7-2017

Proposed Testing of Concrete Sealers

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Kentucky Transportation Center Technical Assistance Report —
KTC-TA-17-04/KHIT2017-6-1F
DOI: http://dx.doi.org/10.13023/KTC.TA.2017.04

KTC's Mission

We provide services to the transportation community through research, technology transfer, and education. We create and participate in partnerships to promote safe and effective transportation systems.

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Proposed Testing of Concrete Sealers

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In Cooperation With
Kentucky Transportation Cabinet
Commonwealth of Kentucky

July 2017

Introduction

Chlorides, in sufficient concentrations, will cause corrosion of steel reinforcement in bridge decks. Previous studies have shown that de-icing chemicals and practices used by the Kentucky Transportation Cabinet (KYTC) can result in problematic levels of chloride at steel reinforcing depths in a relatively short amount of time. With the advent of liquid applied pre-treatment de-icing chemicals testing performed in Kentucky indicate chloride levels in bridge decks at a depth of two inches have increased significantly. The action levels for chlorides in concrete as related to reinforcing steel corrosion are:

- Corrosion will initiate at 0.03% chlorides by weight of concrete.
- Accelerated corrosion begins at 0.08% chlorides by weight of concrete.
- Major section loss of steel occurs at 0.18% chlorides by weight of concrete.

Concrete sealers have proven effective in arresting chloride penetration into bridge decks resulting in lower incidences of cracked and spalled concrete. Concrete sealing is a relatively inexpensive and durable treatment. In 2013 Kentucky Transportation Center (KTC) conducted a study [(1)] to determine the ability of a number of concrete sealers to resist chloride penetration into concrete. KYTC chose four of these products to be used on an experimental basis on the bridge that carries I 471 over 6th Street in Newport, KY. Results from the previous study and this one were combined and sorted by performance at a depth of ½ inch (Appendix 1). The application method varied between the two projects. For the previous study the recommended usage, from the manufacturer's data sheet, was calculated for the surface area of each specimen and spray applied. The specimens for this study were flooded, as described below.

Key properties of concrete sealers are resistance to chloride migration into the concrete and good penetration of the sealer into the concrete. Depth of sealer penetration would help offset wheel path wear and enhance the durability of the treatment. However, when a concrete deck has minor cracking, the performance of penetrating sealers will be limited.

Recently several products have been promoted by manufacturers for potential use by the KYTC to seal bridge decks. The Kentucky Transportation Center (KTC) was asked to test and evaluate some of these products. For this study KTC focused on four of these products (Table 1). The process included specimen preparation, application of material, testing, and evaluation.

Table 1 Products Tested

Product	Manufacturer	Remarks	Specimen Key
Pentreat™244-40	W.R. Meadows	Solvent-based 40% silane (penetrating sealer)	WR 1 – WR 3
Sil-Act® EP-700	Advanced Chemical Technologies, Inc.	Two-component low viscosity epoxy polymer (healer/sealer)	SA 1 – SA 4
Duraguard 401-P	ChemMaster	Two component, low viscosity, solvent free, high molecular weight methacrylate penetrating sealer and crack healer.	CH 1 – CH 4
MasterProtect® H 440 VT	BASF	Solvent-based 40% silane (penetrating sealer) This Previously tested – to be used as a reference standard.	BA 1 – BA 3

Specimen Preparation

For each product tested, specimens were cast (10"x10" x 4") in triplicate using the standard KYTC AA concrete mix. The specimens were cast at the KTC laboratory and Irving Materials Inc. (IMI) provided the concrete from a ready mix truck. Additional specimens were cast to establish baseline chloride content and to determine the performance of untreated concrete. Cylinders were cast to test for compressive strength and tested at 75 days (compressive strength averaged 5065 psi). After the specimens were cast and finished they were covered with plastic and dry cured for approximately 96 hours prior to de-molding. They were then submerged in a curing bath of water saturated with hydrated lime. The specimens remained in wet cure for six weeks. After removal they were allowed to dry for 24 hours. Using coal slag abrasive, one face of each specimen was abrasive blasted to ICRI CSP-3 (Figure 1), then placed in an environmental chamber maintained at 73.5°F +/- 3.5°F (23.0°C +/- 2°C) and 50% RH +/- 5% for an additional 21 days of curing.

In order to test the healer/sealers, it was necessary to simulate a bridge deck crack. To accomplish this, eight specimens were scored across the bottom face to a depth of approximately ½ inch. Using the compression tester the specimens were broken in half (Figure 2). The cracked specimens were then "re-assembled" by applying a small bead of silicon to the outer edges of the fractured surfaces at the sides of the specimen. A copper wire (approximately 0.017" diameter) was embedded in the silicon to act as a spacer (Figure 3). Clamps were fashioned using 2x4 lumber and 5/16" all-thread rods (Figure 4). By applying 15 ft. lbs. of torque to the clamps, the wire was compressed to approximately 0.016". The average crack width as measured by a Germann Crack Scope was 0.0164" (Figure 5).

Sealer Application

Pentreat™ 244-40:
Sealer was applied with a low pressure Hudson sprayer in a single pass allowing material to flood the surface (Figure 6). After approximately five minutes, allowing time for material to saturate the surface, a brush was used to even out the material. This application method was performed in accordance with the product data sheet, which stated a usage of 100 to 150 ft^2 per gallon, however when applying to the small specimens there was considerable run off and therefore no attempt was made to calculate usage.

MasterProtect® H 440 VT (formerly Hydrozo Clear 40 VOC)**:**
Sealer was applied with low pressure Hudson sprayer in two passes. A mist coat was applied followed by coating to saturation. A brush was used to eliminate pooling. This application method was performed in accordance with the product data sheet, which stated usage of 125 to 250 ft^2 per gallon when applying to concrete, however when applying to the small specimens there was considerable run off and no attempt was made to calculate usage.

Sil-Act® EP-700:
This healer/sealer was applied by brush in a manner to saturate the entire surface. To allow maximum penetration the material was pooled over the intentional crack for approximately five minutes, then excess was removed by brushing. Sand was broadcast, to refusal, over the entire test surface (Figure 7). The application method described in the product data sheet was adhered to as closely as possible. The recommended usage was 65 to 80 ft^2 per gallon when applying to broom finished concrete, however when applying to the small specimens there was considerable run off and no attempt was made to calculate usage. Considerable material also ran through the intentional crack.

Duraguard 401-P:
This healer/sealer was applied by brush in a manner to saturate the entire surface. The PDS stated to maintain 15 mils but due to the low viscosity, 3-5 mils was all that could be achieved using the roller method. Switching to the brush method allowed a build-up of 8-10 mils. The recommended usage was stated to be 100 to 150 ft^2 per gallon, however when applying to small specimens there is considerable run off and no attempt was made to calculate usage. Material also ran freely through the intentional crack. Sand was to be broadcast at 1 lb. per yd^2 then back rolled with additional material (Figure 8). Total test area was 4 ft^2 and approximately 1/8 lb. of sand was broadcast. When back-rolling, due to the tackiness of the material, there was a considerable amount of sand removed.

Salt Ponding

After sealer application, all specimens were moved back into the environmental room and allowed to cure for fourteen days at 73.5°F +/- 3.5°F (23.0°C +/- 2°C) and 50% RH +/- 5%. The salt ponding test was performed in accordance with AASHTO T-259 “Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration” & AASHTO T260 “Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials”. Silicon caulk was used to adhere 0.50” x 0.75” HDPE dams to the perimeter of each specimen (Figure 9). The clamps on the healer/sealer specimens remained in place throughout the ponding procedure. After 90 days of ponding, the NaCl solution was removed, dams were removed, residual salt cleaned off of the surface, and the specimens were allowed to dry for approximately 24 hours.

Using the Germann Profile Grinder (Figure 10), the top 2 mm (0.078”) were removed and discarded to eliminate any residual surface contamination. From that point, concrete dust was collected at 4 mm (0.157”) intervals down to 26 mm (1.02”) (Figure 11). Samples from the baseline specimen had previously been collected and tested to establish a baseline chloride content. Since the healer/sealer material ran through the crack during application it was necessary to seal the bottom of the specimen to prevent the salt solution from running out. Therefore, additional dust samples were collected from the fractured surface of the healer/sealer specimens. These samples were collected by drilling 0.125” to 0.375” into the fractured surface, parallel to and approximately 1.5” to 2.0” below the ponded surface (Figure 12). All samples were oven dried for 24 hours at 110°C and sieved using a number 50 sieve. The Germann Rapid Chloride Test (RCT) (Figure 13) was used to determine chloride content. From each sample collected, 1.5 grams were weighed out and put into test vials of extraction solution. To allow for 100% extraction the samples were allowed to “soak” for approximately three days prior to testing. The average chloride content at each level for each of the products as well as the baseline and control specimens can be seen in Table 2 and Chart 1. Specimens SA 1 and CH 4 were ponded with plain water instead of the salt solution in an effort to determine any effect the salt may have on the other tests. The chloride content of SA1 and CH4 (0.016% and 0.010%) were relatively the same as the baseline samples and were not included in the results in Table 2 and Chart 1. All other tests were performed utilizing the ponding specimens after the ponding was complete.

Table 2 Average Chloride Content from Ponding Tests

Average % Chloride Content						
Test Depth	**2-6 mm**	**6-10mm**	**10-14 mm**	**14-18 mm**	**18-22 mm**	**22-26 mm**
Baseline	0.019	0.011	0.012	0.012	0.013	0.013
Non-Ponded Control	0.013	0.011	0.010	0.011	0.011	0.010
Ponded Control	0.172	0.074	0.028	0.016	0.012	0.012
Healer/Sealers:						
Sil-Act® EP-700	0.201	0.057	0.021	0.015	0.012	0.012
Duraguard 401-P	0.116	0.026	0.010	0.010	0.010	0.010
Penetrating Sealers:						
Pentreat™ 244-40	0.150	0.043	0.019	0.015	0.013	0.012
Master Protect® H 440 VT	0.138	0.039	0.015	0.013	0.012	0.011

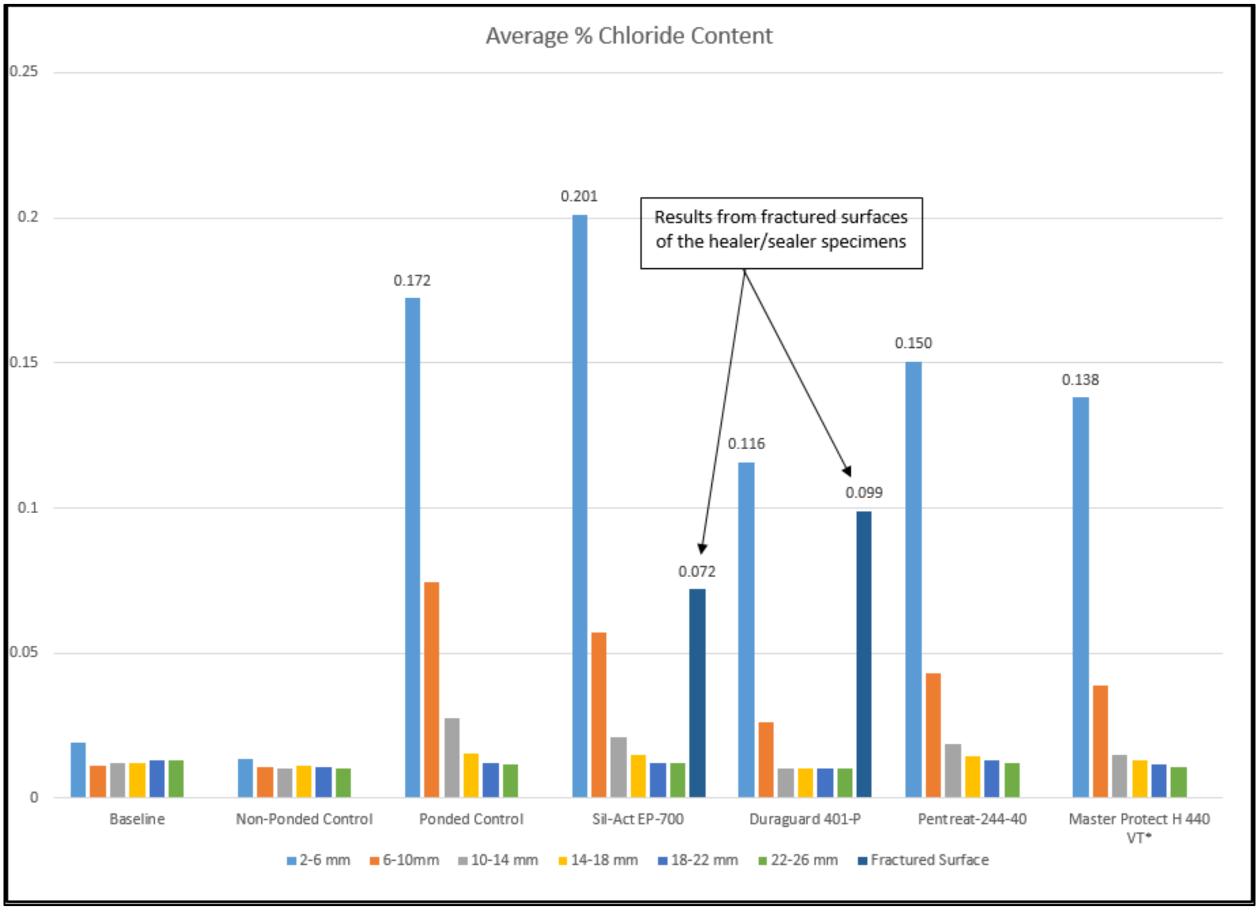

Chart 1 Average Chloride Content

Absorption

A 2.0” x 4.0” (diameter x length) core was extracted from each ponding block for absorption testing. The cores were prepared and tested in accordance with ASTM D6489 “Standard Test Method for Determining the Water Absorption of Hardened concrete With a Water Repellant Coating”. The cores were oven dried at 75°C +/- 5°C (167°F +/- 9°F) for 24 hours then weighed at two hour intervals until a change of less than 0.2% was observed. After cooling to room temperature they were re-weighed and this weight was recorded as the initial weight. To assure the sides of the cores were waterproof, paraffin was melted at approximately 80°C (176°F) and applied by rolling the core in the wax (Figure 14). The depth of the wax was maintained at approximately 0.125” to 0.250”. To prevent wax from adhering to the ends of the core, duct tape had been applied and was removed before testing. Removal of the tape fractured the seal between the sides of the core and the treated surface, therefore in an effort to re-seal this area each core was further treated by dipping, at a shallow angle, into the paraffin to coat only the extreme edge of the test surface (Figure 15). Each core was re-weighed and placed, treated surface down, into 2.5 inches of D.I. water. At 24 and 48 hours the cores were removed, excess water wiped off, and re-weighed. The results can be seen in Table 3 and Chart 2.

Table 3 Absorption Test Results

Average Water Absorption		
	24 hour Average	48 hour Average
Non-ponded Control	1.39%	1.67%
Ponded Control	1.01%	1.17%
Sil-Act® EP-700	0.44%	0.56%
Duraguard 401-P	0.42%	0.50%
Pentreat™ 244-40	0.09%	0.11%
Mater Protect® H 440 VT	0.35%	0.42%

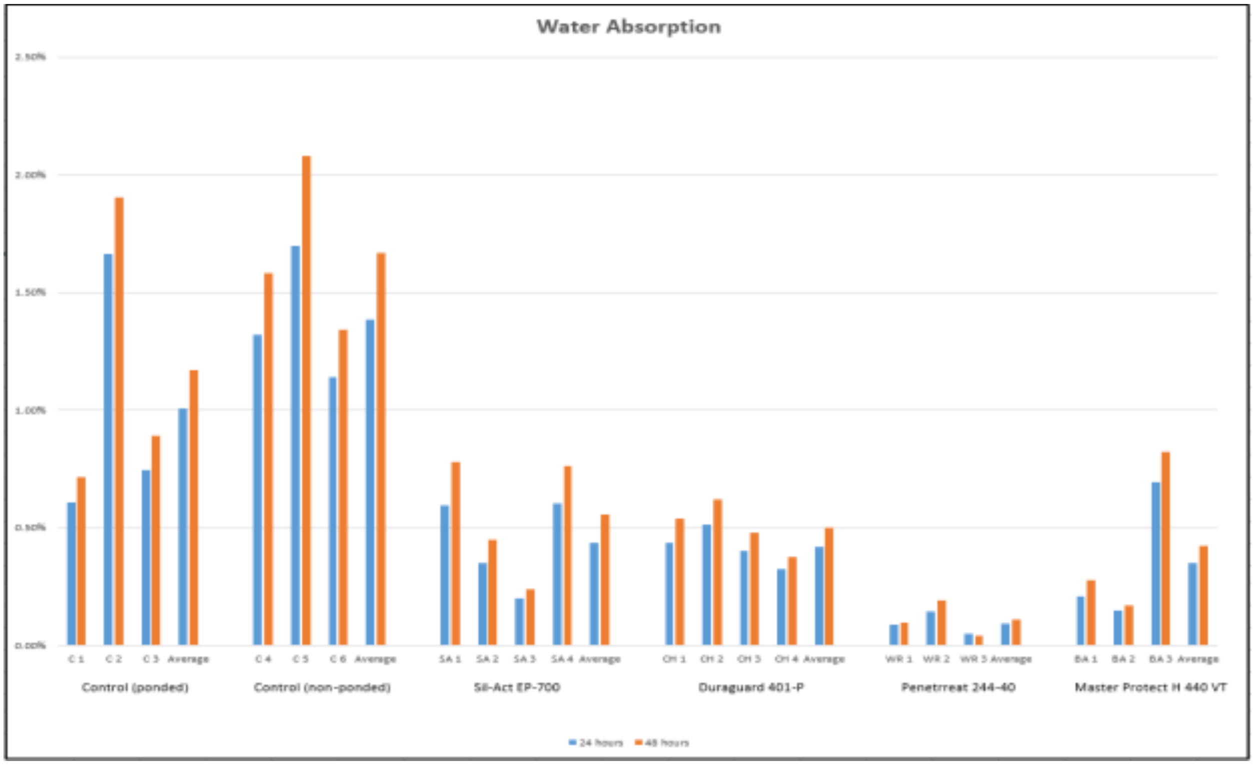

Chart 2 Absorption Test Results

Adhesion

Each block was also tested for adhesion in accordance with ASTM 7234 "Standard Test Method for Pull-off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers". Even though the products tested are not coatings and there should be no issue with adhesion the test was performed to determine the effect each product has on the tensile properties of the concrete. A DeFelsko AT/A adhesion tester was used with 20 mm dollies at a pull rate of 30 psi/s. The results can be seen in Table 4 and Chart 3.

Table 4 Adhesion/Tensile Strength (psi)

Adhesion/Tensile Strength (psi)					
Control (ponded)	**C 1**	**C 2**	**C 3**	**Average**	
	1139	1214	1266	1206	
Control (non-ponded)	**C 4**	**C 5**	**C 6**	**Average**	
	949	513	799	754	
Healer/Sealers:					
Sil-Act® EP-700	**SA 1**	**SA 2**	**SA 3**	**SA 4**	**Average**
	1211	1167	444	1118	985
Duraguard 401-P	**CH 1**	**CH 2**	**CH 3**	**CH 4**	**Average**
	976	1250	997	899	1031
Penetrating Sealers:					
Pentreat™ 244-40	**WR 1**	**WR 2**	**WR 3**	**Average**	
	937	563	588	696	
Master Protect® H 440 VT	**BA 1**	**BA 2**	**BA 3**	**Average**	
	667	598	773	679	

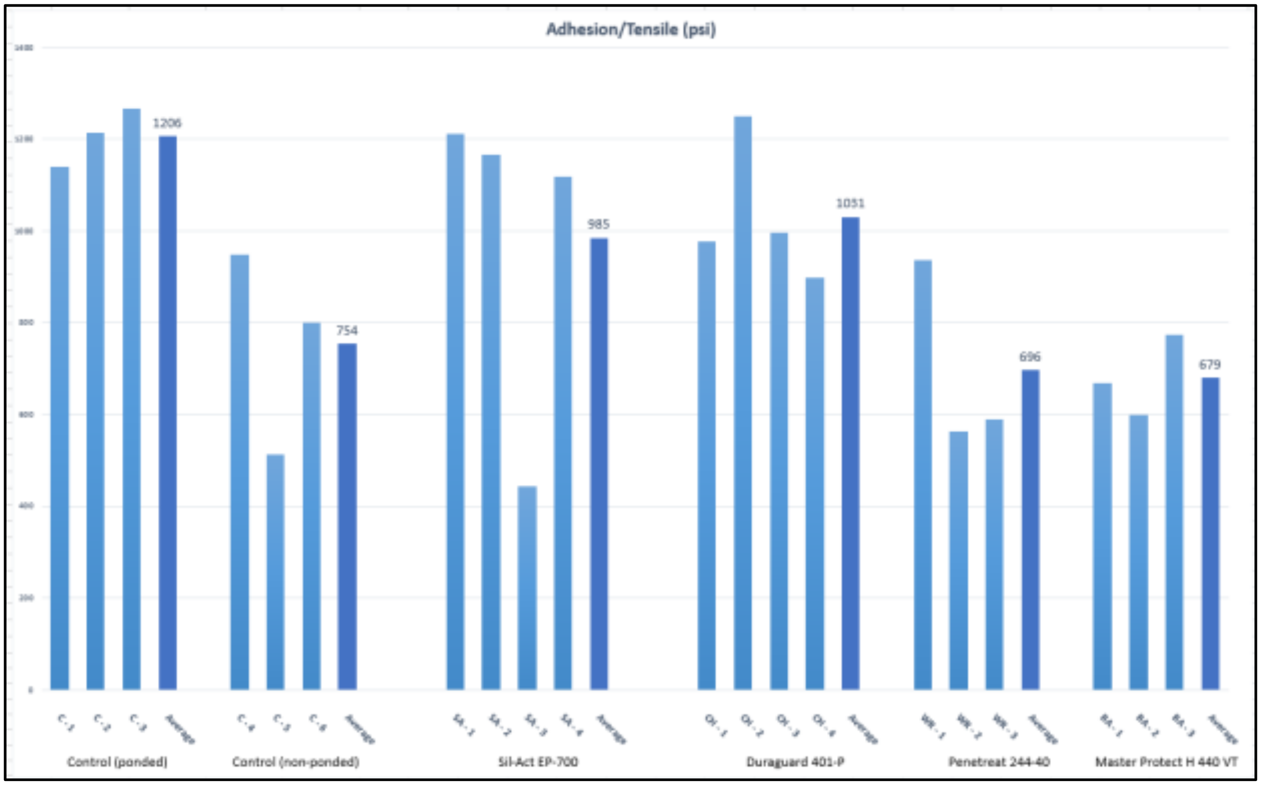

Chart 3 Adhesion/Tensile Strength (psi)

Depth of Penetration

KTC-SOP-24 "Depth of Penetration of Concrete Sealer" (Appendix 3) was used to determine depth of sealer penetration. This SOP was developed for the NTPEP program and was adapted for this study. The test required cutting a cross section of the specimen, drying, and applying a water soluble dye to the cut surface at the interface of the sealing material (Figure 16). The dye should penetrate the concrete and be visible in the area below the point at which the sealer has penetrated. This area was viewed and measured using a Germann Crack Scope with 25x magnification. Penetration was detected with the two penetrating sealers (Table 4), however no penetration was observed with the healer/sealers other than into small crevices. Ambient lighting as well as a black light was utilized in examining these specimens.

Table 5 Depth of Penetration

Depth of Penetration		Date: 03/08/17
KTC-SOP-24		Tester: D. Wells
Sample	**Depth (mm/in.)**	**Comment**
BA 1	0.50/0.019	
	0.40/0.016	
	0.80/0.031	
	0.30/0.012	
	0.50/0.019	
	0.60/0.024	
Average	0.52/0.020	
WR 1	0.50/0.019	
	0.75/0.030	
	0.40/0.016	
	0.80/0.031	
	0.60/0.024	
	0.60/0.024	
Average	0.61/0.024	
CH 3	N/A	Due to healer/sealer build up on the surface, penetration could not be detected, however penetration was observed into microscopic cracks and crevices.
SA 3	N/A	

Observations

- The penetrating sealers are easier to apply, however all sealers tested can be applied in the field without special equipment or training.
- The penetrating sealers are applied by low pressure spray equipment and using broom, brush, and/or roller to spread material and to eliminate pooling.
- The healer/sealers are two component products that require mixing. Once mixed, application time is limited due to pot life. Application can be achieved by brushing, rolling, low pressure sprayer, or pouring and spreading with a squeegee. Before the material solidifies aggregate must be broadcast. The Duraguard PDS specifies silica or aluminum oxide and the Sil-Act® PDS leaves the decision to the engineer.
- The Duraguard 401-P product data sheet recommends maintaining 15 mils wet film thickness. This could not be achieved on the test specimens. This could possibly be due to an inaccurate mix ratio. The resin (Part A) as provided from the manufacturer had the promoter (Part B) pre-mixed for a temperature range of 80°F to 90°F. Application temperature was 70°F. The manufacturer provided a mix ratio chart for a broader range of temperatures. The amount of catalyst (Part C) used at 80°F is 3.0 ounces per gallon and 4 ounces per gallon for 70°F. The total amount of material mixed for application to the test specimens was 32 ounces which required one ounce of Part C for the application temperature. Extreme care was taken to be as accurate as possible but at this amount a slight variance could be significant. There is also a difference in the amount of promoter to be added for various temperatures (if using the three component 401), however the 401-P was pre-dosed by the manufacturer and could not be adjusted. The "P" designation of this product indicates that the promoter has been added to the resin. There is a Duraguard 401 available in the three component version. This allows the user to mix in ratios suited to temperatures, however extreme care should be taken due to the volatility of the promoter. The MSDS should be studied carefully.
- The Duraguard 401P data sheet states a Crack Size Range or 0.001"– 0.125" while Sil-Act has no stated crack size. The Depth of Penetration test did not indicate penetration into sound concrete, however there was penetration, as claimed, into microscopic cracks and crevices created when breaking and/or saw cutting the specimens. These products would not sufficiently seal full depth cracks without capping the crack from the bottom nor would it be adequate for working cracks. As observed in the test specimens, with a crack of 0.016", it was necessary to seal the bottom to contain the material. This size crack was probably not adequate to determine the full capabilities of the healer/sealers.

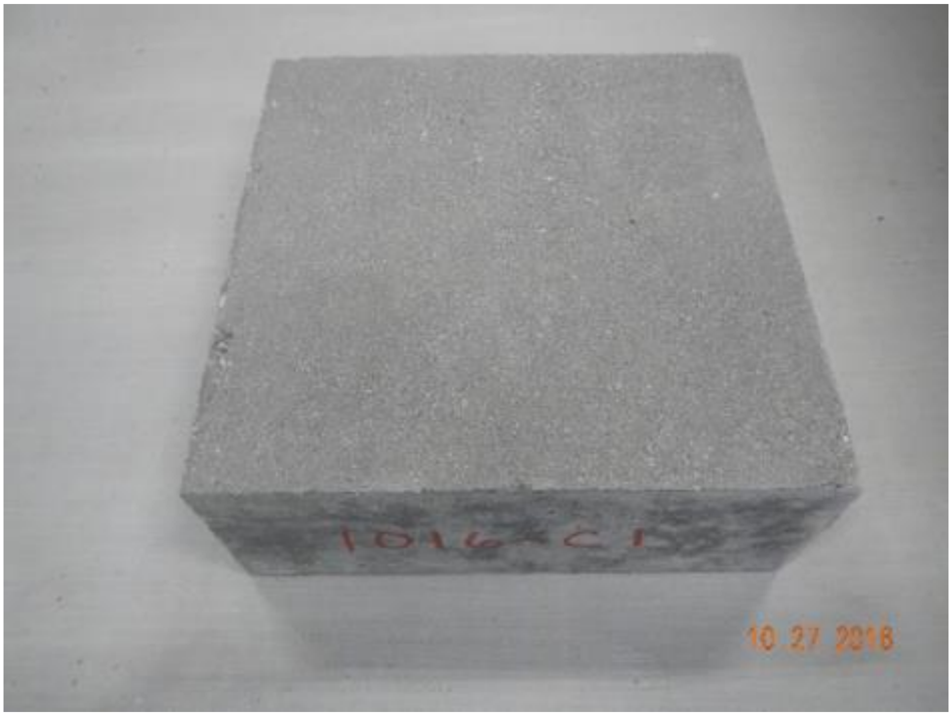

Figure 1 ICRI CSP3 Surface Preparation

Figure 2 Breaking specimen for Healer/Sealer Testing

Figure 3 Fractured Surface with Wire Spacer

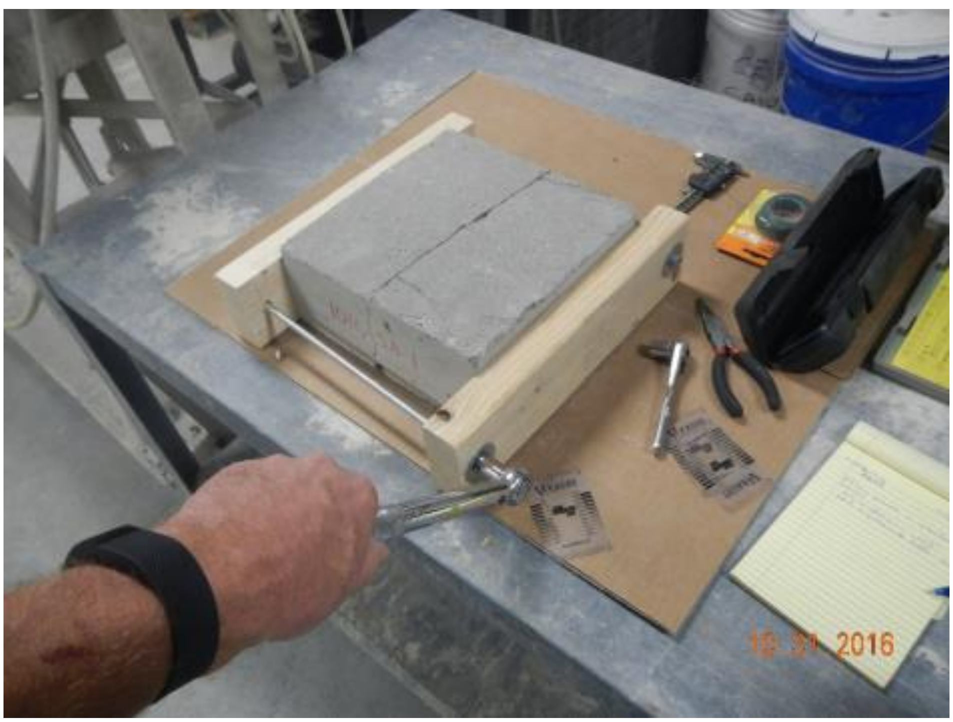

Figure 4 Reassembly of Healer/Sealer Specimens

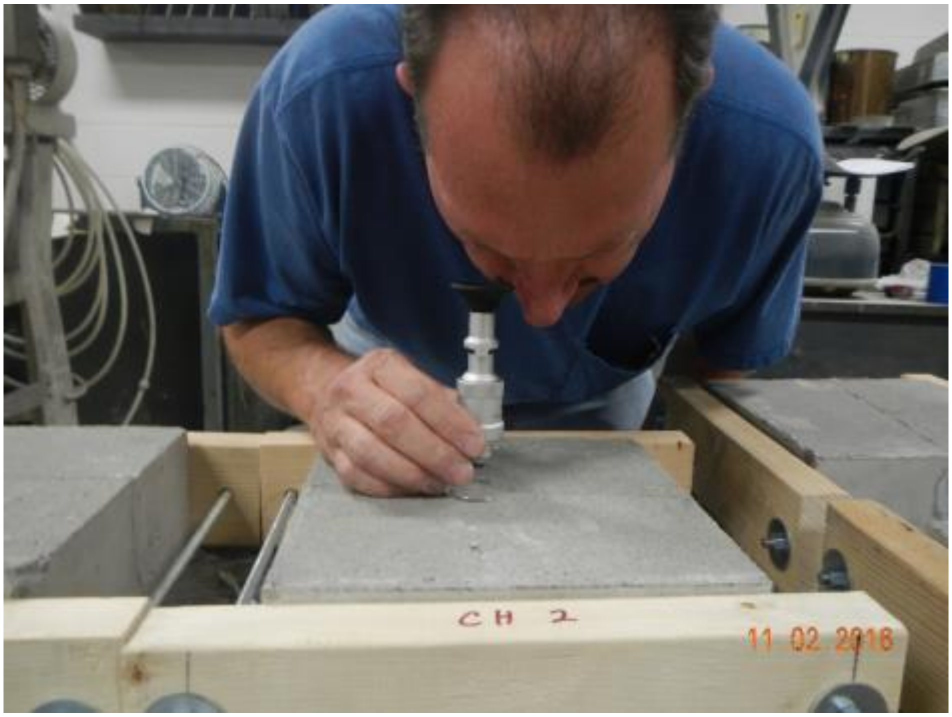

Figure 5 Crack Measurement Using Germann Crack Scope

Figure 6 Application of Penetrating Sealer

Figure 7 Broadcasting Sand on Healer/Sealer

Figure 8 Back-rolling Healer/Sealer Specimens After Application of Sand

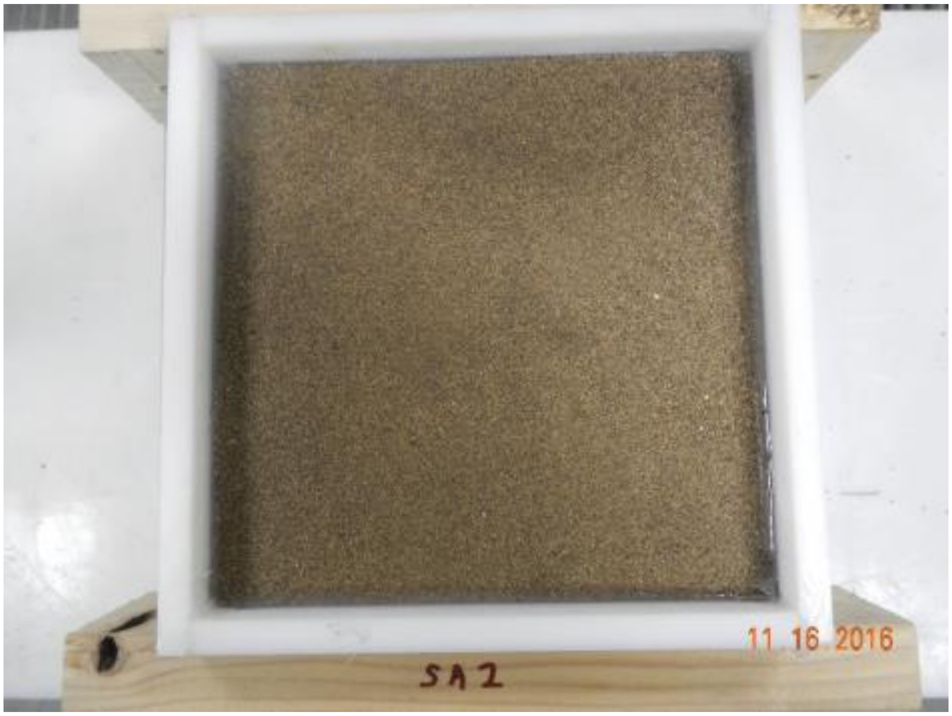

Figure 9 Specimen after application of HDPE dams

Figure 10 Germann Profile Grinder

Figure 11 Germann Profile Grinder

Figure 12 Fractured Surface (Arrows Indicate Sample Collection Area)

Figure 13 Germann Rapid Chloride Test (RCT)

Figure 14 Application of Paraffin with Ends Taped

Figure 15 Application of Paraffin to Edges

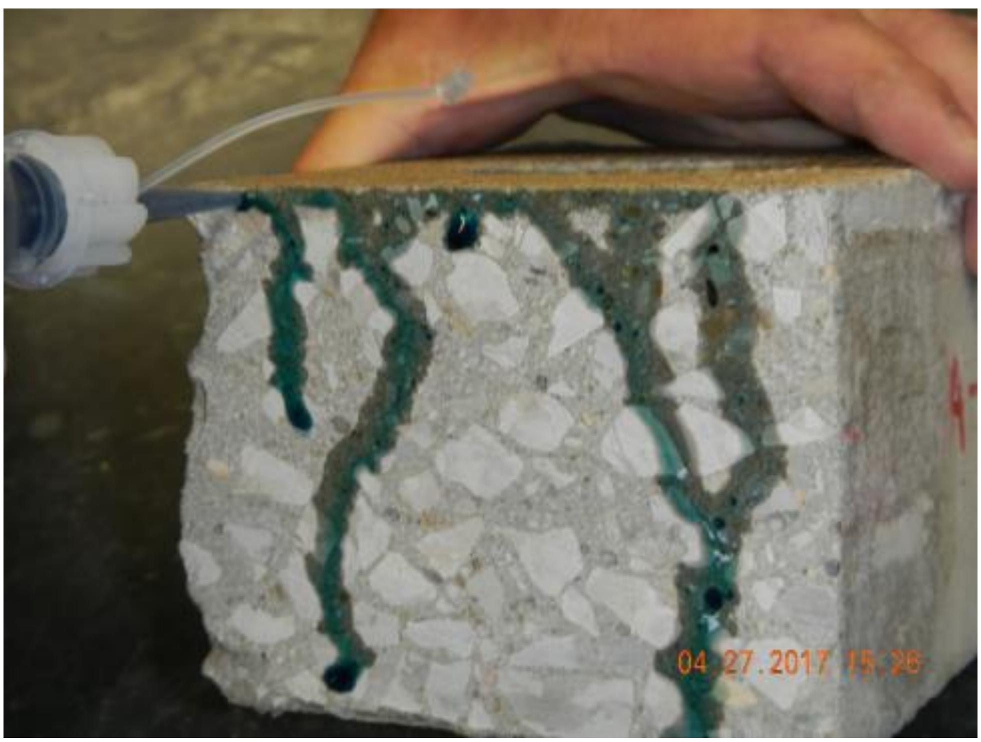

Figure 16 Dye Application for Depth of Penetration Testing

Appendix 1 Sealers Tested by KTC

Supplier	Product	Depth 1/2 Inch (12.7 mm) %Cl	Depth 1 Inch (25.4 mm) %Cl
Non-Ponded Control	N/A	0.011	0.010
BASF	MasterProtect® H 440 VT	0.014	0.011
W.R. Meadows	Pentreat™244-40	0.017	0.012
Ponded Control	N/A	0.022	0.012
Control Sample	N/A	0.023	0.017
Evonik Industries	Protectosil BHN	0.079	0.016
Chemical Products Industries, Inc.	SW-244-100 DOT	0.087	0.027
Evonik Industries	Protectosil 300	0.088	0.013
Vexcon	Powerseal 80	0.092	0.035
Vexcon	Certivex Penseal 244 80	0.093	0.040
BASF	Hydrozo Clear 40 VOC	0.099	0.022
Vexcon	Certivex Penseal 244 O/W 80	0.103	0.021
BASF	Hydrozo 100	0.104	0.050
BASF	Enviroseal 40	0.107	0.031
Sherwin-Williams	Loxon A31T00840	0.117	0.030
Vexcon	CertiVex Penseal BTS	0.129	0.045
TK Products	TK-590-40 Tri-Silane 40%	0.133	0.027
BMS, Inc.	Clear Cladding	0.133	0.026
IMCO Technologies, Inc.	D-Tech 470	0.142	0.040
TK Products	TK-590-1 MS Tri-Silane	0.152	0.016
Fox Industries	FX-821 MMA	0.155	0.041
ChemMasters	Auqanil Plus 40	0.182	0.034
ChemMasters	Auqanil Plus 40A	0.187	0.034
Chemical Product Industries, Inc.	CP-2000W	0.194	0.040
Evonik Industries	Protectosil CIT	0.202	0.059
Control Sample	N/A	0.207	0.042
Chemical Products Industries,Inc.	Vapor Lock VL 0/0	0.225	0.043
IMCO Technologies	Aqua Concrete Primer 1111H	0.235	0.068
ChemTec Int'l, Inc. EPC	ChemTec One	0.245	0.035
Chem-Crete	PaviX CCC100	0.457	0.090
Crack Healer/Sealer *(must broadcast aggregate if used as a sealer)*			
ChemMaster	Duraguard 401-P	0.010	0.010
Advanced Chemical Technologies, Inc.	Sil-Act® EP-700	0.018	0.012
Thin Overlay/Laminate:			
Unitex	Pro-Poxy Type III DOT	0.017	0.016
Sherwin-Williams	FasTop Urethane Coating 4090TC	0.021	0.017
Poly-Carb, Inc.	Mark-163	0.025	0.018
Poly-Carb, Inc.	Mark-154	0.033	0.016

Appendix 2 Depth of Penetration SOP

University of Kentucky Transportation Center

KTC-SOP 24: Depth of Penetration of Concrete Coating System

1. PURPOSE

1.1. The purpose of KTC-SOP 24 is to evaluate concrete coating system for the ability to penetrate concrete specimens in a laboratory setting.

2. SCOPE

2.1. KTC-SOP 24 describes processes related to the performance of the depth of penetration tests and subsequent evaluations when applied to prepared concrete cubes within a laboratory setting. It includes specimen selection, performance of the test, and evaluation of results.

2.2. Reference Documents

2.2.1. Customer Requirements

2.2.2. Equipment Operating Instructions

2.2.3. Product data sheets and MSDS as required

2.2.4. KTC-SOP-11 Concrete Test Panel Manufacturing

2.2.5. KTC-SOP-12 Application of Coatings to Concrete Test Panels

3. MATERIALS / EQUIPMENT

3.1. Test cubes (4" x 4" x 4")

3.2. Concrete Coating System

3.3. Digital camera with macro lens, 10 megapixel resolution (or better)

3.4. Quincy Lab Oven

3.5. Ohaus scales w/readability of 0.1g

3.6. Test chamber/environmental room capable of maintaining 25° +/- 2°C (77° +/- 4°F) and relative humidity of 50 +/- 5%

3.7. Ruler, 6-inch minimum length, ISO certified, precision 5R inch measurements with 10ths and 100ths graduations or digital caliper

3.8. Hammer, 1-2 pound head weight

3.9. Cold chisel

3.10. Food Coloring Dye (dark color)

4. PROCEDURE

Prior to onset of testing carefully review all documentation associated with this procedure.

4.1. Selection of specimens:

4.1.1. Candidate specimens will be selected from the 4"x 4" x 4" cubes ***(coated at 70% moisture content)*** prepared in accordance with KTC-SOP-11 and KTC-SOP-12.

4.1.2. After the Moisture Vapor Test select two post-test cubes per coating system for Depth of Penetration Test.

4.2. Using a hammer and chisel lightly score across the middle of the bottom surface *(surface with the feet attached)* of the specimen. Score progressively deeper in multiple passes until approximately 1/8" deep.

4.3. Place the chisel in the center of the score and strike sharply with the hammer. If the specimen does not break in half, the score may not be deep enough.

4.4. Apply food coloring dye *(undiluted)* at the transition of coated and fractured surface of one half of specimen. Dye will be absorbed into the fractured face of the three edges not impacted by chisel. Do not attempt to soak the fractured surface; capillary action will be sufficient.
- 4.4.1. Blot the excess dye from the specimen.
- 4.4.2. Allow to dry at least 16 hours with fractured face up.
- 4.4.3. The dye will penetrate the unsealed area of the broken edge of the specimen leaving the sealed portion unstained.

5. EVALUATION OF TEST RESULTS:

5.1. After application of dye, there will be three individual edges to evaluate.
5.2. Measure the unstained area of all three edges of the specimen from the sealed surfaces to the stained area in 0.50" increments.
- 5.2.1. Do not measure within 1.0" of the end of each edge. *(This will result in five measurements per edge)*

6. REPORTING TEST RESULTS

6.1. Report the combined average of these measurements as depth of penetration to the nearest 0.01".
6.2. Photograph each measured block face using a ruler for scale.
6.3. Proper identification labels shall be used and visible in each photograph.

7. QUALITY CONTROL/QUALITY ASSURANCE

7.1. In preparation for each test series, all test equipment is to be checked and determined to be in good working order and that calibrations are current.
7.2. The Quality Manager shall be present for a minimum 10% of tests to verify that correct and proper techniques are being applied.
7.3. The functioning of all test equipment will be monitored on a daily basis.

8. CRITICAL MEASUREMENTS/TRACEABILITY OF STANDARDS

8.1. Critical measurements taken during this work include:
- 8.1.1. Environmental chamber set up and monitoring.
- 8.1.2. Ohaus scales set up.

8.2. Standards traceability will be by:
- 8.2.1. Annual calibration on environmental chamber shall be maintained.
- 8.2.2. Annual calibration on Ohaus scales shall be maintained.

9. KTC-SOP-19 REVISION HISTORY

REV	Description of Change:	Effective date	Approved by
0	Initial Release	3/10/15	[signature]
2	Overall update of current practices	7/24/2015	[signature]

Reference

(1) *FRT 194 "Experimental Deck Sealants and Pier Cap Coating on Interstate 471"*