PENETRANT	BLEND PENETRANT	MASONRY COATING	URETHANE	METHYL METHACRYL
Percent of Chloride Ion Reduction						
1. From Rapid Permeability Test	84.67 (14.22)	75.88 (9.66)	51.87 (11.83)	55.35 (5.66)	64.96 (41.73)	77.30 (1.82)
2. From Water Absorption/Vapor Vapor Transmission Test	67.06 (18.67)	72.84 (18.17)	61.50 (33.38)	47.16 (24.41)	23.31 (56.50)	80.51 (9.94)
3. From Accelerating Weathering Test	66.54 (35.91)	90.64 (1.69)	67.90 (32.93)	12.27 (25.38)	48.98 (26.59)	24.27 (29.97)
Percent of Moisture Reduc- tion from Water Absorption Test (Weight Gain)	76.73 (11.36)	83.64 (4.16)	55.00 (39.36)	32.42 (15.66)	35.46 (40.50)	75.91 (21.86)
Weight Loss/Weight Gains Ratio from Water Absorption/ Vapor Transmission Test	208.00 (78.87)	426.85 (63.87)	250.53 (113.40)	118.18 (28.76)	102.40 (3.39)	463.55 (391.03)
Gloss Diminishing from Accelerating Weathering Test	93.78 (3.99)	55.25 (44.24)	93.33 (11.55)	46.67 (37.99)	73.84 (29.56)	74.49 (44.24)

CONCLUSION

Because of limited resources, the experiments in this study were designed with no replicates for each individual coating system, and the testings did not exactly follow NCHRP testing procedures. Compounded with a slightly different ingredient on the formula of each individual sealer and coating, this could result in a drastic difference on their behavior. Therefore, definite conclusions cannot be made at this point. More laboratory and field testings are needed to verify the differences among various generic sealers and coatings. Nevertheless, the following phenomena are apparent.

1. The epoxies were comparatively better chloride and water absorption barriers, but they deteriorated and discolored slightly in the accelerated weathering test.
2. The penetrants (straight silanes, silicone, and siloxane) resisted water and chloride absorption quite well. They also showed little sign of deterioration in the weathering test. The materials that were combinations of penetrants did not perform as consistently as the straight penetrants.
3. Masonry coatings were comparatively ineffective barriers to chloride ions, but they did offer aesthetic benefits.
4. The urethane and methyl methacrylate results varied dramatically from one test to another.

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