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**EVALUATION OF TREATMENT OPTIONS
FOR ASR-AFFECTED CONCRETE**

by
Kim Basham PhD, PE
KB Engineering, LLC
1716 Capitol Avenue
Cheyenne, WY 82001
kbasham@KBEngLLC.com

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Abstract This research project was undertaken to evaluate the potential of using surface treatments including lithium nitrate, sodium tartarate, siloxanes, silane, and boiled linseed oil to mitigate or slow the rate of concrete deterioration associated with alkali-silica reaction (ASR). Significant amounts of concrete pavements, curbs and gutters, sidewalks, etc. across Wyoming suffer from ASR and related freeze/thaw damage. Any extension of the service life of concrete through remediation can result in significant cost savings to Wyoming Department of Transportation (WYDOT). Also, materials and pavement engineers need methods to evaluate damage and rates of deterioration to help assess the life cycle of ASR-affected concrete. Specific objectives of this investigation were: 1) evaluate the effectiveness of applying various surface treatments to mitigate or slow down the deterioration rate associated with ASR, 2) evaluate the appropriateness of using the Damage Rating Index (DRI) and ultrasonic pulse velocity (UPV) methods for assessing concrete damage and determining the rate of deterioration caused by ASR. Scope of work included: a condition survey of the ASR deteriorated concrete air service apron at the Riverton Regional Airport; extracting "before" treatment cores for petrographic examination, and determining DRI scores and measuring wave velocities using UPV; apply surface treatments to seven of nine test panels; wait five years and perform a second or "after" treatment survey, and extract "after" treatment cores located adjacent to the "before" cores; perform a second round of petrographic examinations and measure DRI scores and wave velocities. Next, compare the "before" and "after" test results, evaluate the effectiveness of the surface treatments, and determine if the DRI and UPV methods are appropriate for assessing concrete damage and establishing rates of deterioration. Although the study was prematurely terminated after two years, valuable information was obtained: 1) DRI and UPV methods did measure ASR related damage and deterioration; however, correlation of the measured damage and rates of deterioration between these methods was poor. 2) Test results indicated that surface treatments consisting of lithium nitrate, sodium tartarate and siloxane may reduce the rate of ASR deterioration. However, no firm conclusions were made because of the limited samples tested and conflicting test results from DRI and UPV. This report presents: discussions about ASR, DRI, UPV, test results, comparisons of DRI and UPV test results for "before" and "after" concrete samples representing test panels treated with lithium nitrate, sodium tartarate, siloxanes, silane, and boiled linseed oil. Conclusions and recommendations are also presented.			
Key Words Wyoming, concrete, alkali-silica reaction, ASR, freezing and thawing, taxiway, airport, pavement, service life, sealant, lithium nitrate, siloxane, silane, sodium tartarate, boiled linseed oil, petrographic examination, Damage Rating Index (DRI), ultrasonic pulse velocity (UPV), life cycle		Distribution Statement Unlimited	
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SI* (Modern Metric) Conversion Factors

Approximate Conversion from SI Units					Approximate Conversion to SI Units				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
Length					Length				
mm	millimeters	0.039	inches	in	in	inches	25.4	millimeters	mm
m	meters	3.28	feet	ft	ft	feet	0.305	meters	m
m	meters	1.09	Yards	yd	yd	Yards	0.914	meters	m
km	kilometers	0.621	miles	mi	mi	miles	1.61	kilometers	km
Area					Area				
mm ²	square millimeters	0.0016	square inches	in ²	in ²	square inches	645.2	square millimeters	mm ²
m ²	square meters	10.764	square feet	ft ²	ft ²	square feet	0.093	square meters	m ²
m ²	square meters	1.195	square yards	yd ²	yd ²	square yards	0.836	square meters	m ²
ha	hectares	2.47	acres	ac	ac	acres	0.405	hectares	ha
km ²	square kilometers	0.386	square miles	mi ²	mi ²	square miles	2.59	square kilometers	km ²
Volume					Volume				
ml	milliliters	0.034	fluid ounces	fl oz	fl oz	fluid ounces	29.57	milliliters	ml
l	liters	0.264	gallons	gal	gal	gallons	3.785	liters	l
m ³	cubic meters	35.71	cubic feet	ft ³	ft ³	cubic feet	0.028	cubic meters	m ³
m ³	cubic meters	1.307	cubic yards	yd ³	yd ³	cubic yards	0.765	cubic meters	m ³
Mass					Mass				
g	grams	0.035	ounces	oz	oz	ounces	28.35	grams	g
kg	kilograms	2.202	pounds	lb	lb	pounds	0.454	kilograms	kg
Mg	megagrams	1.103	short tons(2000 lbs)	T	T	short tons (2000 lbs)	0.907	megagrams	Mg
Temperature (exact)					Temperature (exact)				
°C	Centigrade temperature	1.8C + 32	Fahrenheit temperature	°F	°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Centigrade temperature	°C
Illumination					Illumination				
lx	lux	0.0929	foot-candles	fc	fc	foot-candles	10.76	lux	lx
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl	fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
Force and Pressure or Stress					Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf	lbf	poundforce	4.45	newtons	N
kPa	kilopascals	0.145	pound-force per square inch	psi	psi	pound-force per square inch	6.89	kilopascals	kPa

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The Wyoming Department of Transportation, Research Center provided funding for this research project and the Riverton Regional Airport located in Riverton, Wyoming provided the concrete test areas. The author expresses his sincere thanks to these organizations for their support.

Also, the author acknowledges several individuals from the WYDOT and the Riverton Regional Airport that made significant contributions to this research. Tim McDowell, PE and Michael Patritch from the WYDOT, Research Center provided administrative support. Cheryl Bean, PE from Aeronautics Division, WYDOT provided guidance and suggestions, and supervised the research project. She also acted as the liaison official between WYDOT personnel and airport personnel. Jamie Sharp from the WYDOT, Materials Program assisted with the pavement condition surveys and concrete sampling. Special thanks goes to Bill Urbigkit, Airport Manager and Paul Griffin, Operations with the Riverton Regional Airport who continually supported this research project, participated in construction scheduling and provided special access to the air carrier apron.

EXECUTIVE SUMMARY

In 1997, the commercial air service apron at the Riverton Regional Airport in Riverton, Wyoming was constructed of Portland Concrete Cement Pavement (PCCP). Within a few years, “map cracking” associated with alkali-silica reaction (ASR) started to appear and progressed at a rapid rate. The 2004 pavement condition index (PCI) for the apron was 78. In 2007, the PCI had fallen to 33. The Wyoming Department of Transportation (WYDOT) considers PCI values less than 70 as poor, from 70 to 79 as fair, 80 to 94 as good, and 95 to 100 as excellent based on a scale of 0 to 100.

With the increasing costs of construction, it is imperative for material and pavement engineers to determine the best strategy to mitigate this kind of damage and to extend PCCP life as long as possible. Currently, WYDOT designs rigid pavements for a 30-year life with some expected remediation at year 20. Any extension of the service life of PCCP through remediation can result in significant cost savings to the department. Also, it is important for engineers to be able to evaluate damage and rates of deterioration to help assess the life cycle of ASR-affected concrete.

During the summer of 2005, it was determined the concrete apron would provide an ideal concrete test area for evaluating various surface treatments including sodium tartarate, lithium nitrate, siloxane, silane and boiled linseed oil for mitigating ASR-affected pavements. Specifically, WYDOT was interested in determining if surface treatments had the potential to mitigate or more specifically slow the rate of deterioration associated with ASR. Significant amounts of concrete pavements, curbs and gutters, sidewalks, etc. across Wyoming suffer from ASR and related freeze/thaw damage.

The methods selected to evaluate the effectiveness of the surface treatments included petrographic examinations combined with a Damage Rating Index (DRI) method and ultrasonic pulse velocity (UPV). Both methods have been used to evaluate concrete damage resulting from ASR. Therefore, a second objective of assessing the appropriateness of using DRI and UPV for evaluating ASR damage was included.

After applying various surface treatments to seven of nine test panels, “before” and “after” concrete samples were evaluated using petrographic examinations, DRI and UPV methods. Originally, the time period between applying the treatments and evaluating their effectiveness was five years. However, the pavement was replaced after two years because the apron started exhibiting foreign object body damage debris (FOD) creating unsafe conditions and construction funding had become available.

Although the study only lasted for two years, valuable information was discovered and included: 1) DRI and UPV methods did measure ASR related damage and deterioration; however, correlation of the measured damage and rate of deterioration between these methods was poor. Therefore, engineers should use caution when interpreting DRI and UPV test results and only use these damage assessment methods as part of a total evaluation program. Plotting either DRI or UPV results versus time may yield valuable insight with regards to the anticipated service life of ASR-affected concrete. 2) Test results indicated that surface treatments consisting of lithium nitrate, sodium tartarate and siloxane may reduce the rate of ASR deterioration. However, no firm conclusions can be made because of the limited samples tested and conflicting results provided by the DRI and UPV methods. Also, the effectiveness of surface treatments is dependant on items such as the potential reactivity of the coarse and fine aggregates, and exposure conditions including sources of moisture to support ASR.

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1.0 INTRODUCTION

Riverton Regional Airport located at 4800 Airport Road, Riverton, WY 82501 provides private and commercial air service to the communities of Riverton, Dubois, Hudson, Lander, Shoshoni and the Wind River Indian Reservation. It serves as a year-around gateway to Yellowstone and Grand Teton National Parks in Northwest Wyoming.



Figure 1.1 Riverton Regional Airport.

In general the weather in Riverton is mild compared to the rest of Wyoming. The average annual rainfall is 13.60 inches per year. Average daily low temperature during winter 17.6°F and the average high during the summer is 89.2°F. Even with 347 days of sunshine, concrete pavements are subjected to numerous freeze/thaw cycles in the fall, winter and spring.

1.1 Background

In 1997, the commercial air service apron at the Riverton Regional Airport in Riverton, Wyoming was constructed of a 12 inch thick Portland Cement Concrete Pavement (PCCP). The top surface of the pavement had a broom finish and the concrete was placed directly on a bituminous felt membrane. Beneath the felt, KBE understood there was an engineered base material. The top of slab elevation of the pavement was basically the same as the surrounding landscaping so that drainage away from the apron was fair to poor. Formed contraction joints were sealed with a bituminous joint sealant. The apron was approximate 8,100 square yards as shown in Figure 1.2 below.

After approximately five years, map cracking and relative displacements of the pavement associated with alkali-silica reaction (ASR) started to occur. ASR is a chemical reaction between alkalis from the portland cement and certain constituents of some aggregates. Under certain conditions, deleterious expansion of the concrete occurs, resulting in cracking and overall deterioration of the concrete.

During the summer of 2005, this author accompanied Cheryl Bean, PE with the Aeronautics Division of Wyoming Department of Transportation (WYDOT) and other WYDOT personnel to inspect the apron and to meet with Bill Urbigkit, Airport Manager. Shortly thereafter, it was determined the concrete apron would provide an ideal concrete area to test various surface treatments for ASR-affected pavements. Specifically, WYDOT was interested in determining if surface treatments had the potential to mitigate or more specifically slow the rate of deterioration associated with ASR. Significant amounts of concrete pavements, curbs and gutters, sidewalks, etc. across Wyoming suffer from ASR and related freeze/thaw damage. Many parts of the

country, especially the Rocky Mountain Region where ASR is common, deal with reduced service life and premature replacement costs associated with ASR deterioration. The benefits of mitigating or slowing the rate of ASR deterioration would be significant.

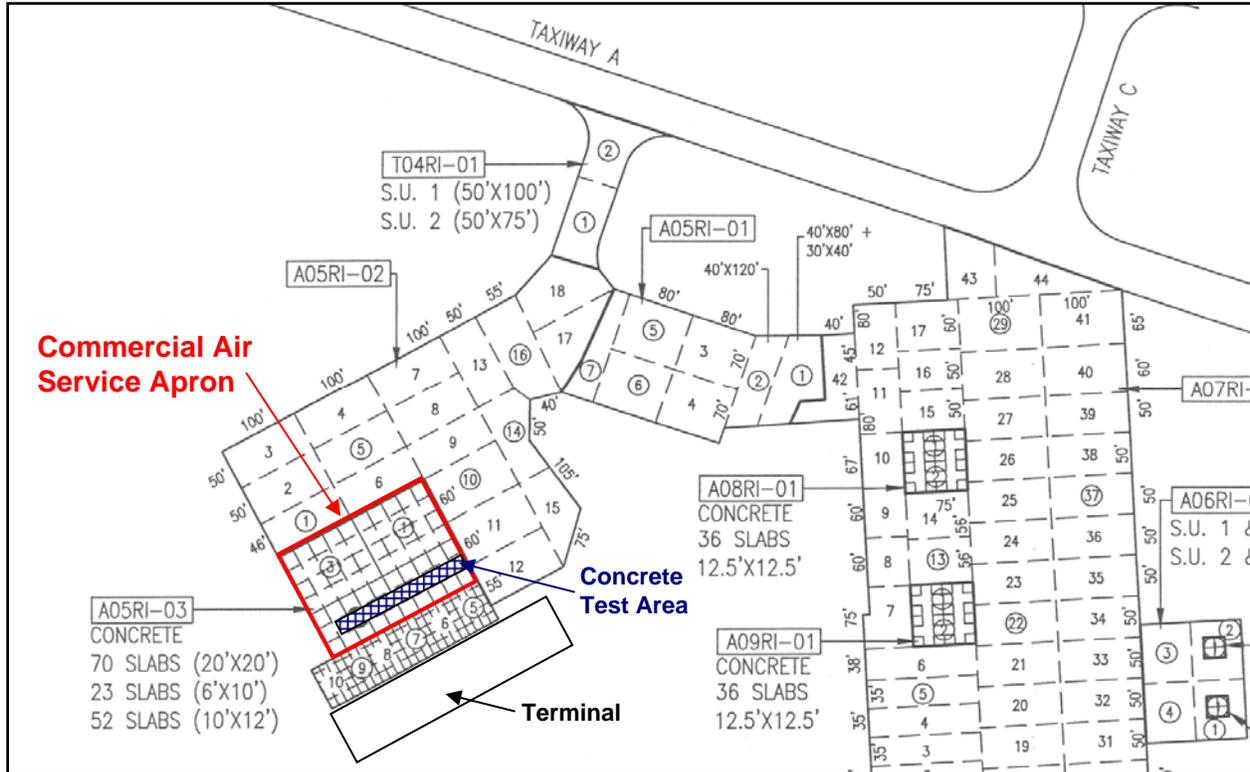


Figure 1.2 Commercial air service apron at the Riverton Regional Airport. The apron consisted of a 12 inch thick Portland cement concrete pavement (PCCP). The cross-hatched rectangular area north of the air terminal was the concrete test area used in this research.

Surface treatments included various chemical treatments and sealers including: lithium nitrate, lithium nitrates combined with different types of sealers, siloxane, silane, sodium tartarate and boiled linseed oil. Surface treatments will be discussed in more detailed in Section 3 of this report.

During the winter of 2006, Cheryl Bean and this author developed a research program to evaluate the effects of various surface treatments on reducing the rate of ASR deterioration. Basically, we decided to evaluate the concrete before applying the treatments using petrographic examinations and ultrasonic pulse velocity (UPV) to determine the existing deterioration or damage level. Then, apply the surface treatments and reevaluate the deterioration after five years. By comparing levels of damage from the “before treatment” to the “after treatment plus five years,” the effectiveness of surface treatments in slowing the rate of ASR deterioration could be determined.

In late March 2006, nine pavement panels of the apron were selected and full-depth cores were drilled and extracted from the pavement. Nine cores, representing the nine test panels, were sent to DRP Consulting, Inc. in Boulder, CO where Dr. David Rothstein PG performed petrographic examinations. Also Rothstein established a *Damage Rating Index* (DRI) for the cores to serve as the before treatment damage index. Other cores were tested using UPV to measure the speed of a stress wave through the cores. Microcracks and ASR deteriorations slow the speed of a stress wave passing through the concrete. By comparing the before DRI and UPV results with the after results, the effectiveness of surface treating concrete deteriorating from ASR was evaluated.

Originally, the second set of cores was scheduled to be removed and evaluated during the summer of 2011 or after five years of additional service. However, the Airport removed and replaced the apron in the fall of 2008. Instead of five years of service after applying the surface treatments, the concrete only had two additional years of service. Thus, the evaluation period was reduced by three years. After some discussions with Cheryl Bean, it was decided to perform the second evaluation. We hoped that two years of exposure would be a sufficient time period to show or at least provide some insight to the effect of surface treating ASR-affected concrete. Consequently, a second set of cores were extracted from the nine test panels in September 2008 and stored until DRP was able to perform the second round of petrographic examinations in the early spring of 2009. The second set of cores were extracted adjacent to the first set of cores extracted in April 2006; thereby, should represent the same concrete except for the additional two years of service.

Details about ASR deterioration, objectives and scope of work for this research project, surface treatments, DRP’s petrographic findings and *Damage Rating Indexes*, UPV test results, comparisons of the “before” and “after” evaluations, conclusions and recommendations are presented in the following sections.

1.2 Alkali-silica Reaction (ASR)

Aggregates containing reactive silica minerals can react with alkali hydroxides in the concrete. The alkali-silica reaction forms a gel that has an affinity for moisture. The reaction is a two step process as shown in Figure 1.3. As the gel absorbs water from the surrounding cement paste, it expands and exerts a pressure that cracks both the aggregate and adjacent paste as shown in Figures 1.5 and 1.6 (pg 5).

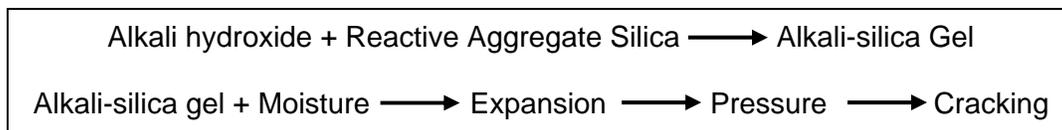


Figure 1.3 Two step process of the ASR deterioration mechanism (Farney, 1997).

Reactive silica, provided by the source aggregate, can include numerous types of rock and minerals with a wide range of compositions. Not all siliceous materials contribute to ASR. Its effect is dependent on the crystalline structure, mineralogy, and ultimately the

solubility. Alkalies are introduced most commonly by the Portland cement but other sources such as aggregates, admixtures and deicing chemicals can also contribute to the reaction. The third and necessary condition that must exist for ASR to occur is sufficient moisture. Research has shown that expansive ASR occurs when the relative humidity is above 80%. Even in arid environments such as Wyoming, it is common to have high relative humidities (> 80%) just below the surface of concrete pavements. Moisture sources include rain fall, snow melt and water or vapor from the ground. Moisture enters concrete through the surface, unsealed cracks and joints, and from the bottom of the slab. Even with a capillary break (engineered base material) between the ground and concrete, moisture vapor from the ground can migrate into the concrete and increase the relative humidity to a sufficient level to promote ASR as illustrated in Figure 1.4 below.

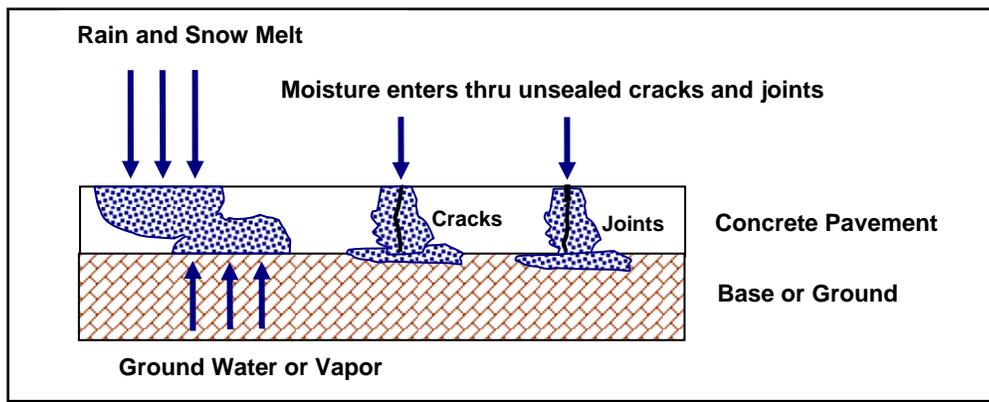


Figure 1.4 Illustration of moisture intrusion pathways into concrete pavements.

ASR indicators are: a network of cracks commonly referred to as “map cracking,” relative displacements of the pavement, closed or spalled joints, and aggregate popouts. Popouts are aggregate and concrete fragments breaking out of the concrete surface. Examples of map cracking are shown in Figures 1.7 and 1.8 (pg 6) for the air carrier apron at the Riverton Regional Airport.

ASR is a slow process that typically takes years to manifest. Therefore, catastrophic concrete failures are very rare. However, continuous deterioration resulting from ASR commonly leads to serviceability problems and a reduced service life. Surface deterioration of airfield pavements is especially unacceptable because deteriorating pavements may lead to foreign object damage (FOD) if concrete fragments are pulled into jet engines. FOD is a major concern for airport managers because of the associated repair costs and safety concerns.

ASR can also exacerbate other deterioration mechanisms caused by concrete exposure to sulfate ions from soils, freezing and thawing, and deicing chemicals. Research also shows that deicing chemicals such as potassium acetate and other deicers may aggravate or even cause ASR. Reportedly, ASR gel-products occur near the surface where the deicing chemicals have penetrated into the concrete and not necessarily throughout the depth of the pavement.



Figure 1.5 Reflected light photomicrograph of polished surface showing reaction rim (measured by red bars) or alkali-silica reaction product on fine aggregate particle. (Figure E4 from DRP's report (Appendix A).

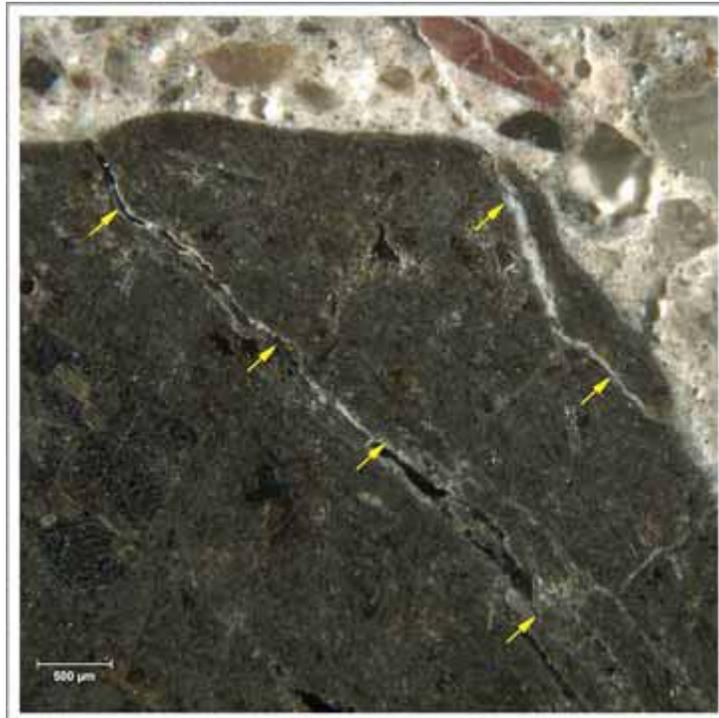


Figure 1.6 Reflected light photomicrograph of polished surface showing coarse aggregate particle with internal fractures that are filled with ASR gel (yellow arrows). (Figure E2 from DRP's report (Appendix A).

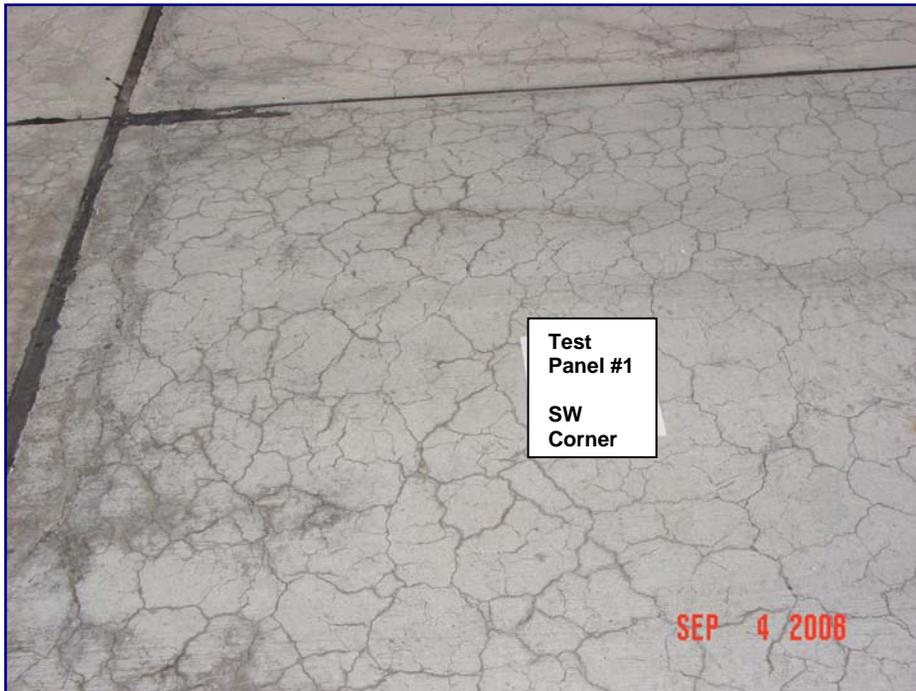


Figure 1.7 Typical “map cracking” caused by ASR damage on concrete test panel #2. ASR damage was worst along joints where joint sealant had failed and provided additional pathways for moisture and external alkalis to enter the concrete. Edges also allowed non-restrictive concrete expansion resulting in more cracks and damage.

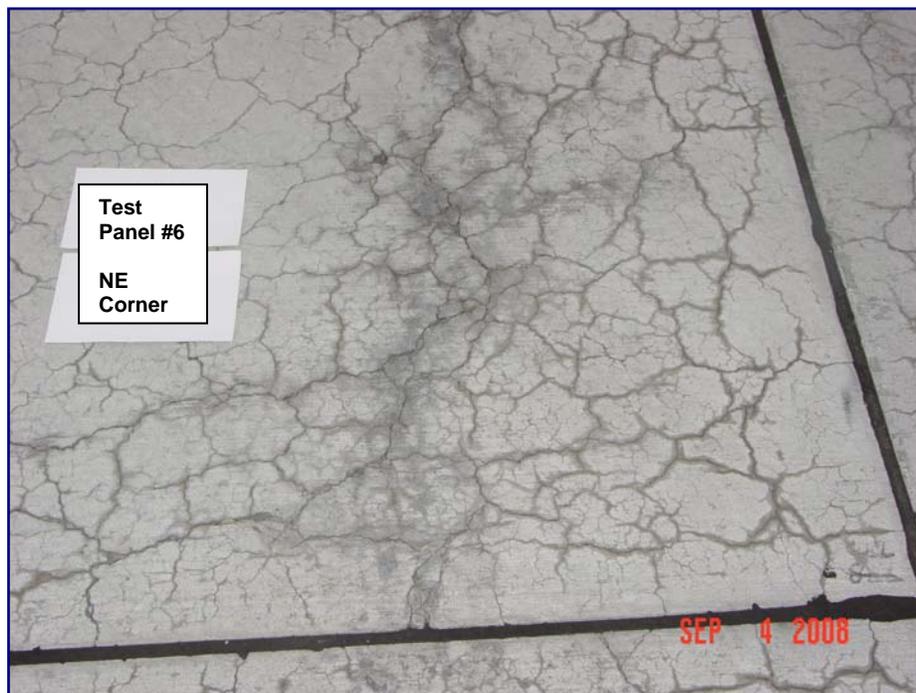


Figure 1.8 Typical, ASR “map cracking” observed on all concrete test panels. Cracking was worse along joints than in the center of the panels. Also, unsealed joints provided pathways for water and external alkalis to enter the concrete from the bottom.

1.3 Cycle of Deterioration Due to ASR, Frost and Deicing Chemicals

The most potential destructive weathering factor for concrete pavements in Wyoming is frost or cycles of freezing and thawing while pavements are wet, especially when exposed to deicing chemicals. Freeze/thaw damage and deterioration is caused by freezing of water in the concrete and the resulting expansion in the cement paste. When water freezes, its volume increases 9%. With a proper air void system, freeze/thaw damage is typically minimized. An air void system consists of microscopic air bubbles purposely created in the cement paste. These bubbles provide void spaces for the unfrozen water displaced by ice crystals to enter and thus the hydrologic pressure created by ice formation is relieved.

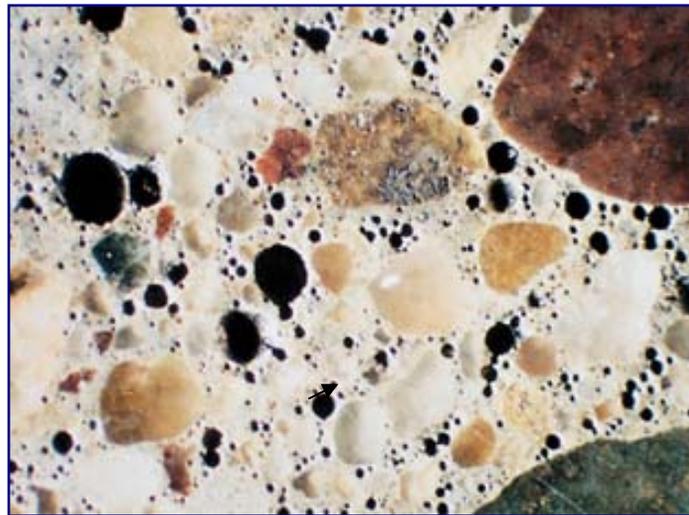


Figure 1.9 Polished section of air-entrained concrete as seen through a microscope (Kosmatka 2002, 129). Air voids are extremely small (10 μm to 100 μm) and provide an escape path for water being displaced by ice crystals. Thus, relieving the hydrostatic pressure created by the formation of ice crystals in the cement paste.

Deicing chemicals (including aircraft deicers) exacerbate the freeze/thaw damage for several reasons. Primarily, deicing chemicals increase the moisture content of the concrete because they have an affinity for water and second, they increase the hydrostatic pressures within the cement paste. Deicing chemicals also cause differential layer freezing in the concrete and may thermally shock the surface of concrete. With regards to ASR, deicing chemicals typically aggravate ASR because they increase the alkalis in the concrete, especially in the zone beneath the surface of the concrete (ACPA, 2005). In addition to providing a pathway for moisture to enter the concrete, unsealed cracks and joints provide a pathway for external alkalis to enter the concrete. Of course, as freeze/thaw and ASR damage occurs, existing cracks enlarge and new cracks form. Enlarged and new cracks provide additional pathways for both moisture and external alkalis from deicing chemicals to enter the concrete creating more expansion and more cracking as illustrated below in Figure 1.10.

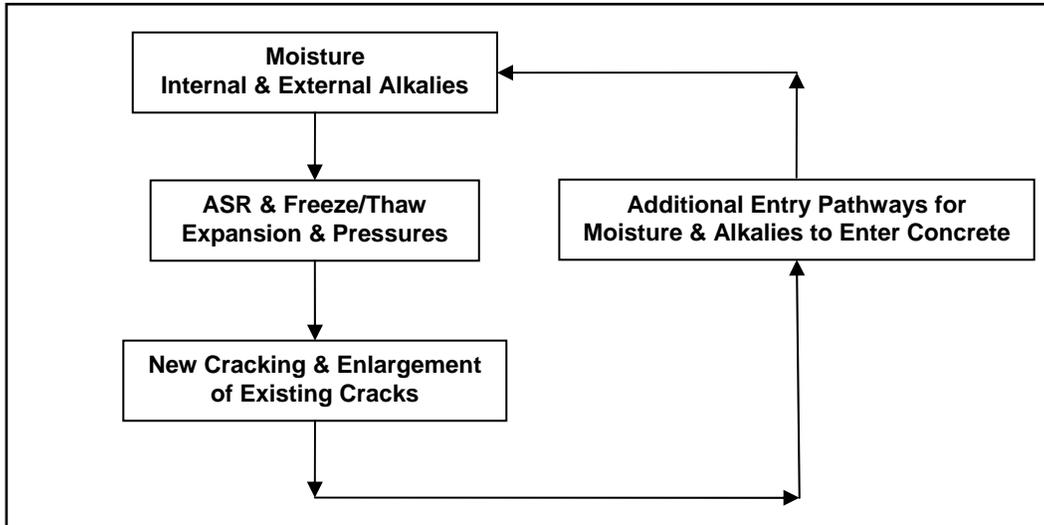


Figure 1.10 Illustration of progressive cycle of concrete deterioration caused by ASR and frost damage.

1.4 Research Objectives and Scope of Work

Primary research objectives included:

1. Evaluate the effectiveness of various surface treatments for mitigating or reducing the rate of ASR deterioration of concrete pavements. Of course, ASR deterioration is closely linked to frost damage. Therefore, this objective also included mitigating or reducing the rate of freeze/thaw damage.
2. Determine if petrographic examinations using the *Damage Rating Index* (DRI) technique and ultrasonic pulse velocity (UPV) are viable test methods for evaluating and rating ASR damage. Also, determine if material and pavement engineers can use these methods to measure the rate of concrete deterioration for the purpose of estimating the amount of remaining service life of concrete pavements suffering from ASR or a combination of ASR and freeze/thaw damage.

The research goal was to provide material and pavement engineers guidance and recommendations with regards to: 1) using surface treatments (e.g., lithium nitrate and penetrating sealers) to mitigate or reduce the rate of ASR concrete deterioration, 2) using DRI and UPV to evaluate and rate concrete deterioration resulting from ASR or a combination of ASR and freeze/thaw activities.

Even with a shortened evaluation time period (two instead of five years), the research objectives were basically fulfilled. A two year evaluation period was sufficient to draw preliminary conclusions regarding the effectiveness of surface treatments for ASR-affected concrete and to determine that DRI and UPV are appropriate methods for assessing and rating ASR related damage in concrete cores.

Scope of work included:

1. Layout and photograph concrete test panels.
2. Select and obtain surface treatments to evaluate.
3. Drill and remove the first set or “before” concrete core samples for petrographic examination including the DRI evaluation and UPV testing.
4. Clean and apply surface treatments to test panels according to the manufacturer’s recommendations.
5. Re-inspect and establish pavement condition indexes annually over a time period of five years. As previously discussed, Riverton Regional Airport replaced the apron including the test panels after two years; thereby, significantly reducing the evaluation time period.
6. Drill and remove the second or “after” concrete core samples for petrographic examination including the DRI evaluation and UPV testing.
7. Compare and rank the “before” and “after” results of DRI and UPV tests.
8. Using the comparison and rankings of the “before” and the “after” test results, determine the effectiveness of using surface treatments to mitigate or reduce the rate of ASR deterioration.
9. Determine if DRI and UPV are appropriate means for evaluating ASR damage or ASR and frost damage of concrete pavements for the purpose of measuring deterioration rates and estimating the remaining service life.
10. Write and submit report to the WYDOT Research Center.

1.5 Damage Rating Index (DRI)

Damage Rating Index (DRI) is an investigation technique developed by P.E. Gratten-Bellow, Senior Research Scientist at the Institute for Research in Construction, National Research Council of Canada in 1995. Gratten-Bellow developed and used the DRI technique to evaluate the severity of ASR deterioration of concrete cores extracted from walls at the Saunders Generating Station in Cornwall, Canada. DRI values are determined by measuring the number of each type of defect in every square of a 1.5 cm (0.6-inch) grid using a mechanical stage under a stereobinocular microscope at a magnification of 16X. Defects include: cracks, with and without ASR gel in both the paste and aggregates; reaction rims; debonding of aggregate particles; and ASR gel in void spaces. Next, the sum of each type of defect is multiplied by a factor designed to relate the defect to its likely contribution to the deterioration of the concrete as shown in Table 1.1 below.

Table 1.1 DRI Factors Applied to Total Number of Each Defect Type

Feature Measured	Multiplication Factor
Coarse aggregate with cracks	0.25
Coarse aggregate with cracks and ASR gel	2
Coarse aggregate debonded	3
Reaction rims around coarse aggregate	0.5
Fine aggregate with cracks	0.25
Fine aggregate with cracks and ASR gel	2
Fine aggregate debonded	2
Reaction rims around fine aggregate	0.25
Cement paste with cracks	2
Cement paste with cracks and ASR gel	4
Air voids with ASR gel	0.5

The sum of the factored totals of each type of observed defect yields the *Damage Rating Index* (DRI) for the concrete sample. DRI gives a measure of the amount of deterioration due to ASR damage but also includes defects associated from other causes such as freezing and thawing and deicing chemicals.

1.6 Ultrasonic Pulse Velocity (UPV)

UPV is one of the oldest nondestructive testing (NDT) methods available for evaluating concrete. It is based on measuring the travel time over a known path length of a pulse of ultrasonic compressional waves. Dividing the path length by the travel time yields the pulse velocity. The velocity of the ultrasonic compressional wave through concrete depends on the elastic properties and density of the concrete. Cracks and voids in the path length will delay the travel time because the compression wave cannot travel through air; therefore, the wave must go around the flaws. Delayed transit times decrease the computed wave speed through the concrete. Reportedly, UPV has been used to define the extent and magnitude of concrete deterioration resulting from fire, mechanical, frost and chemical attack. However, its use to evaluate ASR damage has been somewhat limited, especially with the intent of establishing a rate of deterioration for predicting life cycle.

The equipment consists of a base unit that generates pulse waves, measures and digitally displays the transit time. The user first enters the length of the travel path and the base unit computes the wave speed. The transmitting and receiving transducers are coupled to the concrete using petroleum jelly or water-soluble grease. The electronic timing device measures the interval between the onset and reception of the pulse waves. Figures 1.11 and 1.12 illustrate and show the UPV testing equipment used in this project.

Wave speeds equal to and exceeding 12,000 ft/sec indicates good quality or undamaged concrete. Whereas, speeds between 10,000 and 12,000 ft/sec point to questionable concrete quality and speeds less than 10,000 ft/sec typically indicate poor or damaged concrete.

In this research project, a V-Meter III manufactured by James Instruments, Inc. was used to measure the ultrasonic pulse velocities of drilled cores representing the “before” and “after” concrete. Results are presented in Section 4.1 and Appendix B of this report.

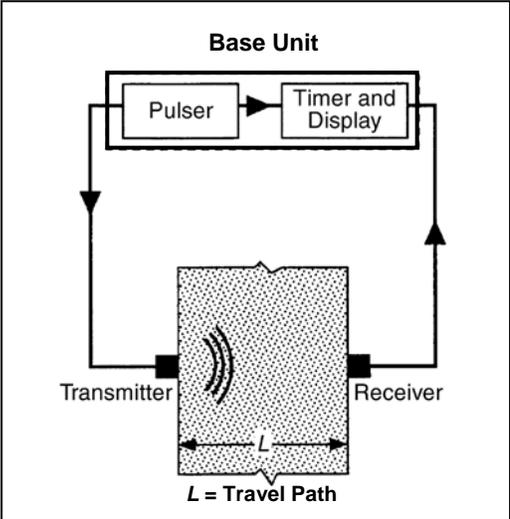


Figure 1.11 UPV testing schematic.



Figure 1.12 Measuring the ultrasonic pulse velocity of a drilled core using a James Instrument V-Meter III. Cracking due to ASR and frost damage (i.e., cracks) slows the travel time yielding slower wave speeds.

2.0 TEST AREAS: VISUAL INSPECTION AND CORES

The “before” cores were extracted from the test areas April 25, 2006. Surface treatments were applied September 7, 2006 and the “after” cores were extracted from test panels September 4, 2008 or about two years after the surface treatments had been applied.

2.1 “Before” Cores and Visual Observations

The concrete test area consisted of nine areas defined by construction joints as shown in Figure 1.2 and Figure 2.1 below. Test areas #1 through #9 are bordered by either concrete or asphalt pavement so the boundary conditions of the test panels were similar.

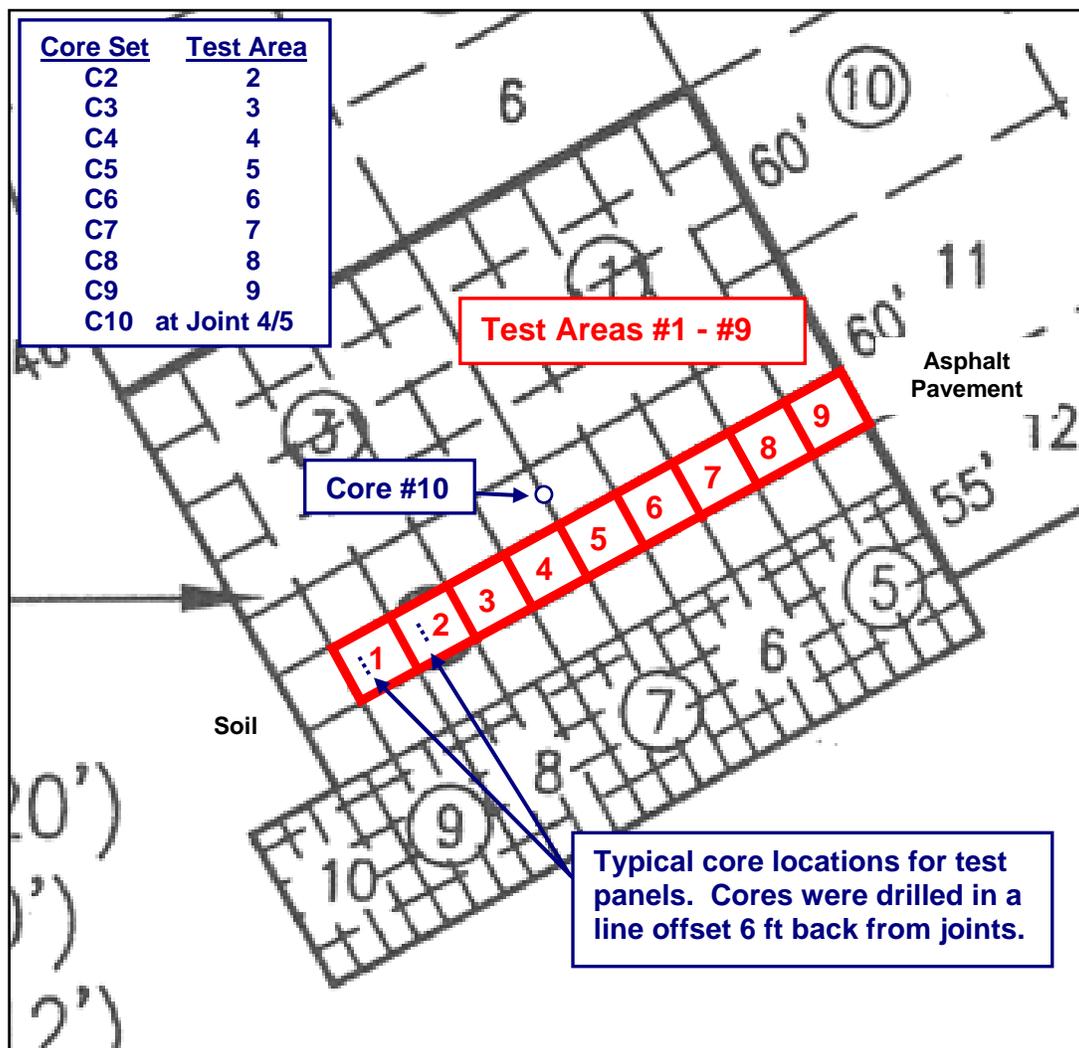


Figure 2.1 Schematic showing test areas 1 – 9 and core locations.

This author, Jamie Sharp and a core drilling crew from WYDOT removed the first set of cores April 25, 2006 (Figure 2.2). Four cores (labeled A – D) were drilled and removed from each test panel plus one additional core (C10) was removed from the construction joint just north of the panels separating test panels #4 and #5 as shown in Figure 2.1 above. Drilled cores were later subjected to a petrographic analysis and damage rated using the DRI method and UPV testing.



Figure 2.2 WYDOT coring crew from Cheyenne quickly and efficiently removed cores from test panels using a trailer mounted core machine.

ASR “map cracking” and cracking oriented parallel to the joints was moderate to severe across the entire concrete apron as shown in Figures 2.3 – 2.5. Cracking was especially severe along the joints and corners of the panels. ASR damage was worst in these areas due to joint sealant failure that allowed water to enter the joints. Thus, concrete along joints were exposed to moisture from top surfaces, sides and bottoms. On several cores, cooling water was stopped prior to drilling entirely through the slab in order to assess the moisture condition beneath the slab. Moisture and water was observed on top of the bituminous felt beneath the concrete.

It appeared as though the bituminous felt located beneath the pavement was preventing surface water that had passed through joints from draining away from the pavement. Therefore, joint edges of the concrete panels were exposed to moisture from three directions: top surfaces, sides and

bottoms. This explains why ASR cracking was more severe along the joint edges of the panels.

In addition to map cracking, cracks along the joint edges were oriented parallel to the joints. This is a common observation for ASR-affected pavements. As expansion occurs due to the swelling ASR gel, it expands unrestricted towards the free edge resulting in cracks oriented parallel to joints. In fact, the concrete apron had pushed the asphalt pavement along the north and east edges so that a roll or small asphalt bump formed. Paul Griffin with the airport reported that airport workers had ground down the asphalt bump several times in the past years but it always returned. Basically, the concrete apron was growing in both length and width due to the ASR expansion.



Figure 2.3 Typical ASR “map cracking” and cracks oriented parallel to panel joints. Free edges allow concrete to expand perpendicular to the edge resulting in cracks parallel to joint.



Figure 2.4 Map cracking was more severe along joints and especially in the corners of the panels due to additional sources of moisture feeding the ASR. Orange paint identifies the coring location for Core 10 – through the construction joint.



Figure 2.5 Water used during the coring operation bubbled up through joints away from the location being cored indicating pathways existed allowing water to move between the pavement and bituminous felt.



Figure 2.6 Core C10 showing an activated joint and other cracks that provided additional entry points for water to enter the concrete and to seep between the pavement and bituminous felt.

While drilling cores, several of the cores broke off before drilling full depth. ASR gel was observed in aggregate pockets and cracks of several of the core fragments without magnification as shown below in Figure 2.7. This illustrates the advanced stage of the ASR damage.



Figure 2.7 ASR gel was observed in aggregate pockets and connecting cracks on several drilled core fragments without magnification.

2.2 “After” Cores and Visual Observations

In general, all test panels exhibited more ASR damage after two years of additional exposure, especially along joint edges and in the corners of the test panels. New cracks and crack width growth were commonly observed. Also, some concrete spalling, especially along joint edges were observed for all test panels. Figures 2.8 and 2.9 below show the “before” and “after” condition of the NW corner of test panel #2. Test panel #2 was a control panel and did not receive a surface treatment. This panel had the highest DRI core reduction of the test panels indicating this panel had the most increase of ASR damage of the panels during the two year evaluation period.

Figures 2.10 and 2.11 show the “before” and “after” condition of the NW corner of test panel #3. Lithium nitrate (LiNO_3) was applied to this panel and DRI results indicate this panel had the least amount of additional ASR damage during the evaluation period.

Only these “before” and “after” panel photographs are presented in the report because the photographs of other test panels are similar. Also, the differences of the “before” and “after” conditions are subtle and difficult to make out in the photographs. Therefore, only photographic examples representing the worst and best performance of the test panels are presented.

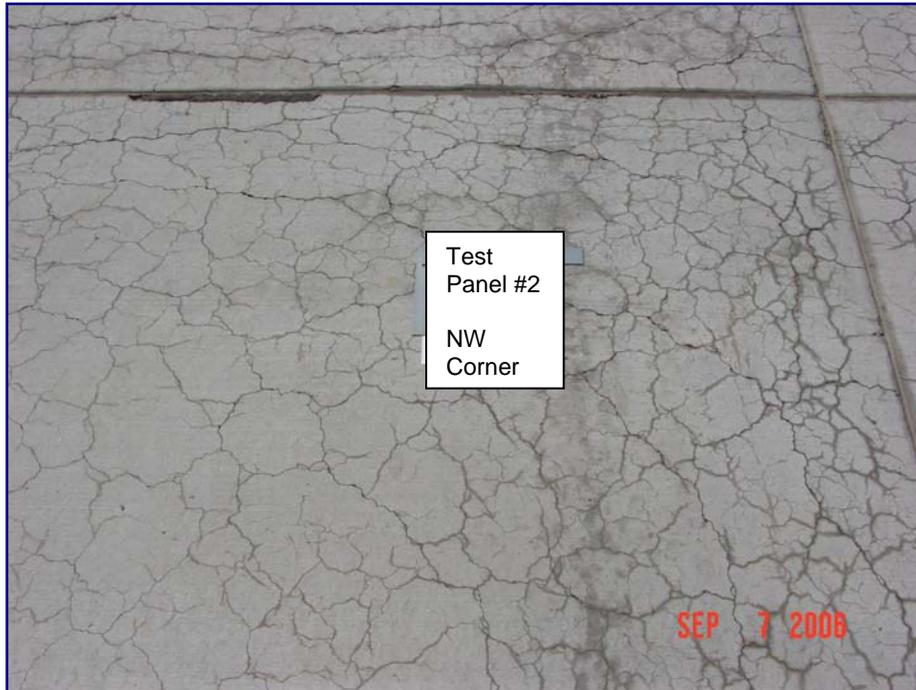


Figure 2.8 ASR damage of NW corner of test panel #2 as of September 7, 2006 commonly referred to as the “before” condition. Because other test panels exhibited similar levels of damage, their photos are not included.

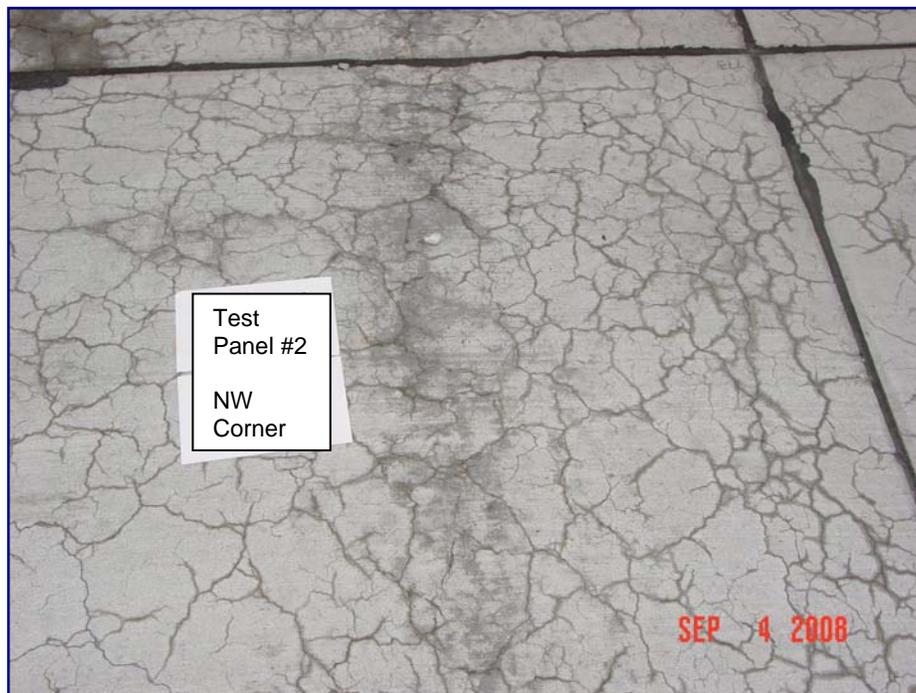


Figure 2.9 “After” condition of the NW corner of test panel #2 as of September 4, 2008. Crack widths had grown and new cracks had formed during the two year evaluation period. Some edge spalling had also occurred along joint edges. Test panel #2 was a control panel and had the largest DRI reduction of the test panels.

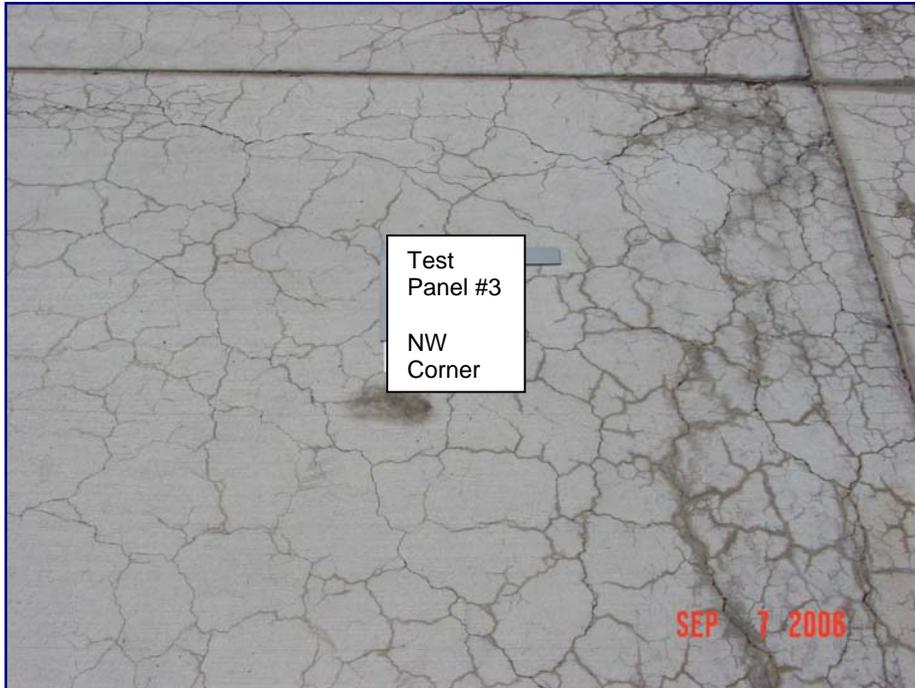


Figure 2.10 ASR damage of NW corner of test panel #3 as of September 7, 2006 commonly referred to as the “before” condition.

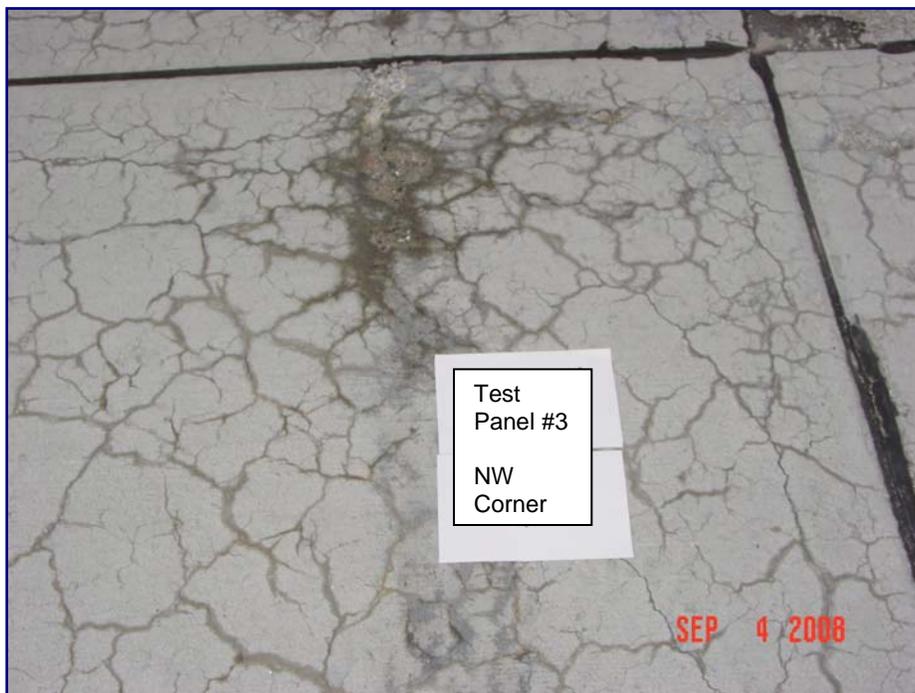


Figure 2.11 “After” condition of the NW corner of test panel #3 as of September 4, 2008. Cracks widths had grown and new cracks had formed during the two year evaluation period. Some minor edge spalling had also occurred along joint edges. Test panel #3 was treated with lithium nitrate and had the least DRI reduction of the test panels.

3.0 SURFACE TREATMENTS FOR ASR-AFFECTED CONCRETE

Surface treatments were selected on their potential to migrate ASR by either directly interfering with the alkali-silica reaction or by reducing the intrusion of water into the concrete. As previously discussed, water is a key part of the ASR process and related damage. By sealing the surface of the concrete and minimizing absorption of water into the concrete that damage or more specifically the rate of damage caused by ASR and frost would be reduced. Five different surface treatments were used:

1. Sodium tartarate is the primary ingredient in a proprietary product manufactured by International Chem-Crete Inc. of Richardson, TX. This low viscosity, water-based chemical product uses crystallization technology to seal concrete against water penetration. Reportedly, it forms two types of crystals with hygroscopic and hydrophilic properties that block and prevent surface water from penetrating into the surface of the concrete. Also, the manufacture claims this product will seal cracks up to 1/16th of an inch. This surface treatment was applied to test panel #1.
2. Lithium nitrate (LiNO₃) is a chemical that alleviates the expansive properties of ASR-affected concrete. While lithium nitrate does not stop or prevent the alkali-silica reaction from occurring, it does inhibit the ASR gel from swelling and creating expansive pressures. Because lithium silicates are less water-soluble than alkalis supplied by portland cement, the alkali-silica gel that forms is non-expansive (Adams, 2002, 102)
3. Siloxane sealers are penetrating (non-film forming) water-repellant concrete sealer. Siloxanes are designed to chemically react with the cementitious products within the concrete to provide a water barrier. It is commonly used to protect concrete structures, decks, and pavements from the adverse effects of deicing chemicals, moisture and freeze/thaw damage.
4. Silane sealers are penetrating water-repellant concrete sealers similar to siloxanes except they have a smaller particle size enabling deeper penetration into the concrete. Silanes are also chemical reactive like siloxanes.

Shortly after application, siloxane and silane sealers will bead water on the surface as shown in Figure 3.1. Also, they typically last longer than film-forming sealers and are less subject to wear under traffic or deterioration from sun exposure and will not alter the surface texture of the concrete. Siloxanes and silanes are breathable sealers that permit water vapor to escape but prevent the ingress of moisture.

5. Boiled linseed oil and solvents are one of the oldest means of sealing concrete. However, this method has been replaced with more modern sealers such as siloxanes and silanes. However, it was included in this study primarily because it is still recommended in various concrete documents. Boiled linseed oil darkens the surface and unlike the other treatments, it creates a thin surface film. Also, it produces a slippery surface when wet; therefore, it is necessary to either sand the surface or keep traffic off the surface until it is absorbed into the concrete surface or cured. It also requires frequent re-applications compared to other sealants.



Figure 3.1 Siloxanes and silanes will bead water shortly after application. However, the surface is not slippery and skid resistance is not affected



Figure 3.2 Water quickly penetrated into the surface and cracks with a water-repellent sealer. Water that enters the concrete can contribute to both ASR and frost damage of the concrete.



Figure 3.3 Siloxanes and silanes also seal water from entering cracks (less than about 0.015 inches or 15 mils). Water repellency is limited by the width of the crack, shape of crack, and crack movements.



Figure 3.4 Siloxanes and silanes initially darken the concrete. However, in several days the concrete lightens and returns to the original appearance. Since these types of sealers are non-film forming, the original surface texture is not altered.

Table 3.1 summarizes the surface treatments and corresponding drilled cores used in this study. Test panels #2 and #7 were control panels where no surface treatments were applied. Surface treatments were applied in accordance with the manufacturers' recommendations. Application rates and costs per square foot for each product are also given below. Test panels #5 and #8 were first coated with the lithium nitrate and then coated with a siloxane and silane sealers, respectively.

Table 3.1 Surface Treatments and Drilled Core Summary

Test Area #1 C1 – A, B, C, D* C1 – E, F** xxxxxx	Sodium Tartarate Recommended: 150 – 200 sq ft per gal Applied: 6 gal per 1,000 sq ft or 167 sq ft per gal Cost: \$0.16 per sq ft
Test Area #2 C2 – A, B, C, D* C2 – G, J** xxxxxxxxxx	Control – No Surface Treatment
Test Area #3 C3 – A, B, C, D* C3 – E, F** xxxxxx	Lithium Nitrate (LiNO₃) Recommended: 3 to 9 gals per 1,000 sq ft Applied: 6 gals per 1,000 sq ft Cost: \$0.15 per sq ft
Test Area #4 C4 – A, B, C, D* C4 – E, H** xxxxxxxxxx	Siloxane Sealer Recommended: 75 – 125 sq ft per gal Applied: 10 gals per 1,000 sq ft or 100 sq ft per gal Cost: \$0.47 per sq ft
Test Area #5 C5 – A, B, C, D* C5 – E, F** xxxxxx	Lithium Nitrate (LiNO₃) Applied: 6 gals per 1,000 sq ft Siloxane Sealer Applied: 10 gals per 1,000 sq ft or 100 sq ft per gal Cost: \$0.62 per sq ft
Test Area #6 C6 – A, B, C, D* C6 – E, F** xxxxxxxxxx	Silane Sealer Recommended: 75 – 125 sq ft per gal Applied: 10 gals per 1,000 sq ft or 100 sq ft per gal Cost: \$0.38 per sq ft
Test Area #7 C7 – A, B, C, D* C7- G, J**	Control – No Surface Treatment
Test Area #8 C8 - A, B, C, D* C9-E, F** xxxxxx	Lithium Nitrate (LiNO₃) Applied: 6 gals per 1,000 sq ft Silane Sealer Applied: 10 gals per 1,000 sq ft or 100 sq ft per gal Cost: \$0.53 per sq ft
Test Area #9 C10 – A, B, C, D* C10 – E, F** xxxxxx	Boiled Linseed Oil Recommended: 300 to 400 sq ft per gal per coat Applied: 2 coats @ 6.7 gals per 1,000 sq ft or 2 x 149.3 sq ft per gal = 299 sq ft per gal Cost: \$0.05 per sq ft

**Cores extracted April 4, 2006

** Cores extracted September 4, 2008



Figure 3.5 Workers applying surface treatments to test panels. Areas (sq. ft.) were first determined and marked on each panel. Then the appropriate gallons of materials were applied to ensure the proper application rates. Here, silane sealer is being applied to test panel #5.



Figure 3.6 Workers followed the manufacturer's recommended application techniques and coverage rates. Here, boiled linseed oil is being applied to test panel #9. The oil darkened and created an extremely slippery surface when wet.

4.0 FINDINGS AND CONCLUSIONS

Results of the petrographic examinations and Damage Rating Index (DRI) evaluations performed by David Rothstein PhD, PG with DRP Consulting, Inc. are presented in Sections 4.1 and 4.2. Ultrasonic pulse velocity (UPV) performed by the author are presented in Section 4.3.

4.1 Petrographic Examination

Significant findings reported by Rothstein include:

1. Concrete represented by the cores is deteriorating from alkali-silica reaction (ASR).
2. Components in both the coarse and fine aggregate show evidence of ASR susceptibility.
3. Cracking and microcracking of the paste is associated with ASR activity relative to both coarse and fine aggregates.
4. Degree of damage increased significantly in all cores between 2006 and 2008 or between the “before” and “after” cores.
5. Concrete represented by C3-A from test panel #3 showed the least significant increase in distress associated with ASR.
6. Deposits of ettringite (white needle-like crystals in air voids and cracks) were abundant throughout the cores indicating a high internal relative humidity. This is consistent with the prevalence of ASR in the cores and continuing deterioration of the concrete.
7. Concrete is air-entrained and the abundance of the air voids appears to range from six percent to nine percent by visual observation. This is the appropriate amount of air entrainment for concrete exposed to severe freeze-thaw conditions.
8. Many of the cracks are suggestive of freeze-thaw damage in the form of frost wedging, rather than classic scaling.
9. DRI scores for the 2006 cores or “before” cores range from 166 to 233 with an average of 206. Six of the nine cores in this set have DRI scores greater than 200. Core 10 which was taken over a joint returned a DR score of 340.
10. DRI scores for the 2008 cores or “after” cores range from 219 to 399 with an average of 344. Eight of the nine cores have DRI scores greater than 320. Core C3 –E showed the lowest score of 219.

11. DRI scores increased for the after cores as compared to the before cores. Increases ranged from a low of 31.7 percent to 91 percent for cores C3 (Lithium Nitrate) and C7 (Control). Other scores showed an increase of at least 50 percent except for C3 cores.

4.2 Damage Rating Index Results

Below in Table 4.1 is DRP's Damage Rating Indexes (DRI) for the before and after cores as shown in DRP's report located in Appendix A of this report. Columns represent the number of occurrences (frequency) of each of the damage indexes shown in Table 1.1 on page 10. DRP's abbreviations for the damage indexes are shown below each table.

Results of Damage Rating Index Evaluation for 2006 or "before" cores.

	CA w/ Frx	CA w/ Frx&Gel	CA Debond	CA Rxn Rim	FA w/ Frx	FA w/ Frx&Gel	FA Rxn Rim	FA Debond	Frx in Paste	Frx w/ Gel in Paste	Gel in Voids	Score	Area (cm ²)	Norm Score
C1A	19	10	6	5	15	25	19	6	36	32	11	321.25	150	214
C2A	18	12	2	2	13	31	22	3	52	23	11	313.75	150	209
C3A	23	5	2	3	16	37	17	1	20	24	12	249.5	150	166
C4A	24	10	3	4	15	32	33	0	23	30	4	281	150	187
C5A	34	14	4	4	21	42	13	1	41	24	9	327.5	150	218
C6A	7	14	1	1	7	36	7	0	82	13	11	330.25	150	220
C7A	26	11	0	0	22	57	20	0	35	15	14	290	150	193
C8A	19	3	1	1	16	55	22	2	59	17	19	333.25	150	222
C9A	31	16	3	7	32	45	21	3	49	17	15	335	150	223
C10A	10	9	2	1	9	43	7	1	54	69	15	510.5	150	340

Note: Core C10A was extracted through a construction joint.

*Abbreviations are as follows: CA = Coarse Aggregate, Frx = Fractures; Debond = Debonding; Rxn = Reaction; FA = Fine Aggregate; w/ = with

Results of Damage Rating Index Evaluation for 2008 or "after" cores.

	CA w/ Frx	CA w/ Frx&Gel	CA Debond	CA Rxn Rim	FA w/ Frx	FA w/ Frx&Gel	FA Rxn Rim	FA Debond	Frx in Paste	Frx w/Gel in Paste	Gel in Voids	Score	Area (cm ²)	Norm Score
C1E	19	16	8	8	21	53	14	4	61	42	18	486.5	150	324
C2E	11	7	6	6	18	52	15	4	86	65	17	598.5	150	399
C3E	20	11	4	12	22	36	22	0	41	29	5	328.5	150	219
C4E	17	12	6	6	12	45	24	1	38	72	8	518.25	150	346
C5E	27	15	17	6	31	60	34	6	59	47	14	552	150	368
C6E	27	13	9	11	41	83	31	1	98	19	12	529.25	150	353
C7G	25	14	6	6	18	55	17	1	86	51	4	554	150	369
C8E	19	14	11	16	17	56	33	2	82	42	14	541.25	150	361
C9E	22	16	7	12	16	58	19	4	88	39	26	542.25	150	362

*Abbreviations are as follows: CA = Coarse Aggregate, Frx = Fractures; Debond = Debonding; Rxn = Reaction; FA = Fine Aggregate; w/ = with

Table 4.1 DRI evaluations for before and after treatments from DRP's report located in Appendix A of this report. (Tables shown are DRP's Tables D.1 and D.2)

Before and after DRI scores for cores representing test panels #1 - #9 are compared in Figures 4.1 and 4.2 below. Only one core was extracted from a joint (C10A) in 2006 as shown below in Figure 4.1.

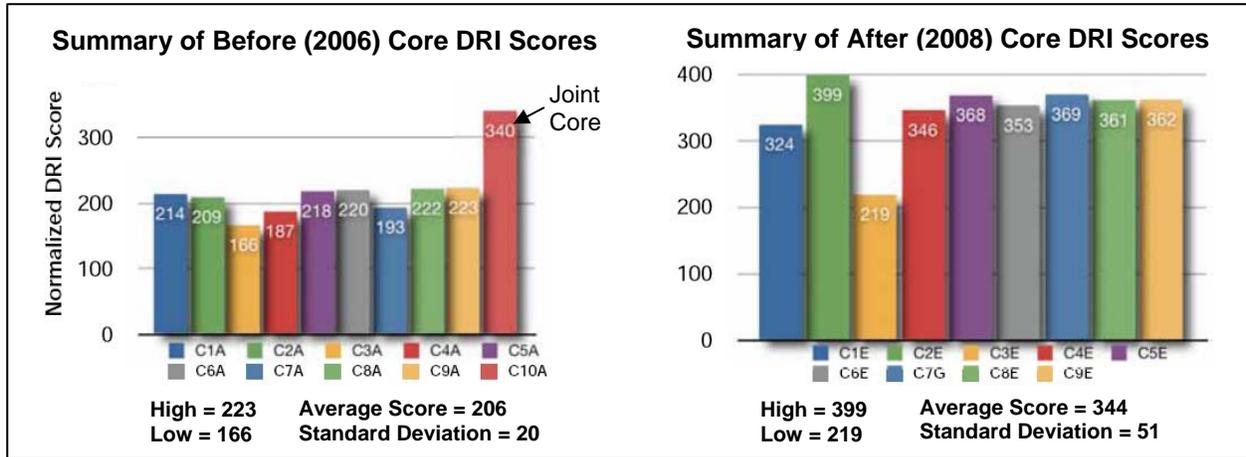


Figure 4.1 Comparison of before and after DRI scores for test panels 1 – 9 from DRP’s report.

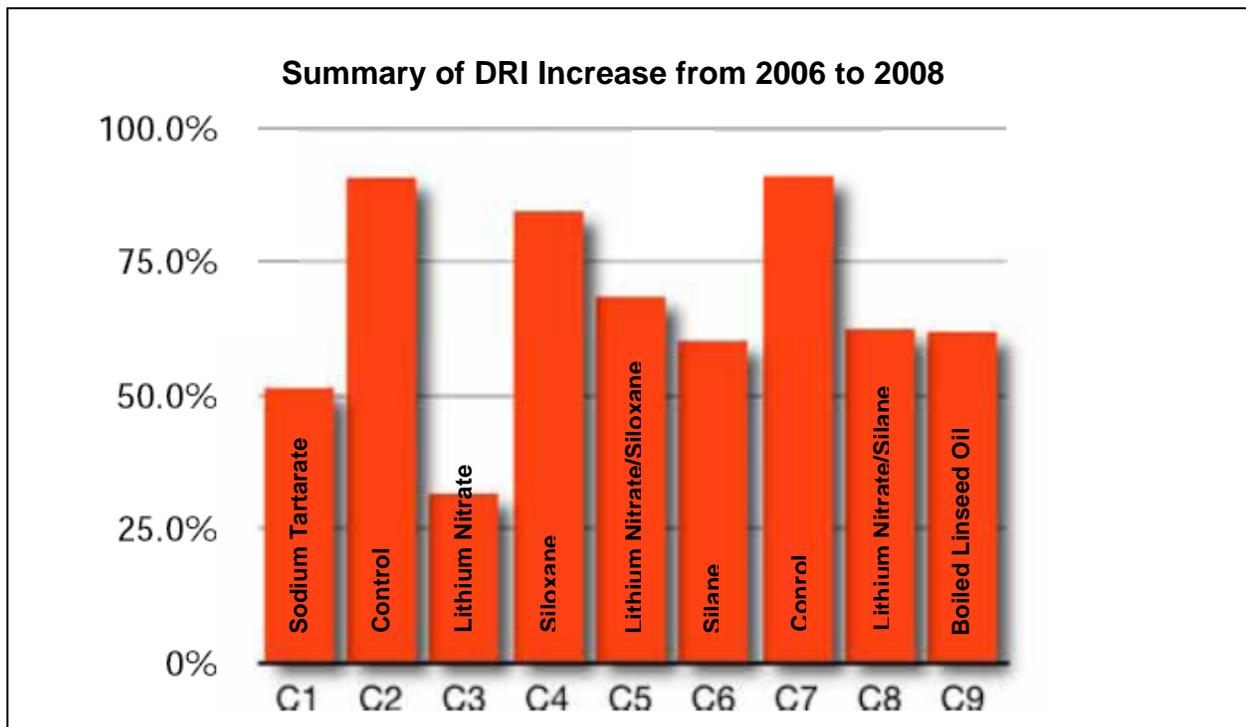


Figure 4.2 Summary of DRI increases from before and after cores (DRP’s report – Appendix D).

As shown in Figure 4.1 above, all DRI scores increased indicating that ASR related concrete damage increased during the two-year evaluation period. Except for the DRI score of 340 for Core C10-A in the before set, these scores are fairly consistent with an average of 206 and a standard deviation of 20. However, the DRI score for Core C3-A is noticeable less than the other scores. Except for the Core C3-E in the after set, DRI scores are rather consistent with average of 344 and a standard deviation of 51.

The DRI score for Core C10-A, which was drilled from a construction joint in 2006, was 340 and considerable larger than other scores for cores extracted six feet away from joints. A larger DRI score at the joint agrees with the visual damage exhibited by all panels. As previously discussed, joints were exposed to more moisture than non-joint locations and were less restrained than interior panels cores resulting in more visual damage.

The summary of DRI score increases as shown in Figure 4.2 above show that all scores increased but not by the same percentages. Especially, the percentage of DRI score increases representing test panels 1 and 3. Percentage of increased damage for C1 (Sodium Tartarate) and C3 (Lithium Nitrate) were the lowest with C3 (Lithium Nitrate) being the absolute lowest. Whereas, C2 (control) and C7 (Control) had the largest percentage of increased damage. For additional information regarding Rothstein's petrographic findings and DRI evaluations, see Appendix A of this report.

4.3 Ultrasonic Pulse Velocity (UPV) Test Result

A summary of the ultrasonic pulse velocities measured for the “before” and “after” cores are shown in Table 4.2 below. The average UPV for the before cores was 13,270 feet per second with a low and high of 12,453 and 14,503 feet per sec, respectively. Wave velocities were slower for the after cores with an average of 10,759 feet per second indicating additional cracking had occurred during the two year evaluation period. The low and high wave velocities were 9,564 and 13,455 feet per second. The average UPV reduction was 19.1 percent. UPV measurements used to create Table 4.2 are shown in Appendix B.

Table 4.2 Summary of UPV Tests Results for “Before” and “After” Cores

Test Panel	UPV (feet per second)		Percent Reduction
	Before Cores*	After Cores*	
1	12,453	10,625	14.7
2	12,454	10,079	19.1
3	14,035	11,934	15.0
4	14,503	13,455	7.23
5	13,656	10,810	20.8
6	12,914	9,780	24.3
7	13,796	10,556	23.5
8	12,635	9,564	24.3
9	12,983	10,025	22.8
Average	13,270	10,759	19.1
Std. Deviation	748	1,230	5.8

* Speeds are averages for a set of cores extracted from each test panel (Appendix B)

As discussed in Section 1.6, wave speeds or ultrasonic pulse velocities equal to or exceeding 12,000 ft/sec typically indicate good quality or undamaged concrete. Whereas, speeds between 10,000 and 12,000 ft/sec suggest the concrete quality is questionable and speeds less than 10,000 ft/sec indicate poor or damaged concrete. An average UPV of 13,270 ft/sec for the before cores indicates the concrete is of high quality. However, the overall visual appearance and related ASR damage indicates this was not the case. UPV values are somewhat faster than expected for the overall appearance because cores were not removed from areas with noticeable surface cracking. Therefore, the UPV values are more indicative of velocities for concrete suffering from internal microcracks and not visible surface cracks. Also, cores representing the after treatment condition were drilled in areas where no visible surface cracks existed. Consequently, UPV's are more of a quality index value for the internal damage related to ASR and not the visual surface damage.

Figure 4.3 below summarizes the UPV reductions for cores removed from the test panels. UPV results for test panel #4 (siloxane) showed the smallest reduction followed by test panels #1 (sodium tartarate) and #3 (lithium nitrate). The remaining cores showed a UPV reduction of approximately 20 percent or slightly more. The two control panels (#2 and #7) had reductions of 19.1 and 23.5 percent, respectively.

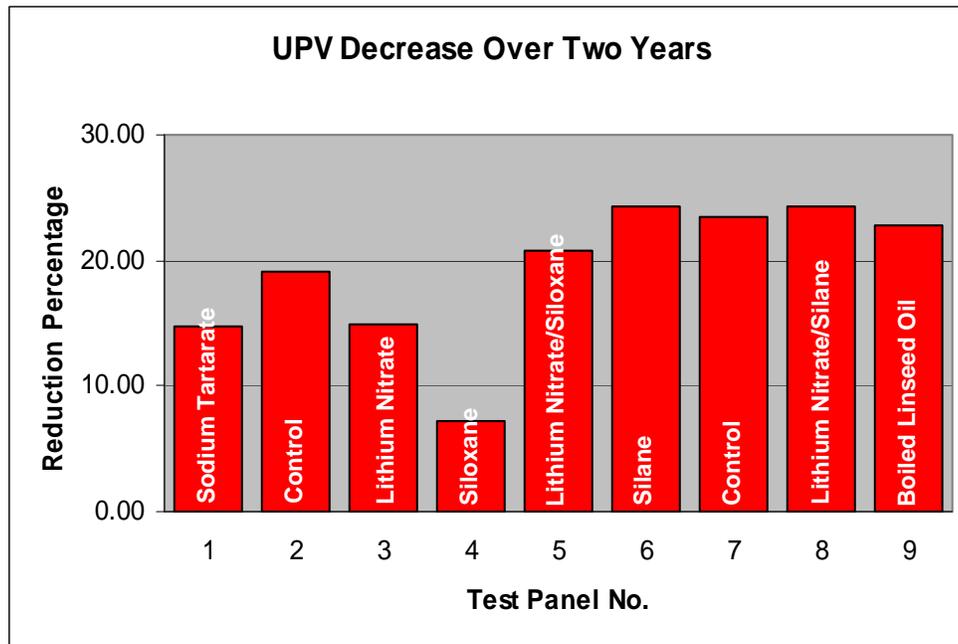


Figure 4.3 Summary of UPV decrease over the two-year evaluation period.

5.0 SUMMARY AND RECOMMENDATIONS

Using the DRI increase and UPV reduction percentages, the performance or effectiveness of the surface treatments have been ranked from best to worst as shown below in Table 5.1.

Rank	DRI Increase	Percentage	UPV Reduction	Percentage
1 st	C3 – Lithium Nitrate	31.9	C4 – Siloxane Sealer	7.23
2 nd	C1 – Sodium Tartarate	51.4	C1 – Sodium Tartarate	14.7
3 rd	C6 – Silane Sealer	60.5	C3 – Lithium Nitrate	15.0
4 th	C9 – Boiled Linseed Oil	62.3	C2 - Control	19.1
5 th	C8 – Lithium Nitrate/Silane	62.6	C5 – Lithium Nitrate/Siloxane	20.8
6 th	C5 – Lithium Nitrate/Siloxane	68.8	C9 – Boiled Linseed Oil	22.8
7 th	C4 – Siloxane Sealer	85.0	C7 - Control	23.50
8 th	C2 - Control	90.9	C6 – Silane Sealer	24.30
9 th	C7 - Control	91.2	C8 – Lithium Nitrate/Silane	24.30

The top three rankings for the DRI evaluation method were core sets C3, C1 and C6. However, the top three rankings from the UPV evaluation method were cores sets C4, C1 and C3. Both methods ranked both C3 and C1 in the top three. C6 was ranked third by the DRI method but the UPV method ranked it eighth. Likewise, the UPV method ranked C4 first; however, the DRI method ranked C4 seventh.

With regards to the control panels represented by core sets C2 and C7, the DRI method ranked them eight and ninth, respectively. However, the UPV method ranked C2 and C7 fourth and seventh, respectively. Except for the ranking of C1 and C3, there seems to be few similarities between the rankings of the core samples using DRI and UPV evaluation methods.

Both evaluation methods seem appropriate for assessing ASR concrete damage; however, they are based on different approaches. DRI used a magnification of 16x to count the occurrences of eleven visual defects over an area of 23.25 square inches or roughly a 4 inch x 6 inch rectangle on a vertical plane of a single core as shown in Figure 5.1 below.

However, UPV equipment measured the velocity of a compression wave traveling through a four inch diameter by 12 inch long core. While the DRI method used one core per test panel in this study, the UPV method used core sets for each test panel. Therefore, UPV values were the average of several tests (three of the “before” cores and two for the “after” cores). UPV also evaluated the entire volume of a core or about 150 cubic inches. Therefore, some differences between the DRI and UPV methods should be anticipated. However, this author was hoping for a better correlation between the two methods.

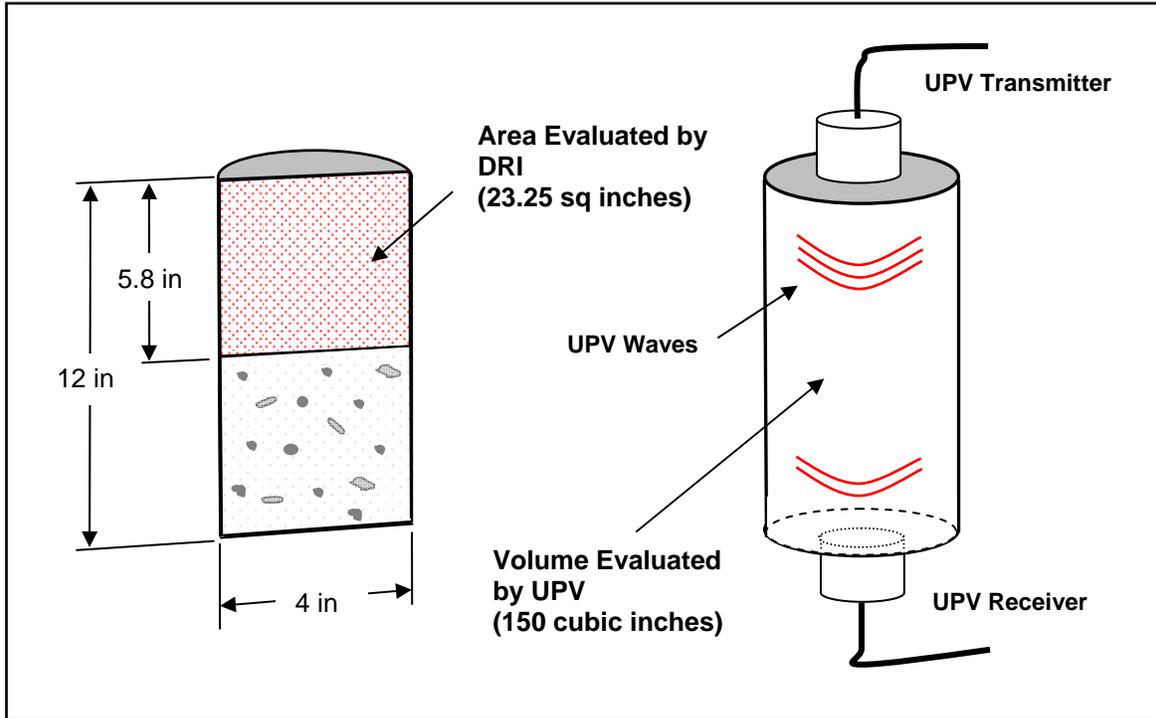


Figure 5.1 Comparison of the amount of concrete evaluated by DRI versus UPV.

Illustrations in Figure 5.1 show that DRI evaluates approximately 50 percent of a cross-sectional plane located in the upper portion of the core; whereas, UPV evaluates the entire volume of the core. Most likely, the different amount of concrete being evaluated for each evaluation method was primarily responsible for the poor correlation of the two methods.

It appears that both DRI and UPV are appropriate methods for detecting, evaluating and monitoring concrete damaged associated with ASR. However, test results in this limited investigation yielded a poor correlation between the two methods. Although results did not correlate well, DRI and UPV can yield useful and valuable information when evaluating ASR damage and rates of deterioration, especially when used as a part of an overall assessment program.

Because the DRI and UPV damage assessment methods yielded significantly different results, it is difficult to make conclusions with any level of confidence regarding the performance of the different surface treatments. However, test results did indicate that lithium nitrate and sodium tartarate may have slowed the ASR deterioration or may have been more effective than the other surface treatments. If the evaluation period had been longer as originally planned, test results may have been more definitive.

Findings from this investigation suggest the following:

1. Concrete damage and deterioration associated with ASR can be evaluated using the Damage Rating Index (DRI) and ultrasonic pulse velocity (UPV) methods, especially when employed at the first signs of ASR damage. However, caution should be used when interpreting results and making engineering decisions. It is recommended to use these concrete damage evaluation methods as a part of a total evaluation program and not as stand alone tests. Also, plotting either DRI or UPV results versus time may yield valuable insight with regards to the anticipated service life of ASR-affected concrete.
2. Material and pavement engineers should consider the following when evaluating ASR damage and rates of deterioration: review the concrete mix design if available and determine hardened concrete properties; petrographic examination of concrete to determine the potential reactivity of the coarse and fine aggregates; visual inspection of the concrete to assess damage, severity and orientation of cracks and spalling and determine if the concrete is pushing other elements such as foundations, sidewalks, etc. due to concrete expansion.

As part of the investigation, it is important to assess all moisture sources for the concrete including: surface drainage, integrity of joint sealants, ground moisture conditions and drainage, and internal relative humidity of the concrete. If the relative humidity equals or exceeds 80 percent, there is sufficient moisture to support ASR. Also, investigators should determine the concrete's past and present exposure to deicing chemicals since these can aggravate both ASR and frost damage.

3. There are two approaches for mitigation ASR-affected concrete: 1) apply a surface treatment consisting of lithium nitrate to inhibit the ASR gel from swelling and creating expansive pressures, and 2) apply penetrating water-repellency sealers to limit the amount of moisture available to support ASR and frost actions. Of course, the success of either approach depends on several factors that include: potential reactivity of the coarse and fine aggregates; ASR activity and damage level; hardened concrete properties including cementitious materials, strength, air content, etc.; exposure conditions including exposure to deicing chemicals and especially moisture. Most likely, the effectiveness of any surface treatment will increase if applied at the first signs of ASR damage.

Applying a penetrating water-repellency sealer will not reduce ASR activity if there are other sources of moisture including ground moisture and vapor, surface water drainage into unsealed joints or joints with failed sealants that supply sufficient amounts of moisture to maintain an internal relative humidity of 80 percent or more. Applying a penetrating, water-repellency sealer may also reduce the damage and progressive deterioration associated with freeze-thaw actions. However, effectiveness of water-repellant sealants on ASR-affected concrete is highly dependant on sealing all moisture pathways. For pavements cast directly on the ground, this may be difficult to achieve.

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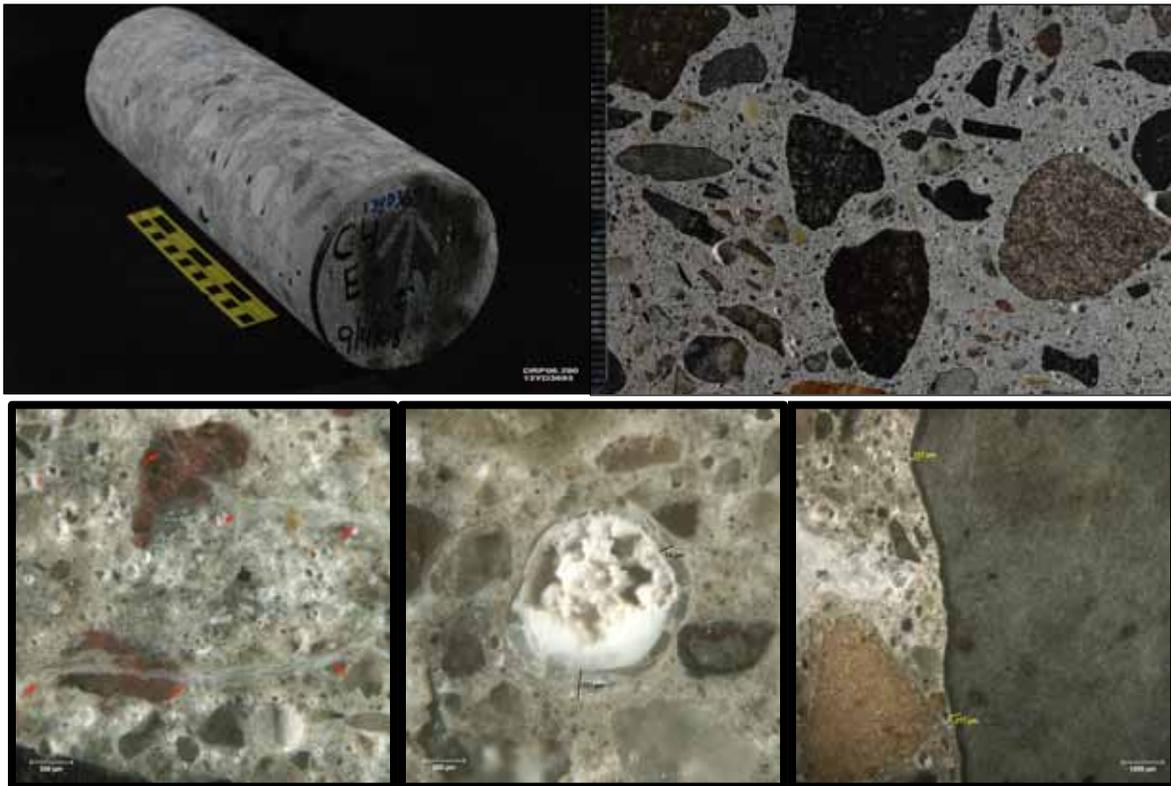
Appendix A

Rothstein, PhD, PG, David. *Petrographic Investigation of Concrete Cores Taken From Airfield Pavements at the Riverton Regional Airport Located in Riverton, Wyoming*. August 2009.

Note: Dr. Rothstein referenced the “before” treatment cores extracted April 4, 2006 as the May 2006 cores because DRP started the petrographic examinations in May 2006. Likewise, Dr. Rothstein referenced the “after” treatment cores extracted September 4, 2008 as the January 2009 cores because DRP started the petrographic examination in January 2009.

Petrographic Investigation of Concrete Cores Taken From Airfield Pavements at the Riverton Regional Airport located in Riverton, Wyoming

RE: WYDOT Project Number: RS04(206)



Prepared for: Kim Basham, Ph.D., P.E.
KB Engineering, LLC
Cheyenne, Wyoming

Prepared by: David Rothstein, Ph.D., P.G.
Report No.: DRP06.290

23 AUGUST 2009



DRP Consulting, Inc. 3200 Carbon Place #104 Boulder, CO 80301
T 303.938.0166 F 303.938.0167 petro@drpcinc.com
drpcinc.com

EXECUTIVE SUMMARY

Petrographic examination of concrete cores from airfield pavements at the Riverton Airport located in Riverton, Wyoming indicate that the concrete represented by the cores is deteriorating from alkali-silica reaction (ASR). Components in both the coarse and fine aggregate show evidence of susceptibility to ASR. Cracking and microcracking of the paste is associated with reactive components in both the coarse and fine aggregate. The degree of damage increased significantly in all of the cores between 2006 and 2009. Concrete removed from area C3 showed the least significant increase in distress associated with ASR.

Deposits of ettringite are abundant throughout the cores. These deposits are not associated with distress such as cracking or microcracking but demonstrate that the internal relative humidity of the concrete represented by the cores is high. This is consistent with the prevalence of ASR in the cores and the continuing deterioration of the concrete.

1.0 INTRODUCTION

Mr. Kim Basham, Ph.D., P.E. of KB Engineering (**KBE**) located in Cheyenne, Wyoming requested DRP Consulting, Inc. (**DRP**) to conduct petrographic examinations to determine the severity of alkali-silica reaction (ASR) in concrete cores extracted from an airfield pavement at the Riverton Regional Airport located in Riverton, Wyoming. On 2 May 2007 **DRP** received ten (10) concrete cores from **KBE** for petrographic examination. These cores were subjected to preliminary petrographic examinations in late May 2007; this examination established that the degree of ASR in the concrete represented by the different cores was broadly similar. On 21 April 2009 **DRP** received an additional nine (9) cores from **KBE**. These cores were taken essentially next to the original cores to compare the extent of ASR after an additional two years of exposure in the field. **Table A1** summarizes the information regarding the samples.

2.0 SCOPE OF WORK

The testing involved petrographic analysis following ASTM C856 [1]. The severity of ASR was ranked following a protocol set for by P.E. Grattan-Belw [2] and is known as the *Damage Rating Index (DRI)*. This report summarizes the findings of these examinations. Appendices to this report contain photographs and micrographs from the cores and the results of the *DRI* surveys.

3.0 PROCEDURES

General Petrographic Examination The cores were measured, inspected visually and with a hand lens, and photographed in their as-received condition. A slab representing a cross section of each core was cut using a water-cooled saw. The slabs were oven dried overnight at ~ 40°C (~ 105°F) and then impregnated with epoxy to stabilize the material because it was somewhat friable. After the impregnation the samples were lapped and polished using progressively finer diamond wheels and an aqueous lubricant following procedures in accordance with ASTM C457 [3]. Phenolphthalein was applied to a freshly saw-cut surface to assess the extent of carbonation, along with thin section analysis. Phenolphthalein is an organic stain that colors materials with pH of greater than or equal to 9.5 purple. Portland cement concrete generally has a pH of 12.5. Carbonation lowers the pH of the paste below 9.5, so areas not stained by phenolphthalein are an indicator of the depth of carbonation. The polished and saw-cut surfaces of each of the cores were examined visually and via a stereomicroscope with 3-180x magnification capability in

1 *Standard Practice for Petrographic Examination of Hardened Concrete*. Annual Book of ASTM Standards, Vol. 4.02., ASTM C856-04.

2 Grattan-Belw, P.E., 1995, Laboratory Evaluation of Alkali-Silica Reaction in Concrete from Saunders Generating Station, *ACI Materials Journal*, v. 92, No. 2, p. 126-134.

3 *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*, Annual Book of ASTM Standards, Vol. 4.02, ASTM C457-06.

accordance with the standard practice set forth in ASTM C856. Petrographic thin sections were prepared from two cores by impregnating billets with epoxy, trimming and grinding the samples on a Buehler Petro-Thin device and polishing to a final thickness of ~ 20 µm on a Buehler Beta-Vector machine. All of the thin section preparations were done in a non-aqueous environment. The thin sections were examined with a petrographic microscope with 50-500x magnification capability. This work was done to provide information regarding the cementitious components present in the subject concrete, to assess the degree of hydration and to observe the morphology, size and distribution of calcium hydroxide in the paste. Thin sections were not used in the DRI work described below.

Damage Rating Index (DRI) The DRI is described in detail by Grattan-Belew [2]; a review of the method by Rivard et al. [4]. Essentially the DRI is a method that quantifies the extent of ASR and degree of damage associated with ASR based on petrographic features. The method is based on the recognition of features that are commonly associated with ASR and applies weighting factors to these features in attempt to account for the relative importance of these features in damaging the concrete. The observations are made on a polished surface from a core of concrete using a stereoscopic microscope.

Table 1 summarizes the features and weighting factors used in the present investigation to determine the DRI for the concrete represented by the cores. The features are the same as those used by Grattan-Belew [3] with the addition of features to account for reactive fine aggregates. The inclusion of the fine aggregate factors stemmed from preliminary petrographic work by **DRP** which indicated that the fine aggregate in the subject concrete showed evidence of ASR. The petrographic work was done at a magnification of 16x.

Table 1. Features and weighting factors used for DRI

Petrographic Feature	Weighting Factor
Coarse aggregate with cracks	0.25
Coarse aggregate with cracks and gel	2
Debonded coarse aggregate	3
Reaction rim on coarse aggregate	0.5
Fine aggregate with cracks	0.25
Fine aggregate with cracks and gel	2
Debonded fine aggregate	2
Reaction rim on fine aggregate	0.25
Cement paste with cracks	2
Cement paste with cracks and gel	4
Air voids lined with gel	0.5

4 Rivard, P., Fournier, B., and Ballivy, G., 2002, The Damage Rating Index Method for ASR Affected Concrete—A Critical Review of Petrographic Features of Deterioration and Evaluation Criteria, *Cement, Concrete and Aggregates*, v. 24, No. 2, p.

4.0 FINDINGS—GENERAL

The following findings are relevant to the general condition and composition of the concrete represented by the cores.

- 4.1 The cores are vertical in orientation and represent the full depth of the pavement slabs. The cores are 100 mm (4 in.) in diameter and range from 305-325 mm (~ 12-13 in.) in length except for Core 10, Core 8E and Core 9E, which measure 150 mm (6 in.) in diameter.
- 4.2 The top surface of the cores are have a broom finish and the bottom is cast on a bituminous felt membrane such that the cores represent the full depth of the cores. The top surfaces of the cores are intact and show no evidence of scaling.
- 4.3 The color of the paste is generally light to medium gray but most cores show significant mottling with color ranging from nearly white to dark gray. Mortar coatings with lower water-cement ratio (w/c) are present on occasional aggregate particles in most of the cores. These are indications of incomplete mixing or retempering (or both). Many cores show darkening of the paste color near the top of the core, consistent with penetration of the concrete by a sealer or other type of compound.
- 4.4 The paste fraction of the concrete consists of portland cement; no other supplemental cementitious materials were observed. The hydration is normal with 4-8% relict and residual cement grains that consist primarily of belite with minor amounts of alite. Clusters of belite occasionally reach 100-15 μm (4-6 mil) across. The paste contains 17-25% calcium hydroxide that is fine-grained and evenly disseminated through the paste with occasional coarsening around aggregate particles and on the rims of entrained air voids.
- 4.5 The concrete is air-entrained and the abundance of the air voids appears to range from 6-9% by visual estimation (not measured). Some clustering of voids was observed but no evidence of scaling was observed. There is no evidence of a loss of air near the finished surface of the concrete. Some cores show occasional large entrapped air voids and consolidation voids that measure up to 25 mm
- 4.6 Deposits of ettringite are commonly observed in air voids. The deposits commonly fill or partially fill the voids. No cracking or microcracking due to ettringite mineralization was observed. The cores show minimal carbonation as indicated by phenolphthalein indicator.
- 4.7 Many cores show evidence of shrinkage cracking and microcracking at the top of the core. These cracks are generally less than 100 μm (4 mil) wide and cut to depths less than 9.5 mm ($\frac{3}{8}$ in.). Occasional cracks reaching widths of 500 μm (20 mil) cut to depths of 25-50 mm (1-2 in.). These cracks are generally free of secondary deposits.

- 4.8 Other cracks are present in the concrete and these often cut sub-horizontally across the cores. Many of these cracks are suggestive of freeze-thaw damage in the form of frost wedging, rather than classic scaling.

5.0 FINDINGS—ALKALI-SILICA REACTION

- 5.1 The concrete aggregates have a 25 mm (1 in.) nominal top size and are derived from a natural river gravel. The particles are mostly sub-cuboidal in shape with occasional oblong particles; the particle edges are sub-angular to sub-round. The grading and distribution of the aggregates are relatively even.
- 5.2 The aggregate is siliceous in composition and consists of a diverse mixture of intrusive and volcanic igneous rocks that range in composition from granitic to dioritic (intrusive rocks crystallize below the earth's surface whereas volcanic rocks crystallize on the earth's surface). The rock types are dominated by intrusive rocks that range from granite to granodiorite in composition. Some of the granitic rocks show evidence of dynamic recrystallization. The volcanic rocks most commonly range in composition from siliceous tuffs to rhyolite to latite. Other rock types include more mafic intrusive rocks such as diorite and more mafic volcanic rocks such as andesite. The rock types in the coarse and fine aggregate are similar, indicating they are derived from a common geologic source.
- 5.3 Reactive components are present in both the coarse and fine aggregate in all of the cores. The reactive components include granitic rocks, rhyolite and other siliceous volcanic rocks, and granodiorite.
- 5.4 *Appendix D* summarizes the results of the DRI determinations. The DRI scores for the May 2006 cores range from 166-223 with an average of 206. Six of the nine cores in this set have DRI greater than 200. Core 10, which was taken over a joint, returned a DRI of 340.
- 5.5 The DRI for the January 2009 Cores range from 219-399 with an average of 344. Eight of the nine cores have a DRI greater than 320. Core 3E showed the lowest DRI score of 219; the sample from this pavement section also recorded the lowest DRI score (166) in the May 2006 core suite.
- 5.6 The normalized DRI scores increased from the May 2006 cores to the January 2009 cores. These increases ranged from a low of 31.7% for the C3 cores to a high of ~ 91% for the C2 and C7 cores. All of the cores showed an increase of at least 50% except for the C3 cores.
- 5.7 The top 15-30 mm ($\frac{5}{8}$ -1 $\frac{1}{4}$ in.) of the cores consistently showed less evidence of ASR than was observed in the rest of the cores.

6.0 CONCLUSIONS

Based on the findings described above the concrete represented by the cores is deteriorating significantly due to ASR. Components in both the coarse and fine aggregate show evidence of susceptibility to ASR. Cracking and microcracking of the paste is associated with reactive components in both the coarse and fine aggregate. The degree of damage increased significantly in all of the cores between 2006 and 2009. Concrete removed from area C3 showed the least significant increase in distress associated with ASR.

Deposits of ettringite are abundant throughout the cores. These deposits are not associated with distress such as cracking or microcracking but demonstrate that the internal relative humidity of the concrete represented by the cores is high. This is consistent with the prevalence of ASR in the cores and the continuing deterioration of the concrete.

This concludes work performed on this project to date.



David Rothstein, Ph.D., P.G.

RIVERTON AIRFIELD CONCRETE INVESTIGATION

APPENDICES

APPENDIX A: AS-RECEIVED PHOTOGRAPHS

APPENDIX B: PREPARED SURFACES PHOTOGRAPHS

APPENDIX C: AGGREGATE PHOTOGRAPHS

APPENDIX D: DAMAGE RATING INDEX TESTING

APPENDIX E: ASR MICROGRAPHS

Table A1a. Summary of Cores Received - Phase I

KBE No.	DRP No.	As-received Comments
C1A	10YD2075	0.25 mm crack on top surface; large voids on sides; white deposit on side surface; 2 mm asphalt on bottom surface
C2A	10YD2079	Some consolidated air voids and white deposits on side surface of core; 3 mm asphalt on bottom surface
C3A	10YD2083	Consolidated air voids and white deposits on side surface; 3 mm asphalt on bottom surface
C4A	10YD2087	Consolidated air voids and white deposits on side surface; 2 mm asphalt on bottom surface;
C5A	10YD2091	0.30 mm crack on top surface extending 45 mm down the side of core; some white deposits and consolidated voids on the side of core; 3 mm asphalt on bottom surface
C6A	10YD2095	0.30 mm crack on top surface extending 28 mm down the side of core; some white deposits and consolidated voids on the side of core; 2 mm asphalt on bottom surface
C7A	10YD2099	0.15 mm cracking on top surface extending 28 mm down the side of core; some white deposits and consolidated voids on the side of core; 2 mm asphalt on bottom surface
C8A	10YD2103	Cracking, up to 1 mm wide, extending down the side of core 50 -60 mm; consolidated voids and white deposits on the side surface of core on the top surface; 2 mm asphalt on bottom surface
C9A	10YD2107	Some 0.15 mm cracking on top surface extending down the side of core 25 mm; consolidated voids and white deposits on the side surface of core on the top surface; 3 mm asphalt on bottom surface
C10	10YD2111	Crack extends from joint entire length of core, up to 5 mm in width, crack at top surface is 10 mm wide; 2 mm asphalt on bottom surface

Table A1b. Summary of Cores Received - Phase II

KBE No.	DRP No.	As-received Comments
C1E	13YD3690	Consolidated air voids along side of core; cracks across top surface up to 0.25 mm wide, 75 mm long, down the side of core, 5 mm; white deposits along side of core reaction rims around some aggregate; "grease" spot on top surface.
C2E	13YD3691	Crack across top surface, 50 mm long, 0.25 mm wide down the side of core 5 mm; white deposits and reaction rims along the side of core; some white deposits on the top surface; some scaling on the edges of the top surface; consolidated air voids along the side of core; "grease" spot on top surface
C3E	13YD3692	White deposits and reaction rims along the side of core; consolidated air voids along the side surface of core; "grease" spot on top & bottom surface
C4E	13YD3693	White deposits and reaction rims along the side of core; consolidated air voids along the side surface of core; "grease" spot on top & bottom surface
C5E	13YD3694	White deposits , consolidated air voids and reaction rims present along the side of the core; "grease" spots on top & bottom surface
C6E	13YD3695	100 mm long crack across the top surface, branches, up to 0.25 mm wide, continues along the side of core in three places as far as 25 mm down the side; consolidated air voids, white deposits and reaction rims present along the side of the core; A piece cracked off the top surface and end of crack; "grease" spots on top & bottom surface
C7G	13YD3696	50 mm long crack on top surface, 0.25 mm wide and travels 10 mm down the side of the core; white deposits, consolidated air voids and reaction rims present along the side of the core; "grease" spots on top & bottom surface
C8E	13YD3697	40 mm long crack, up to 0.75 mm wide on top surface, continues down the side of core 20 mm; white deposits, consolidated air voids and reaction rims present along the side of the core; Consolidated air voids on bottom surface; "grease" spots on top & bottom surface
C9E	13YD3698	Cracking on the top surface of core 50 mm long, up to 0.5 mm wide ; scaling near the edges; white deposits on top surface; consolidated air voids and reaction rims present on the side of the core; grease spots on top & bottom surface

FIGURES

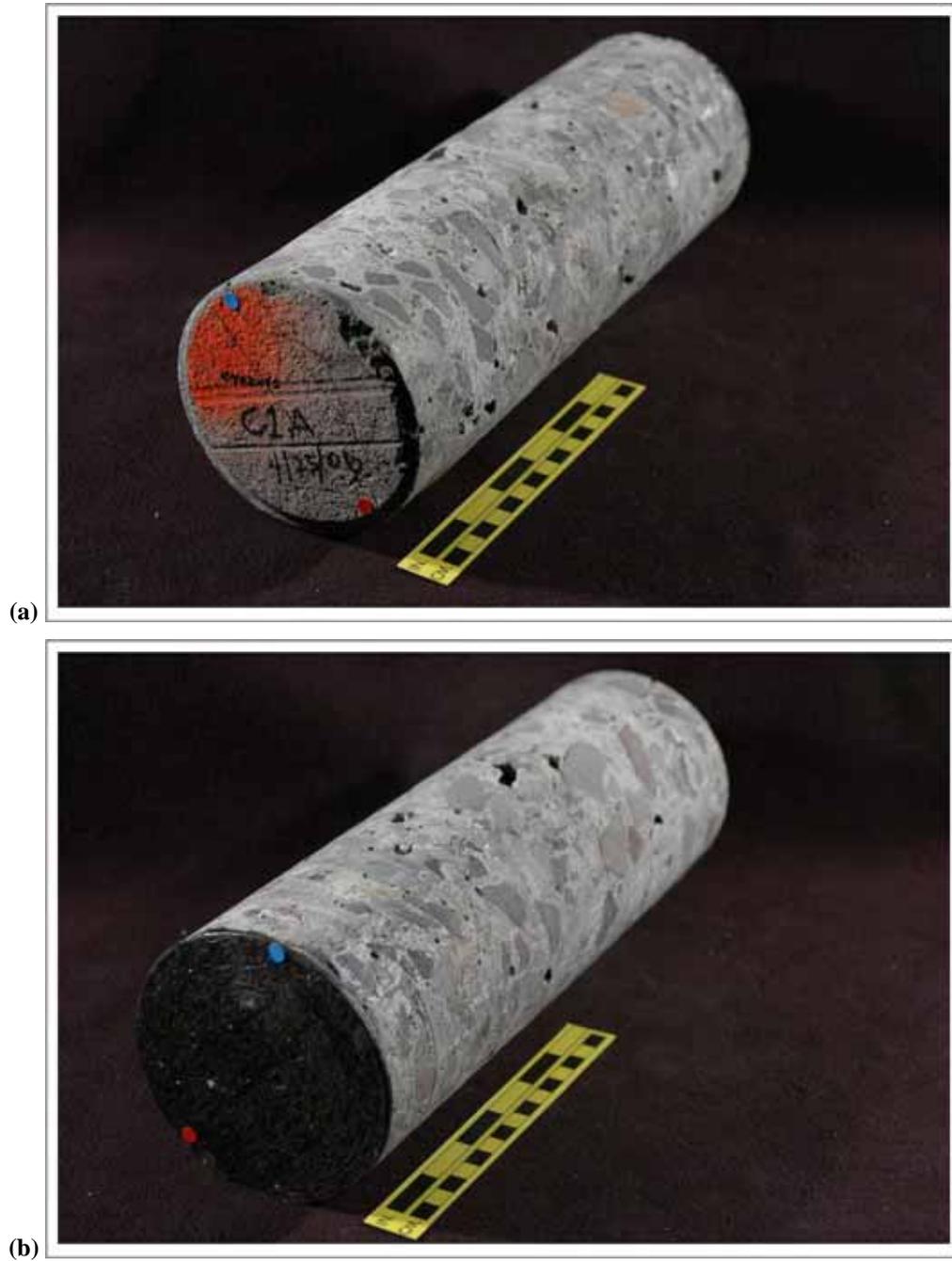


Figure A1. C1A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



(c)



(d)

Figure A1 (cont'd). C1A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.



(a)



(b)

Figure A2. C2A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



Figure A2 (cont'd). C2A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.

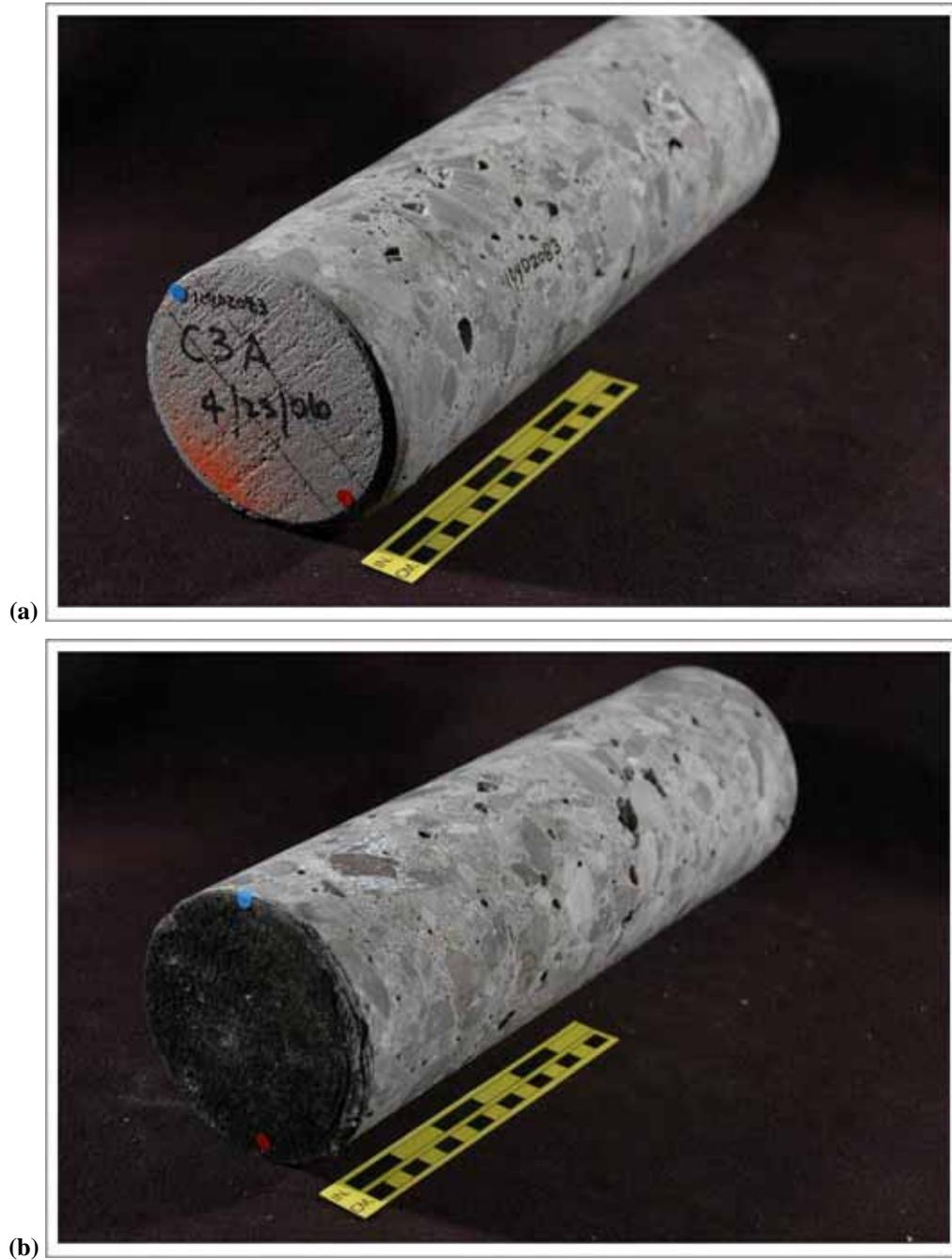


Figure A3. C3A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.

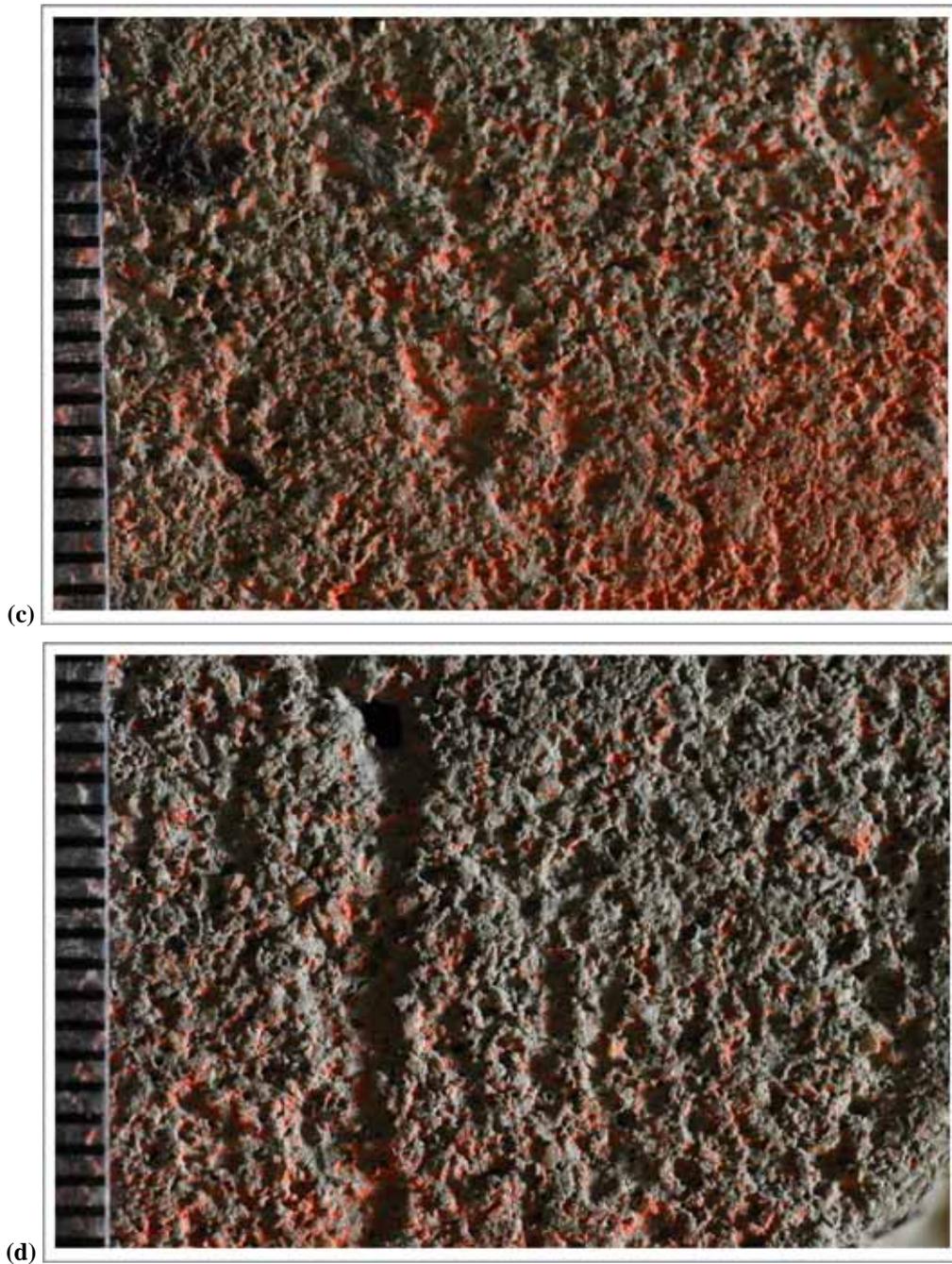


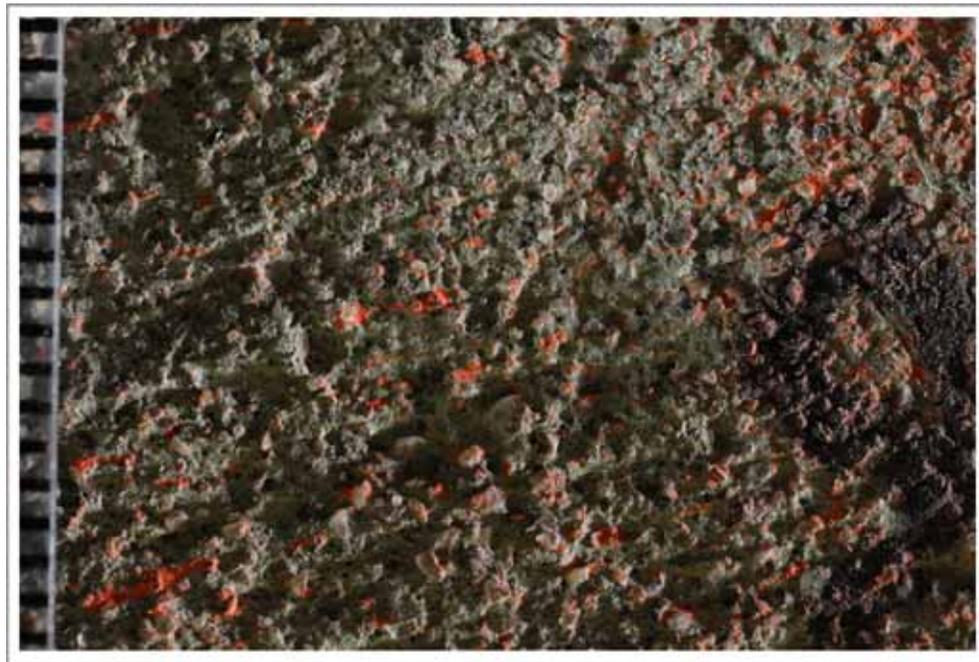
Figure A3 (cont'd). C3A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.



Figure A4. C4A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



(c)

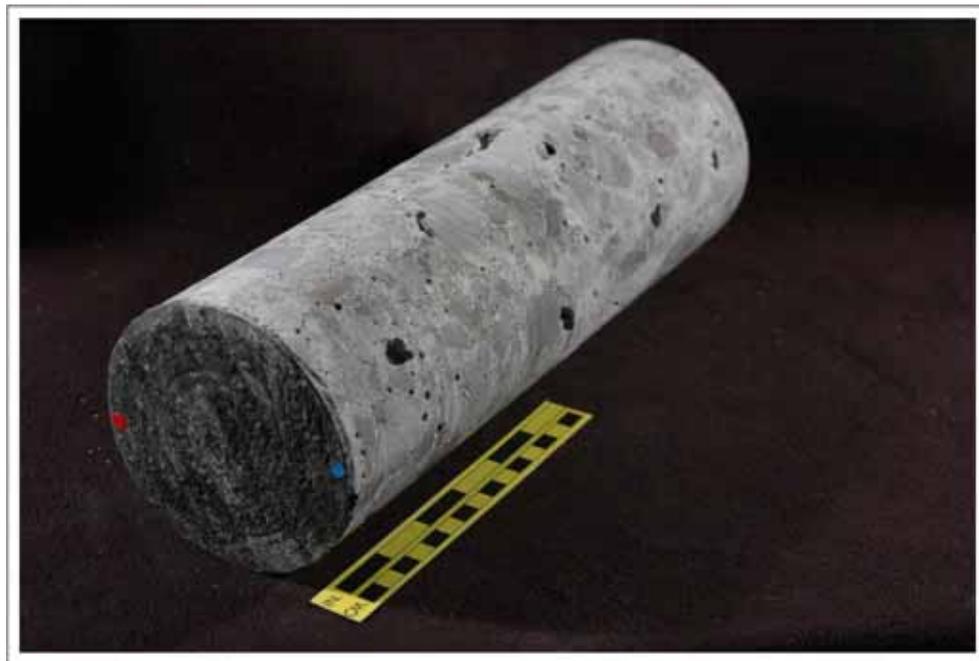


(b)

Figure A4 (cont'd). C4A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.



(a)



(b)

Figure A5. C5A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.

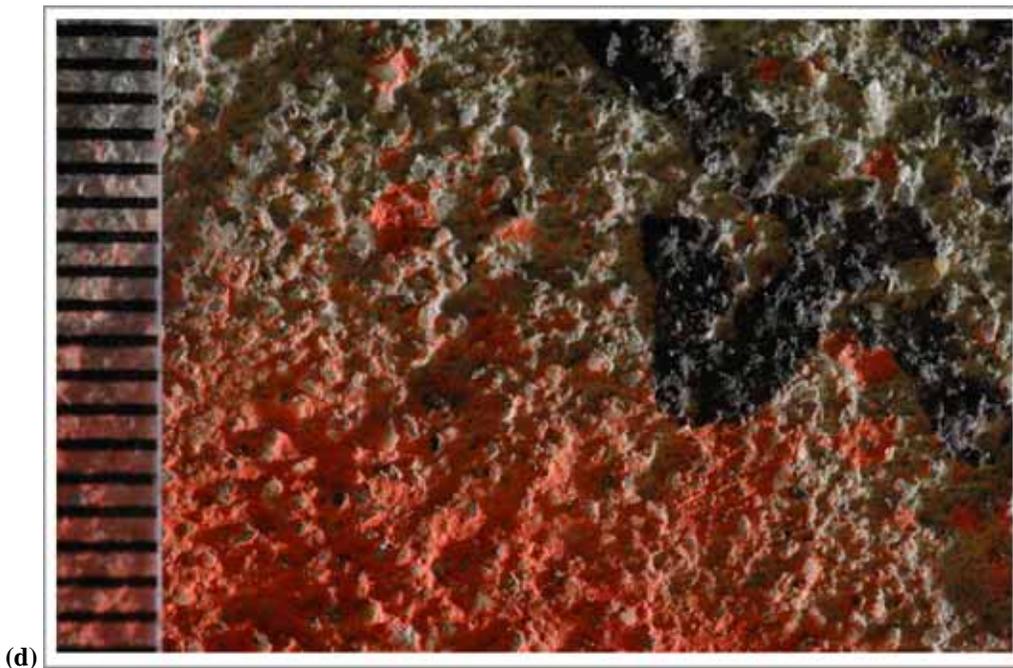


Figure A5 (cont'd). C5A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.



Figure A6. C6A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.

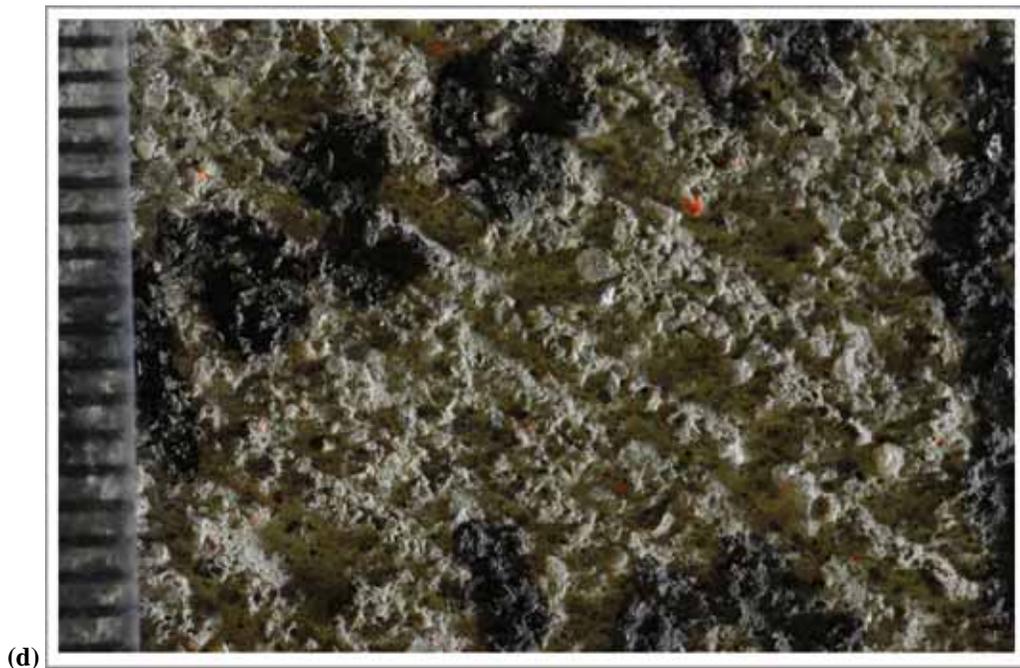


Figure A6 (cont'd). C6A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.



Figure A7. C7A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



Figure A7 (cont'd). C7A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.



(a)



(b)

Figure A8. C8A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



Figure A8 (cont'd). C8A. Photographs of sample in as-received condition showing top surface detail. Scale in millimeters.

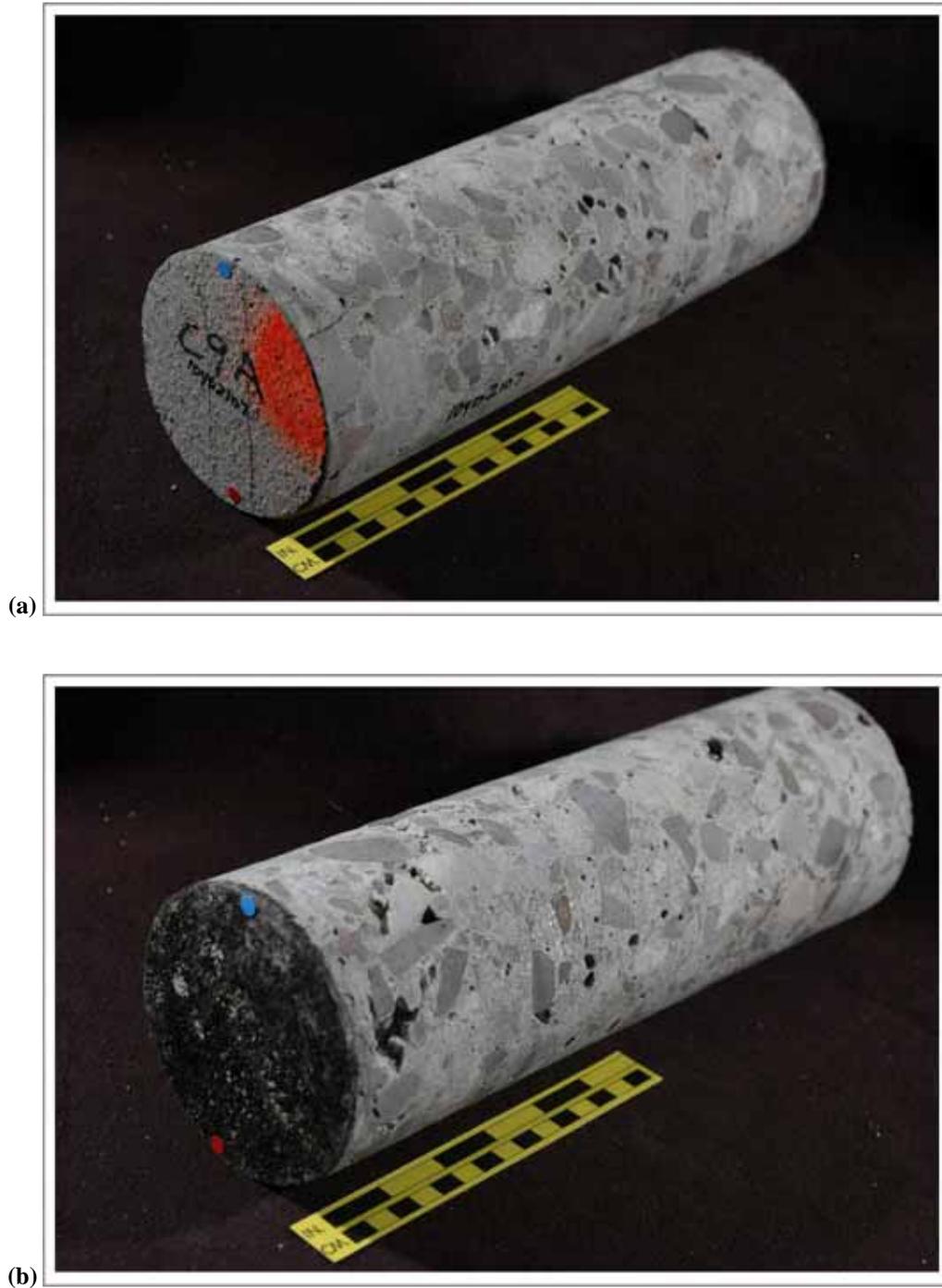


Figure A9. C9A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



Figure A9 (cont'd). C9A. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.

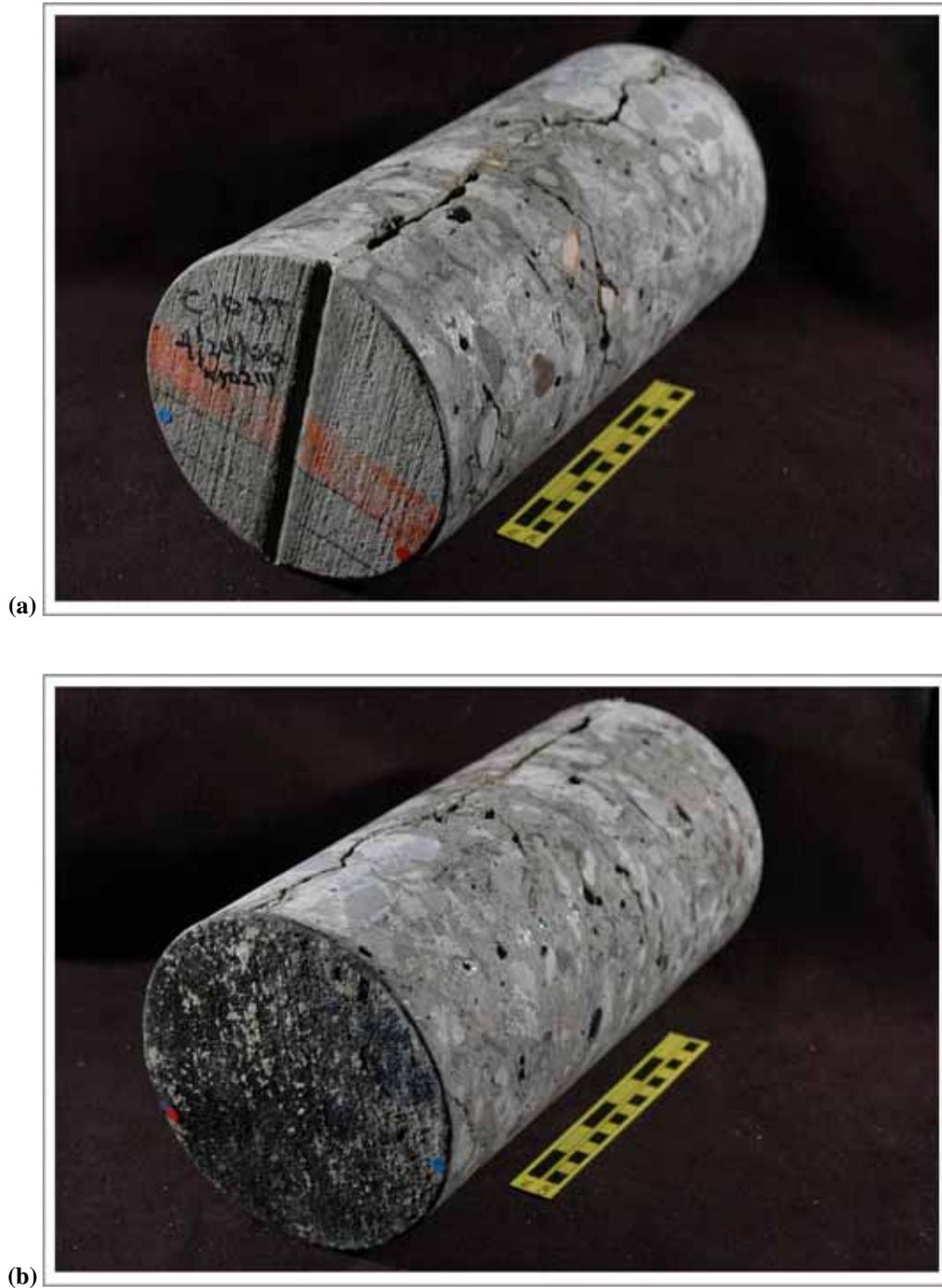


Figure A10. C10. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



Figure A10 (cont'd). C10. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots show the orientation of saw-cuts used to prepare the sample.



Figure A11. C1E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A11 (cont'd). C1E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.



Figure A12. C2E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A12 (cont'd). C2E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.

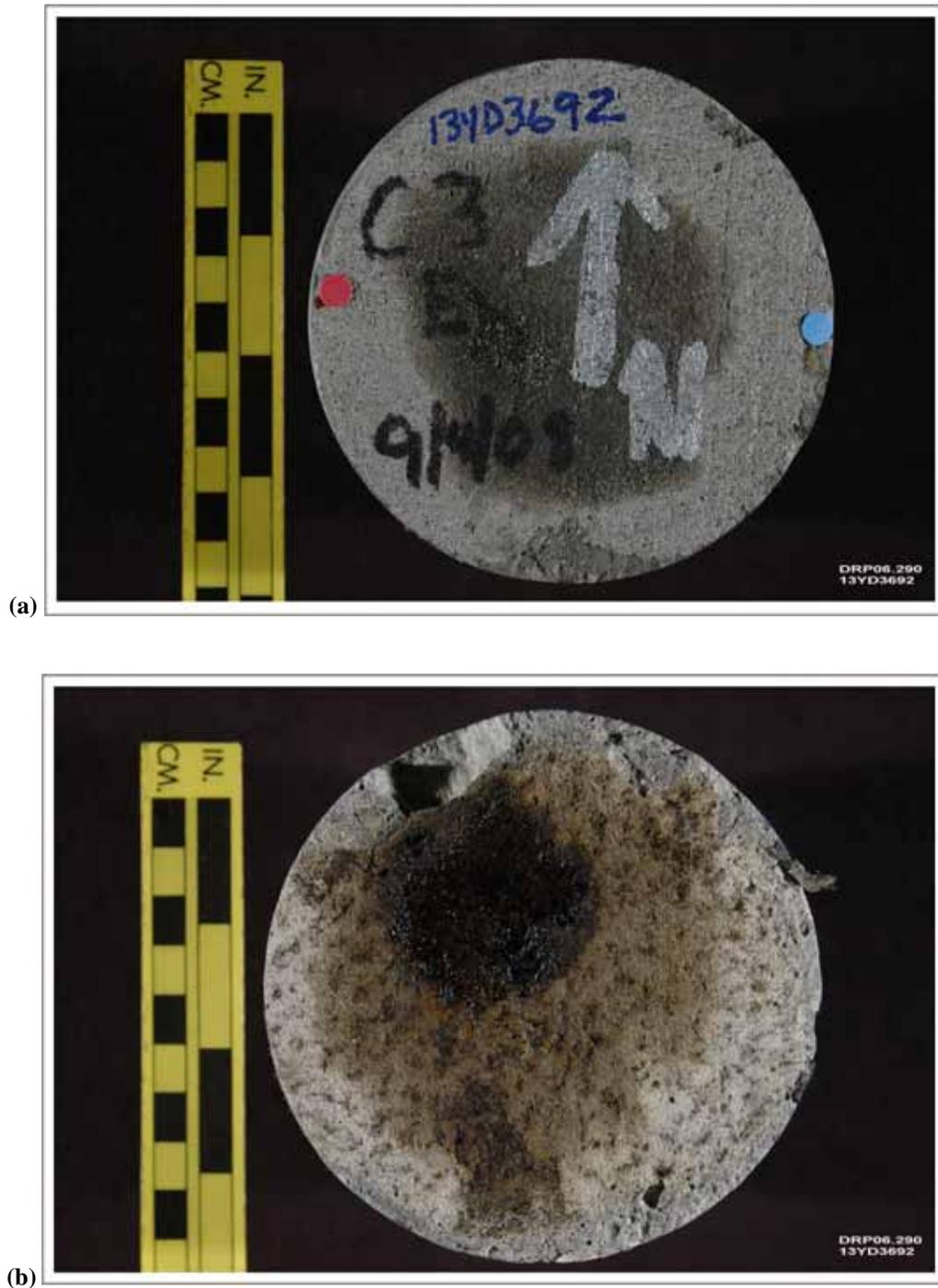


Figure A13. C3E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A13 (cont'd). C3E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.



Figure A14. C4E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A14 (cont'd). C4E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.

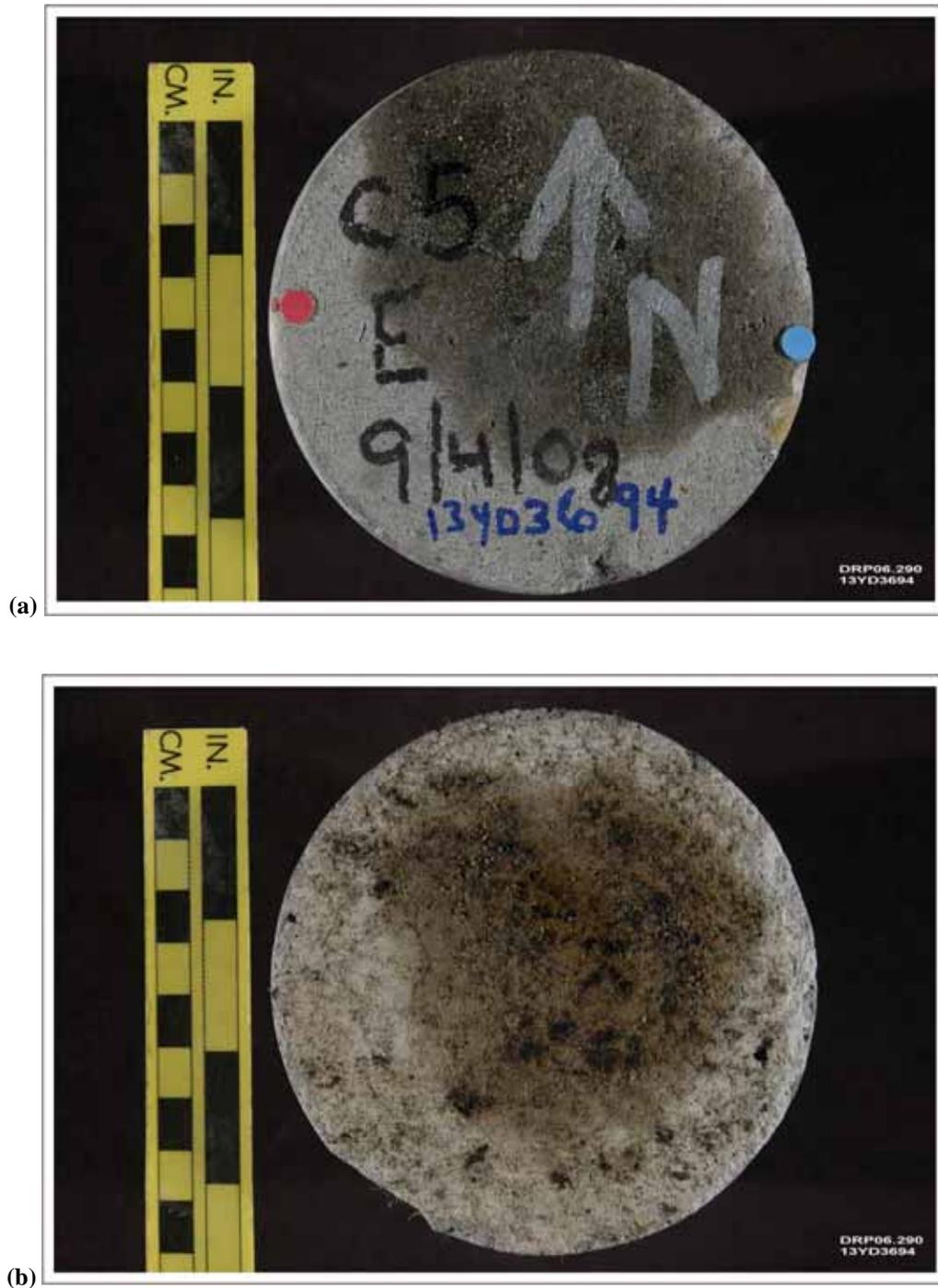


Figure A15. C5E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.

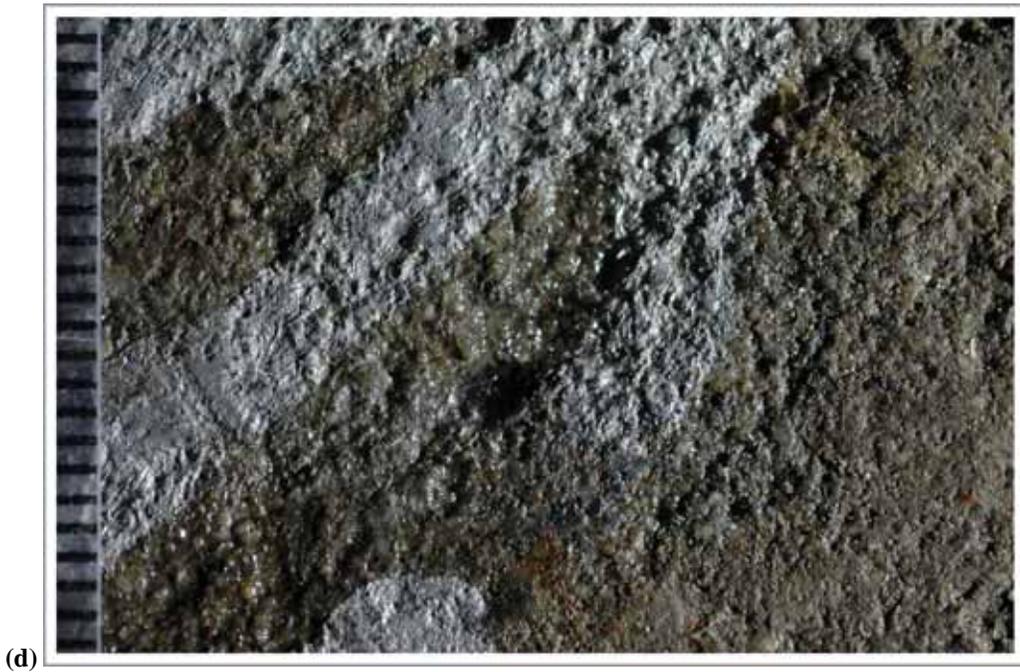


Figure A15 (cont'd). C5E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.

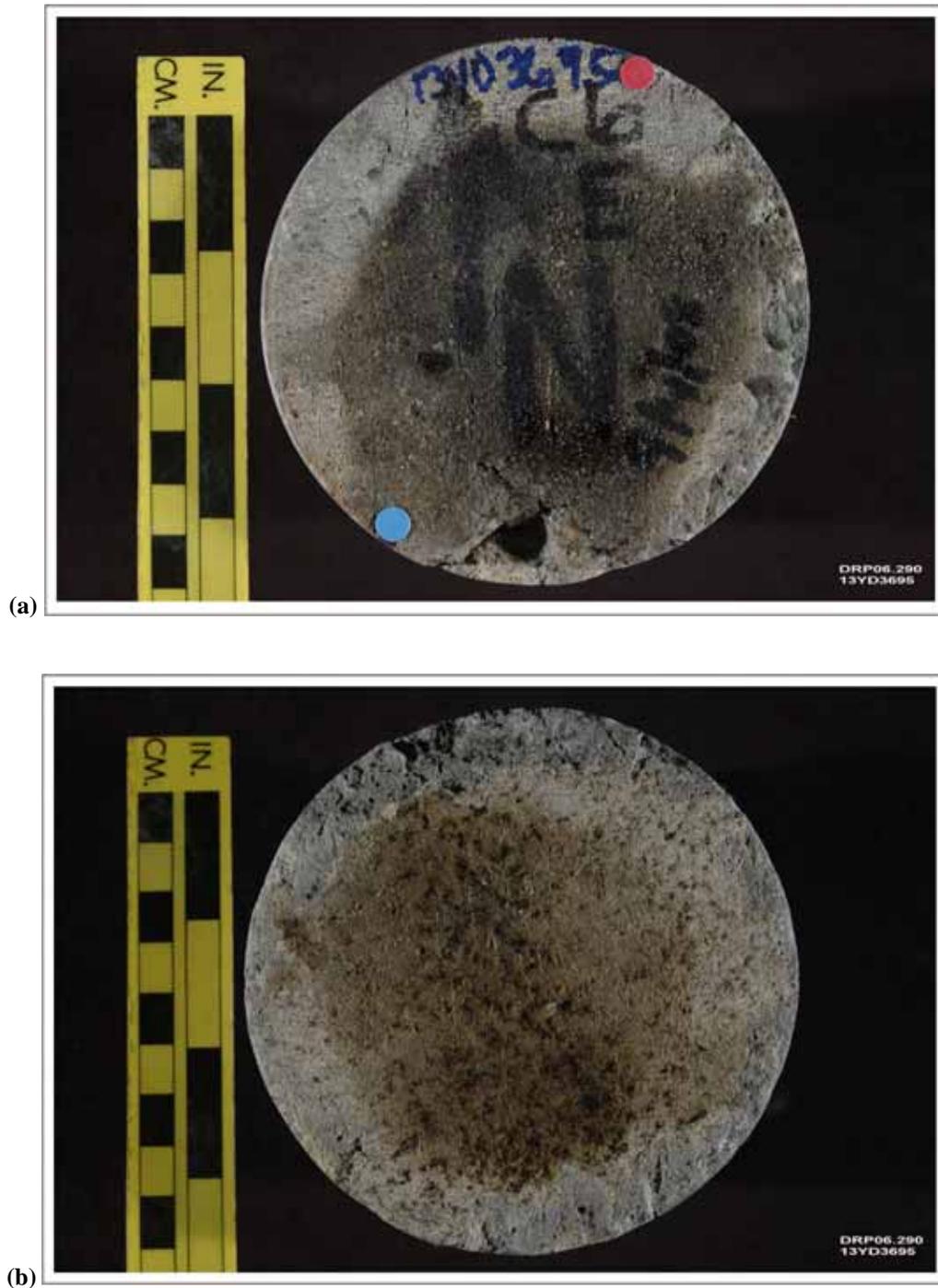


Figure A16. C6E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A16 (cont'd). C6E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.



Figure A17. C7G. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A17 (cont'd). C7G. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.



Figure A18. C8E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A18 (cont'd). C8E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.

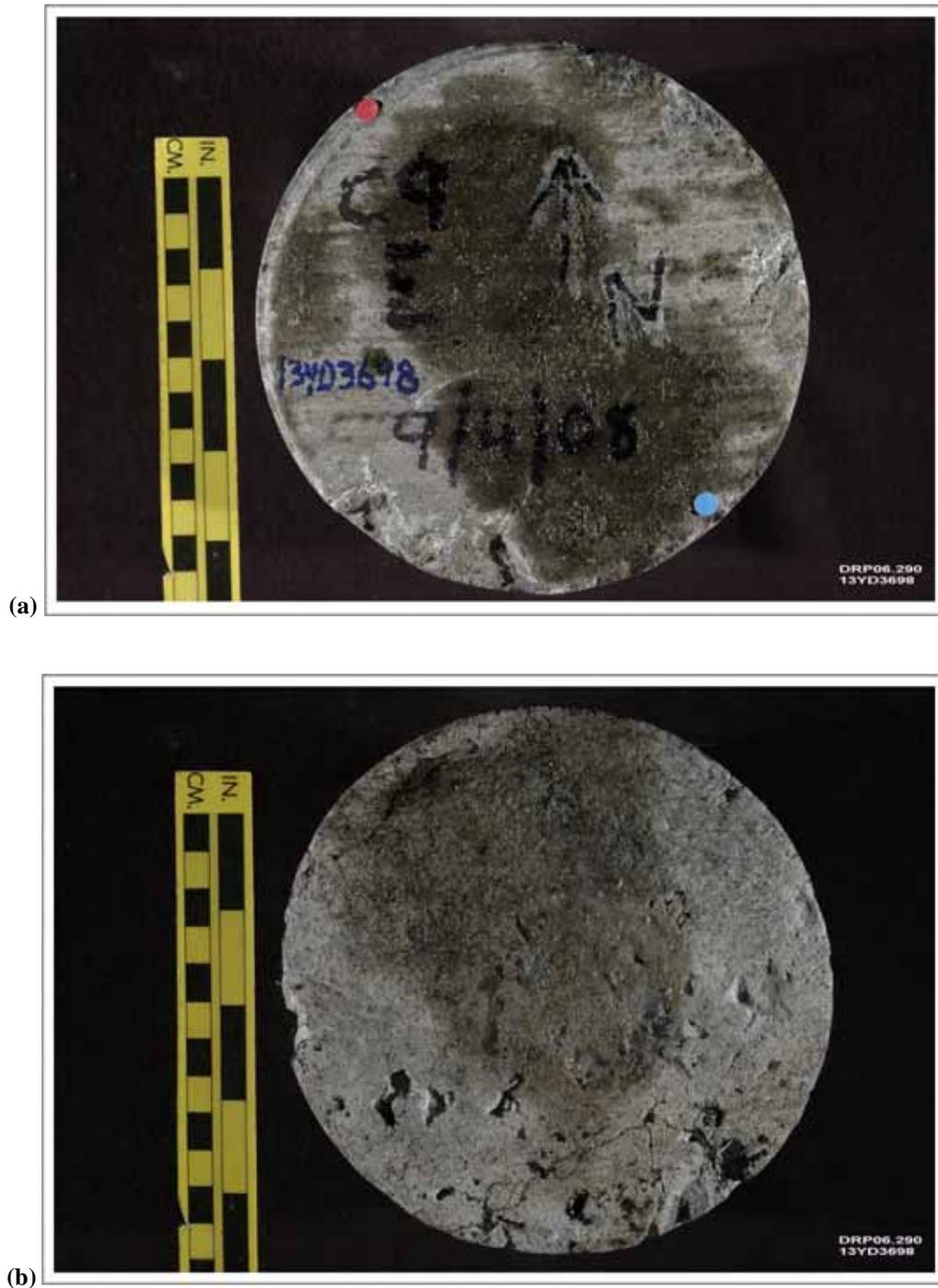


Figure A19. C9E. Photographs of sample in as-received condition showing (a) top and (b) bottom surface of core. Red and blue dots in (a) show the orientation of saw-cuts used to prepare the sample.



Figure A19 (cont'd). C9E. Photographs of sample in as-received condition showing (c) side of core and (d) detail of top surface. Scale in (d) millimeters.

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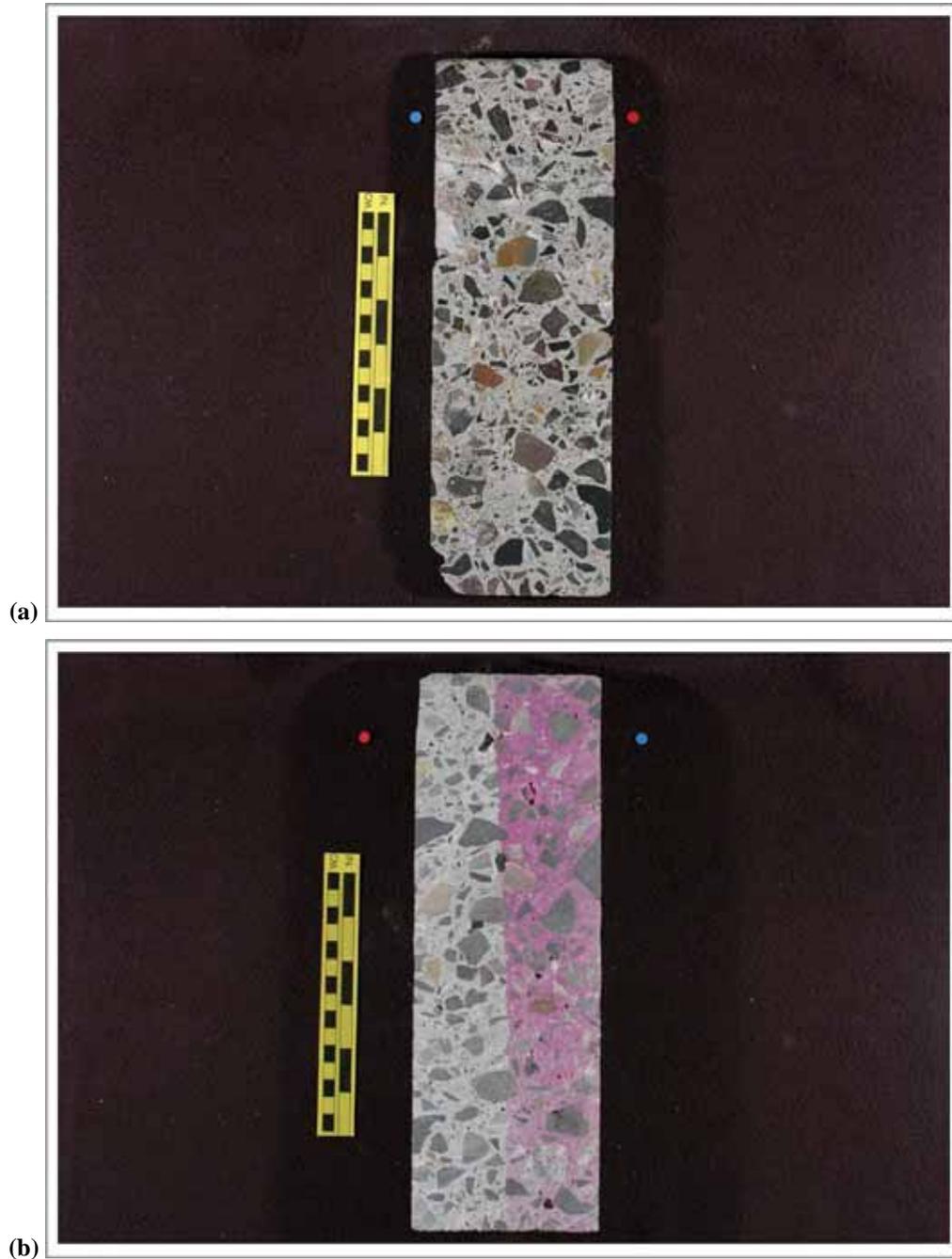


Figure B1. Core C1A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.



Figure B2. Core C2A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

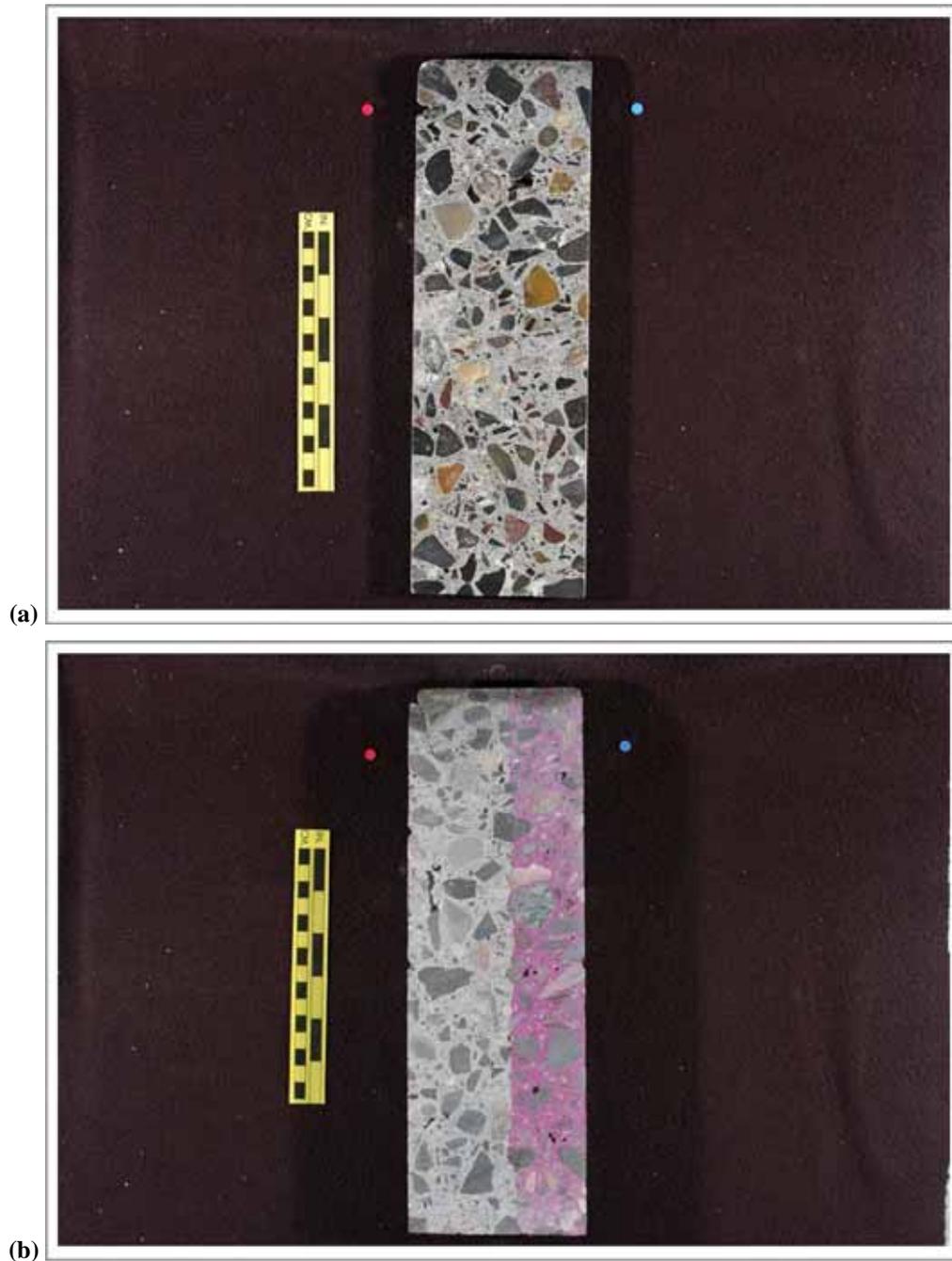
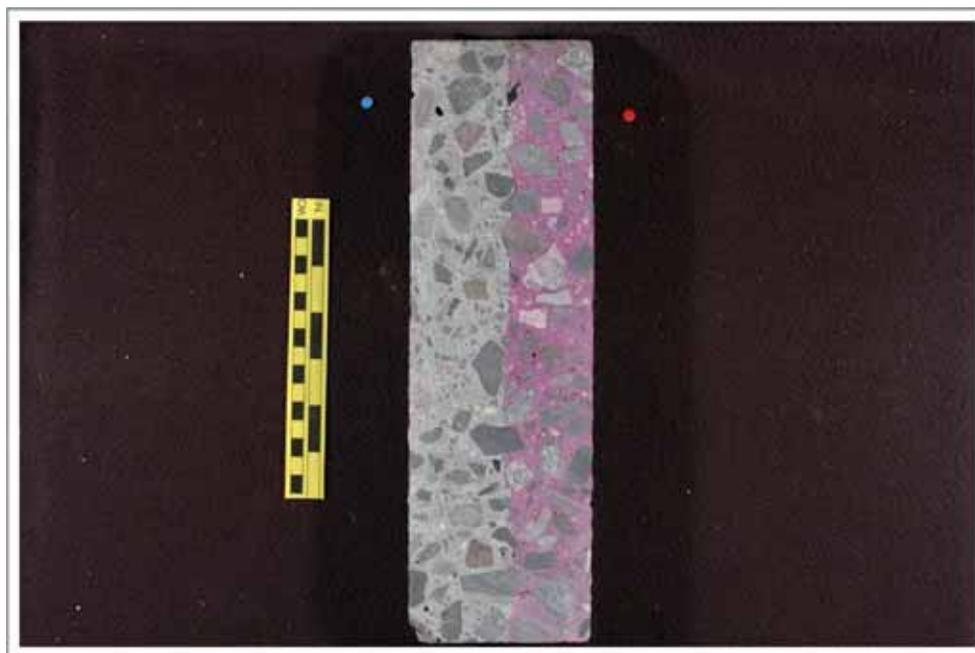


Figure B3. Core C3A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.



(a)



(b)

Figure B4. Core C4A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

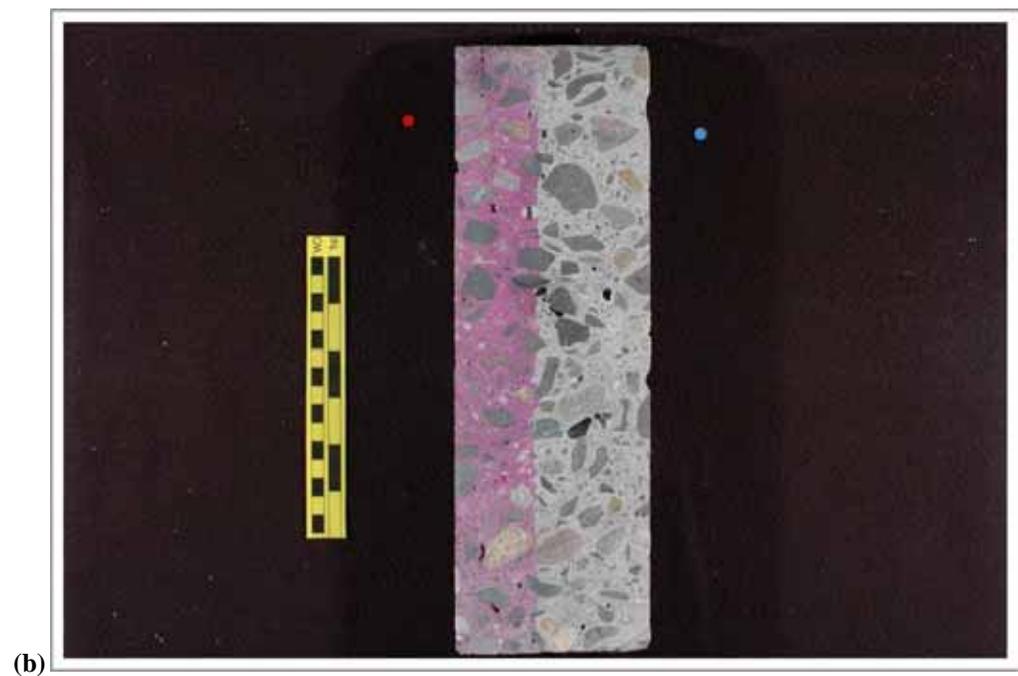
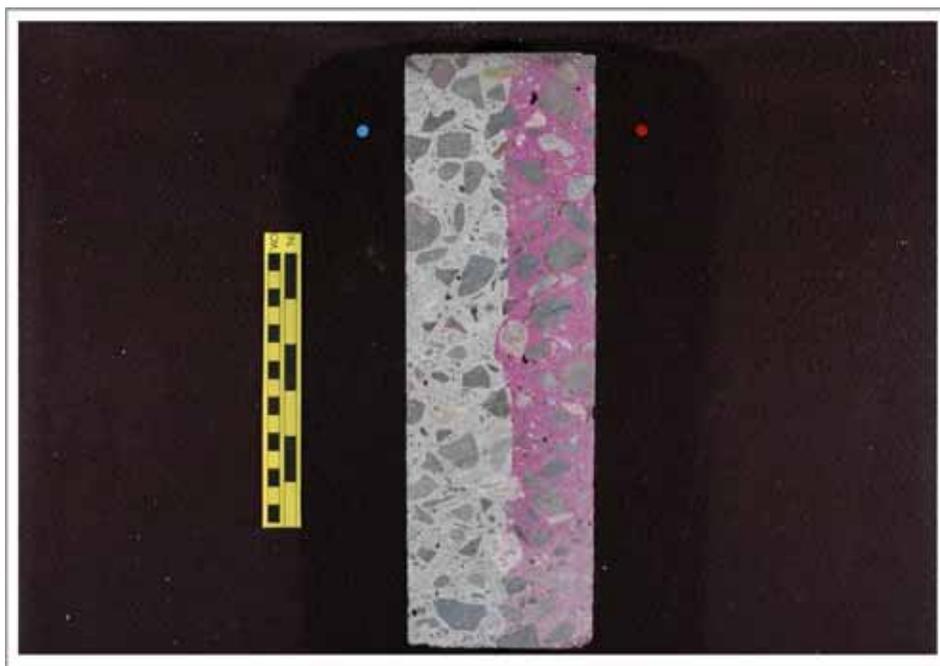


Figure B5. Core C5A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.



(a)



(b)

Figure B6. Core C6A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.



Figure B7. Core C7A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.



Figure B8. Core C8A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

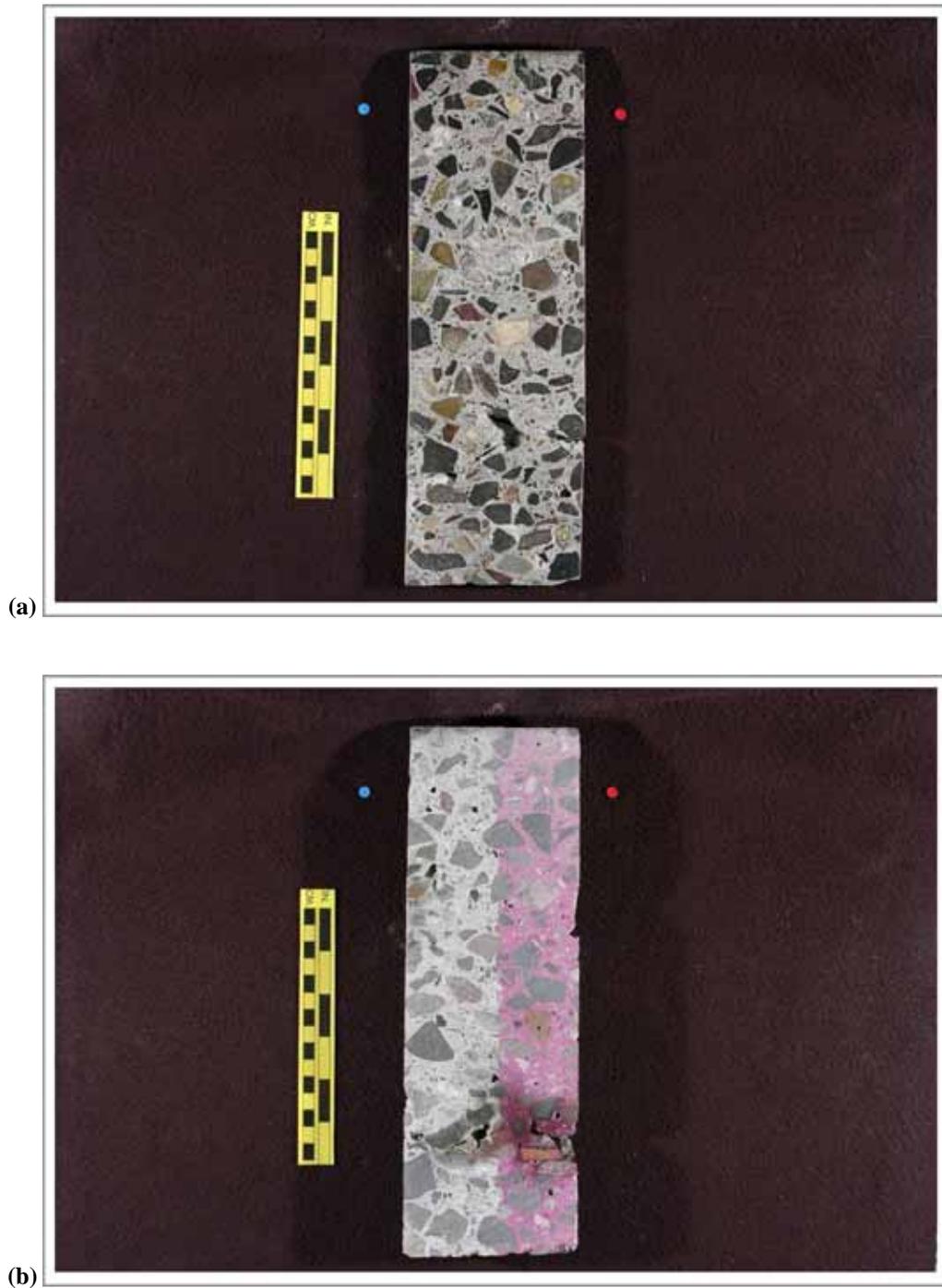


Figure B9. Core C9A. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.



Figure B10. Core C10. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

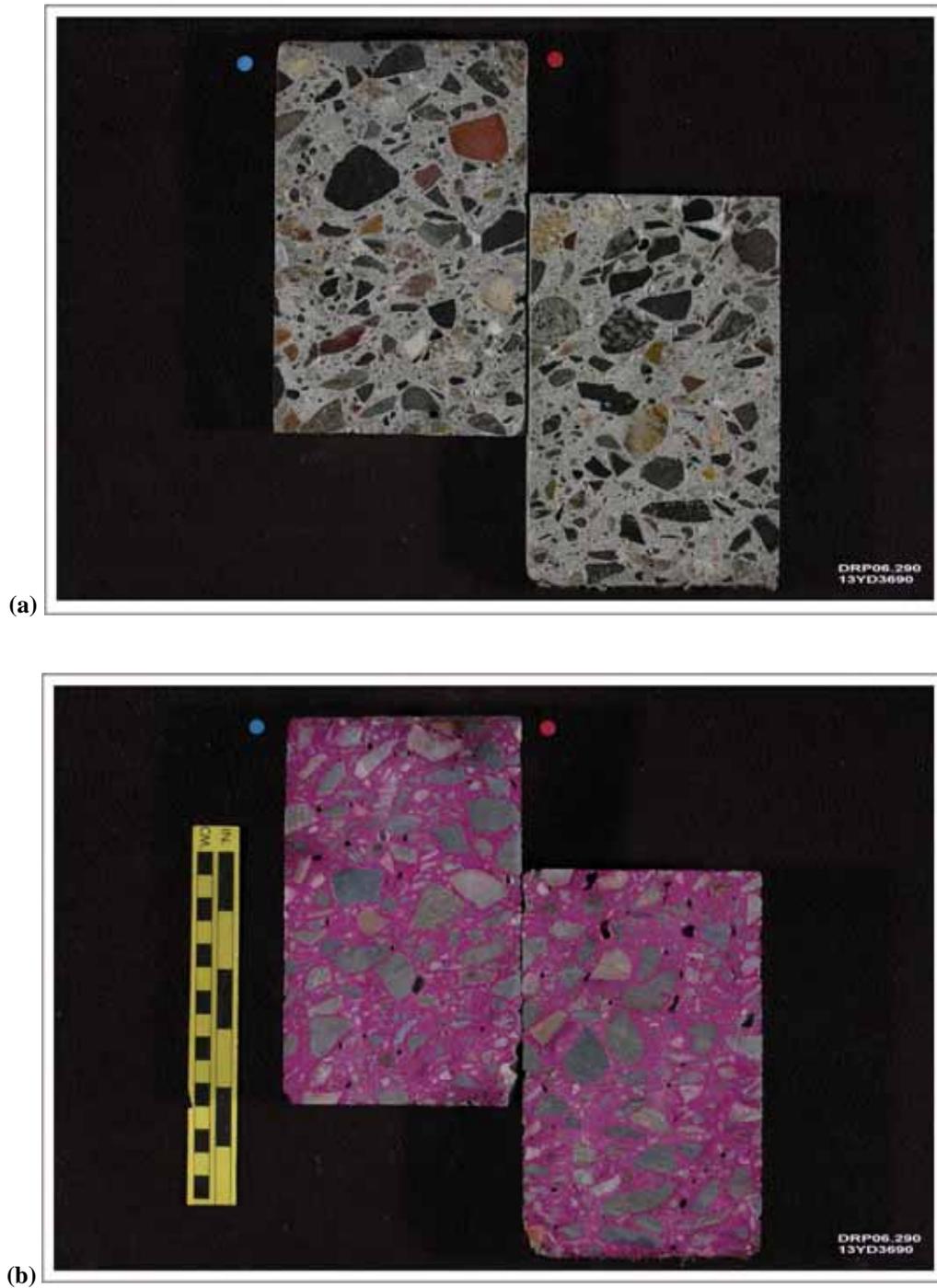


Figure B11. Core C1E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

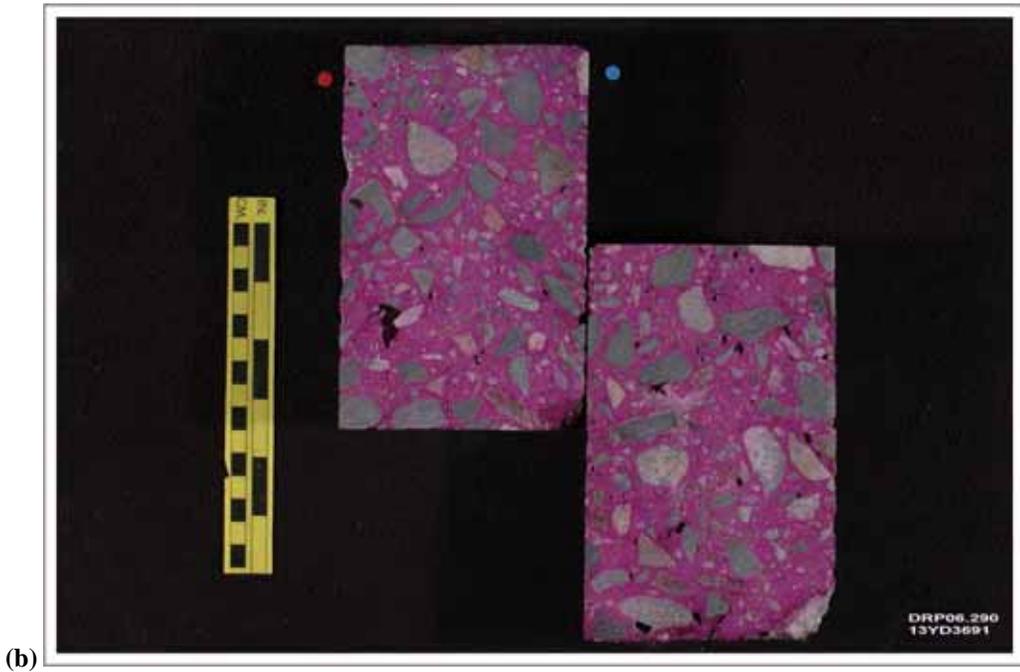
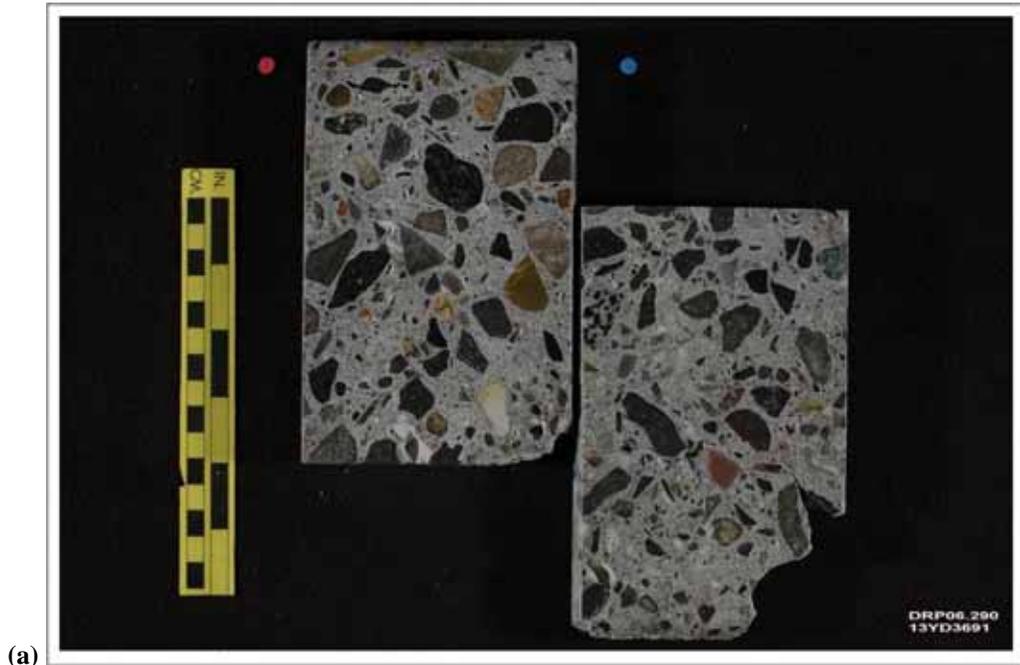


Figure B12. Core C2E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

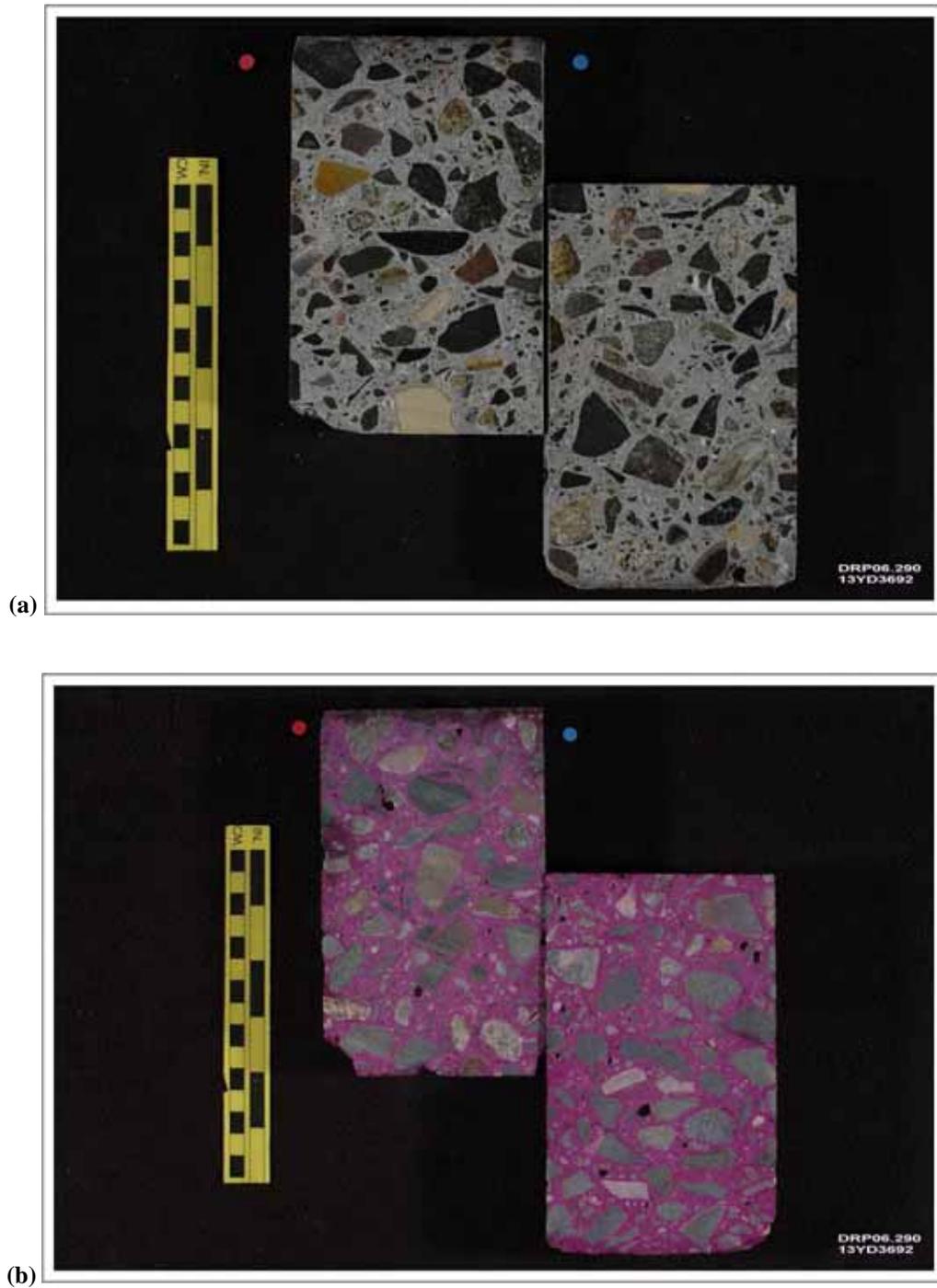


Figure B13. Core C3E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

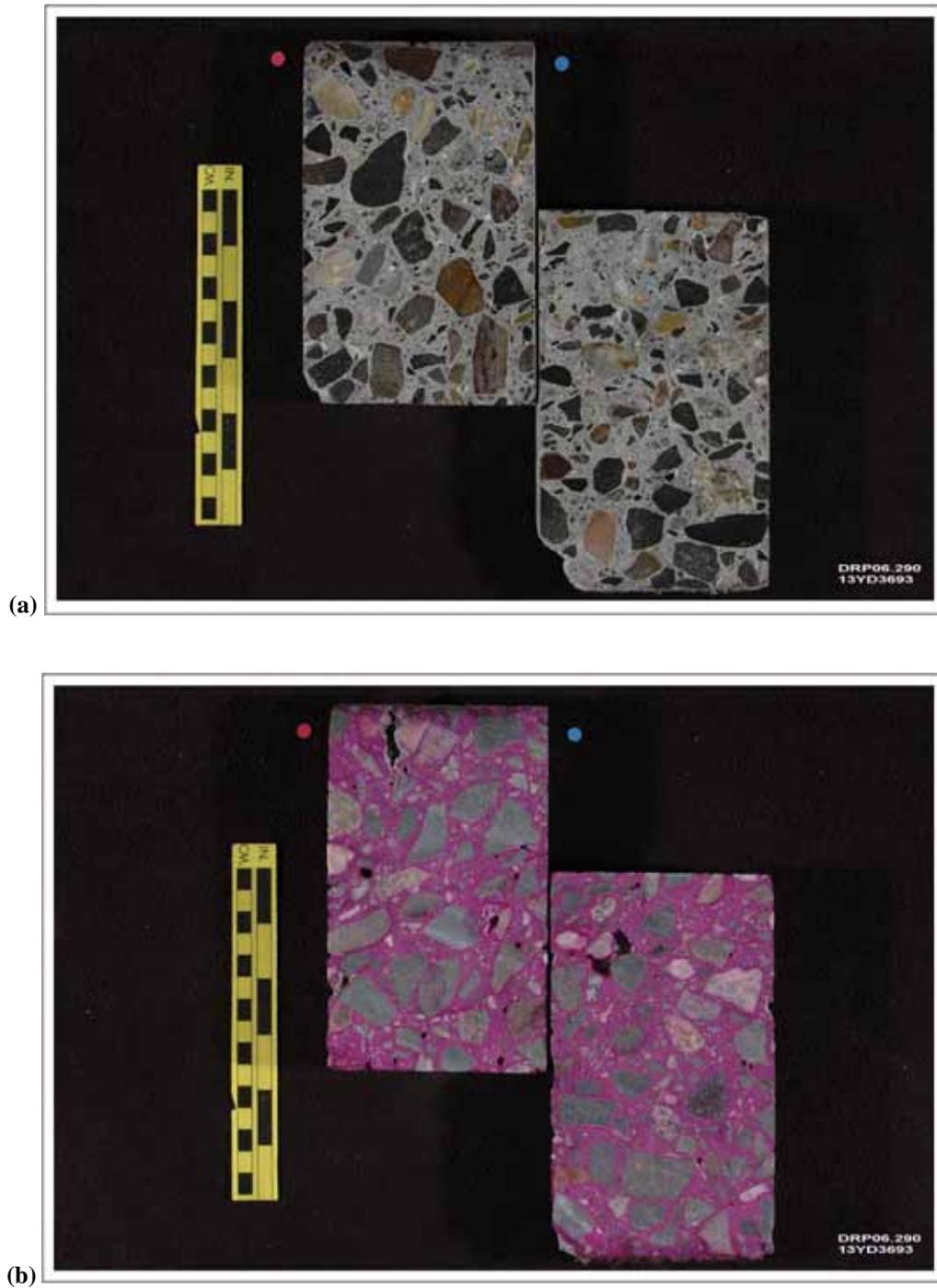


Figure B14. Core C4E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

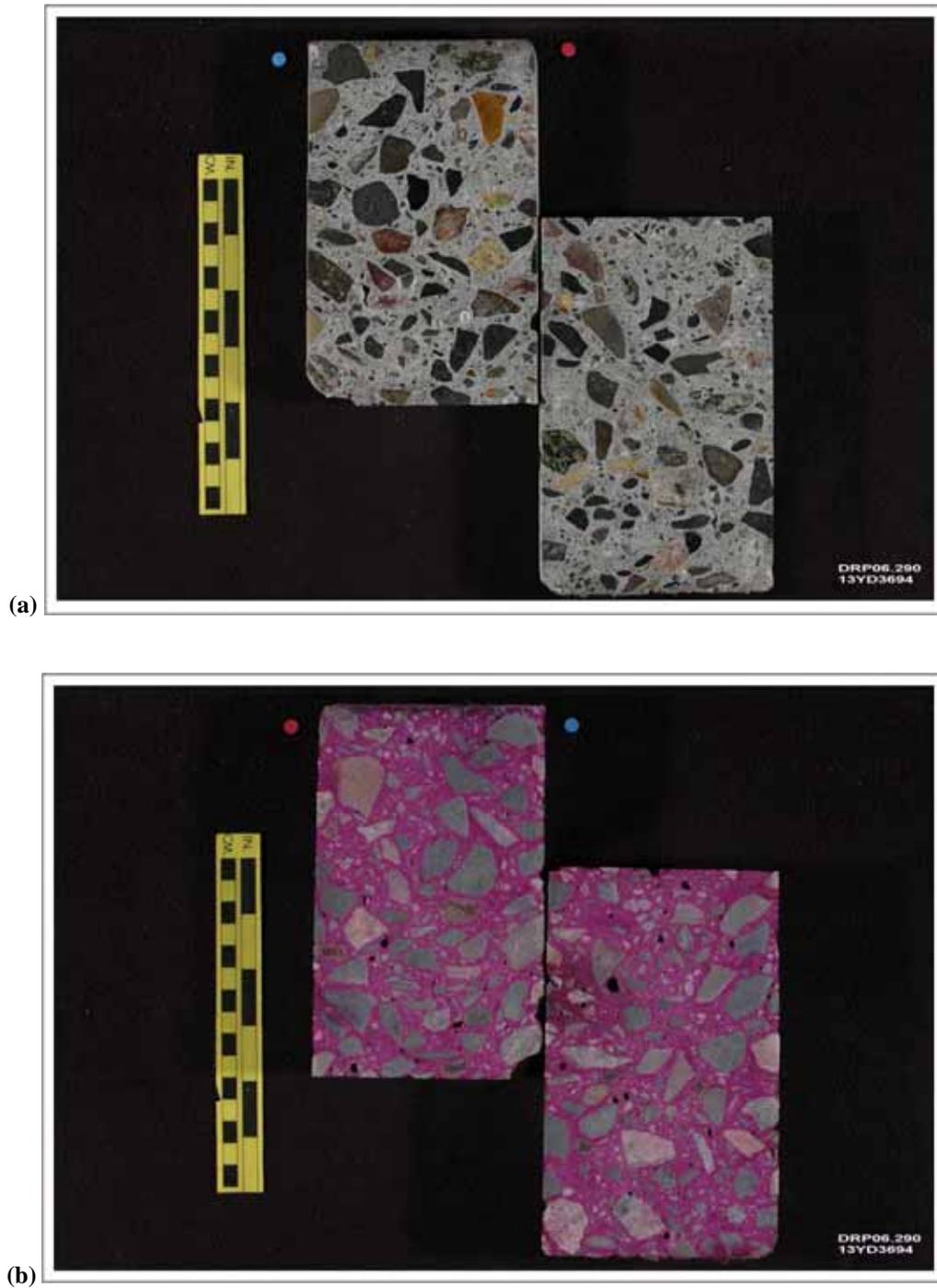


Figure B15. Core C5E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

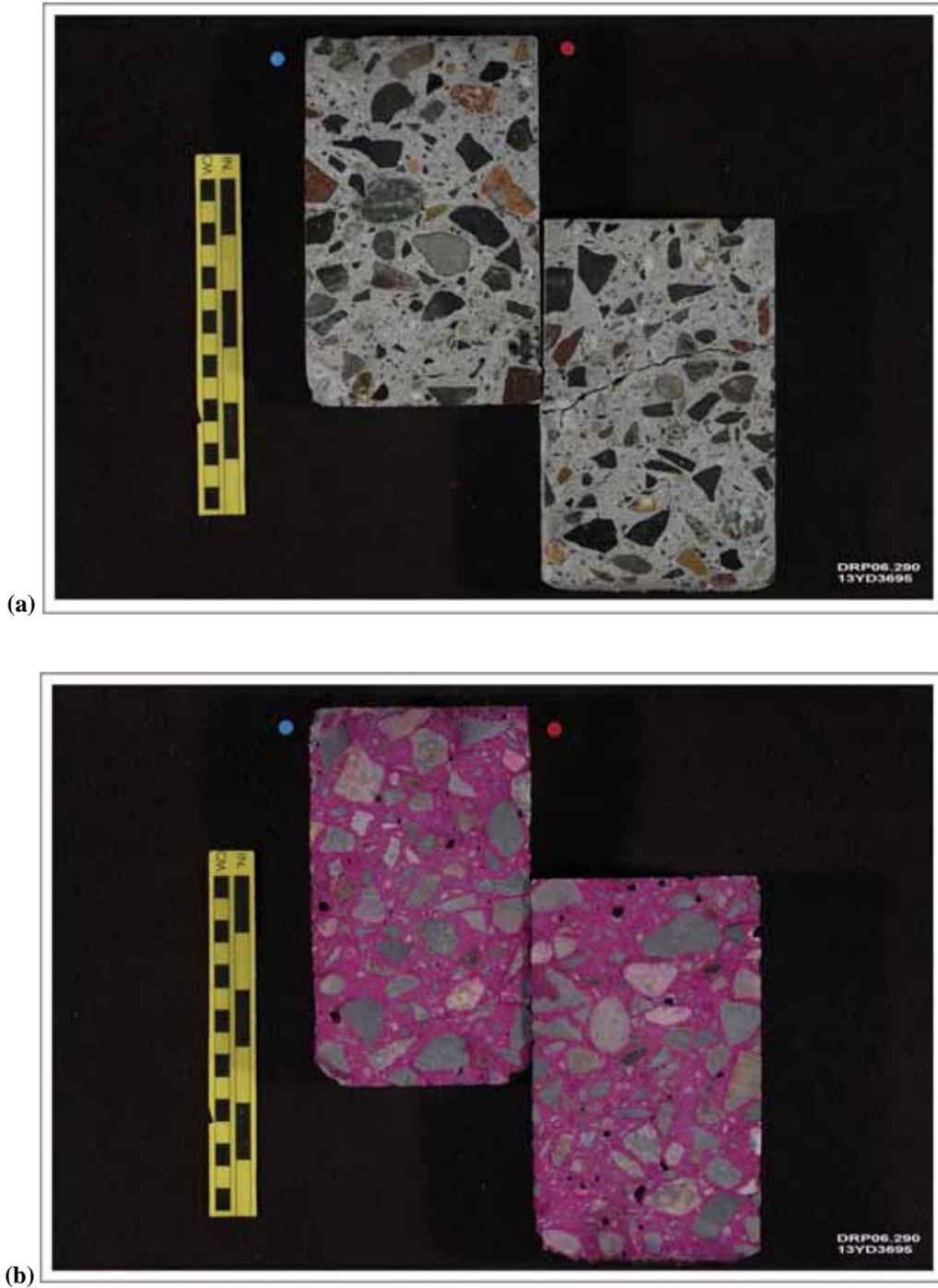


Figure B16. Core C6E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

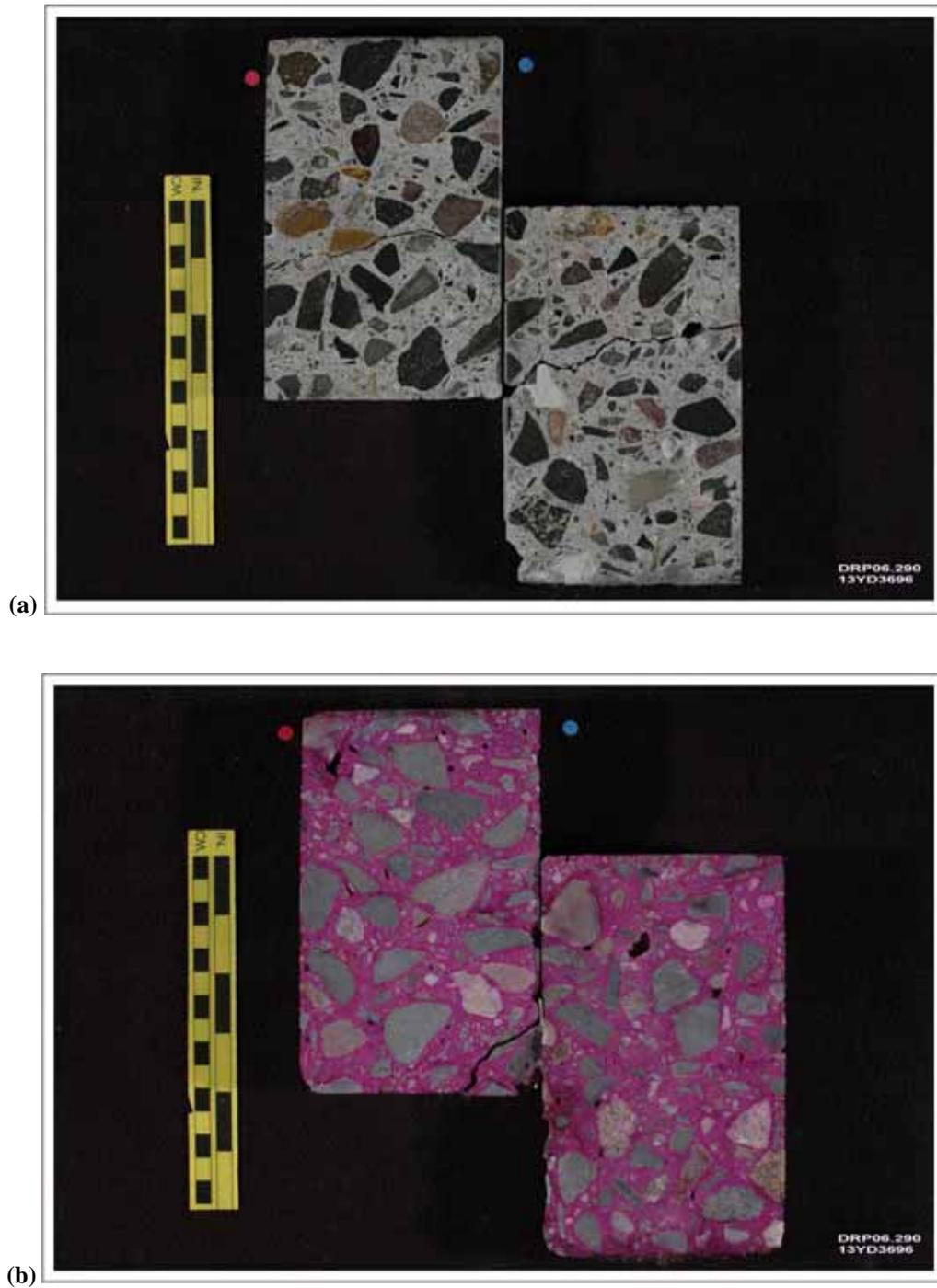


Figure B17. Core C7G. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

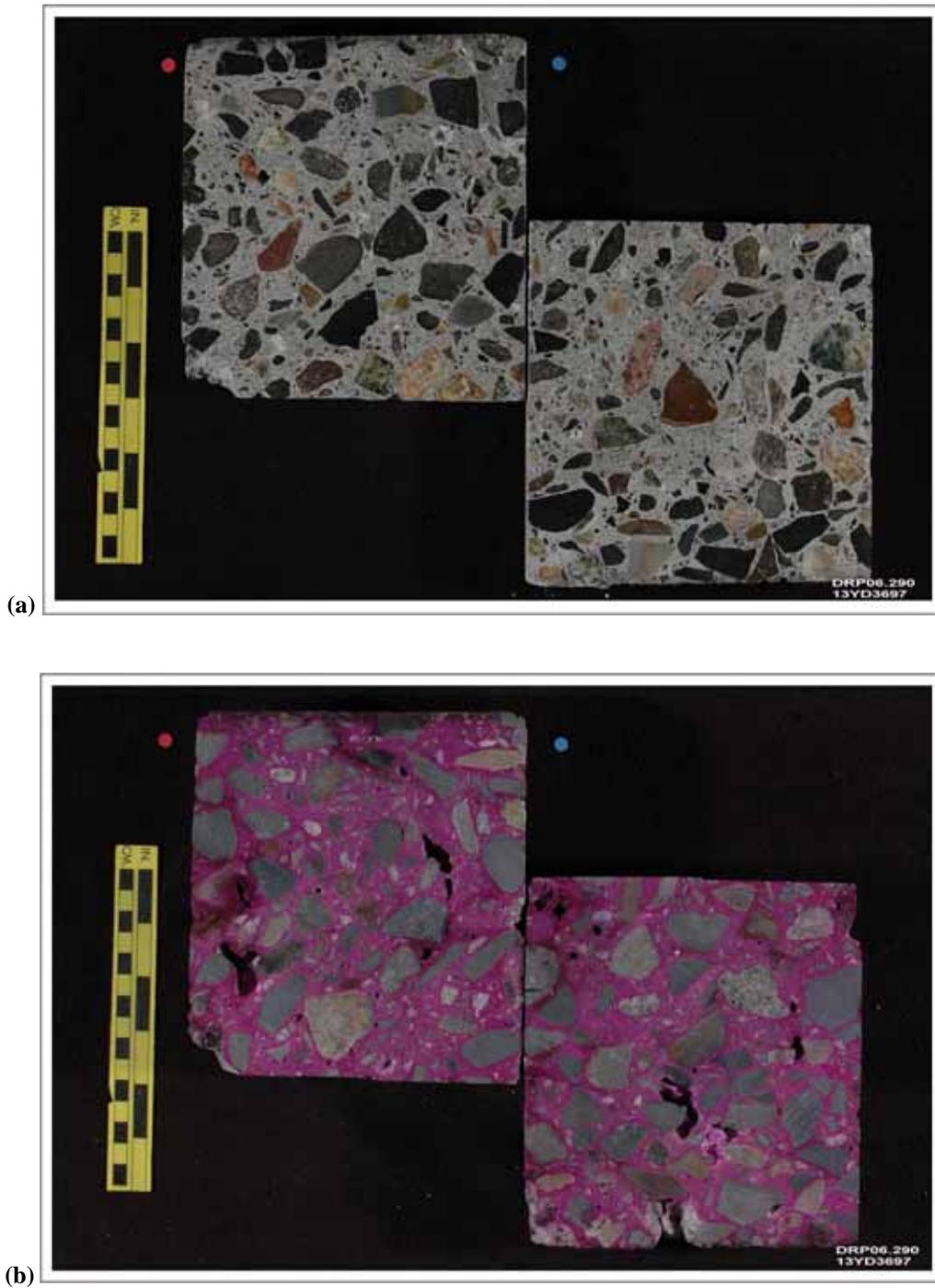


Figure B18. Core C8E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

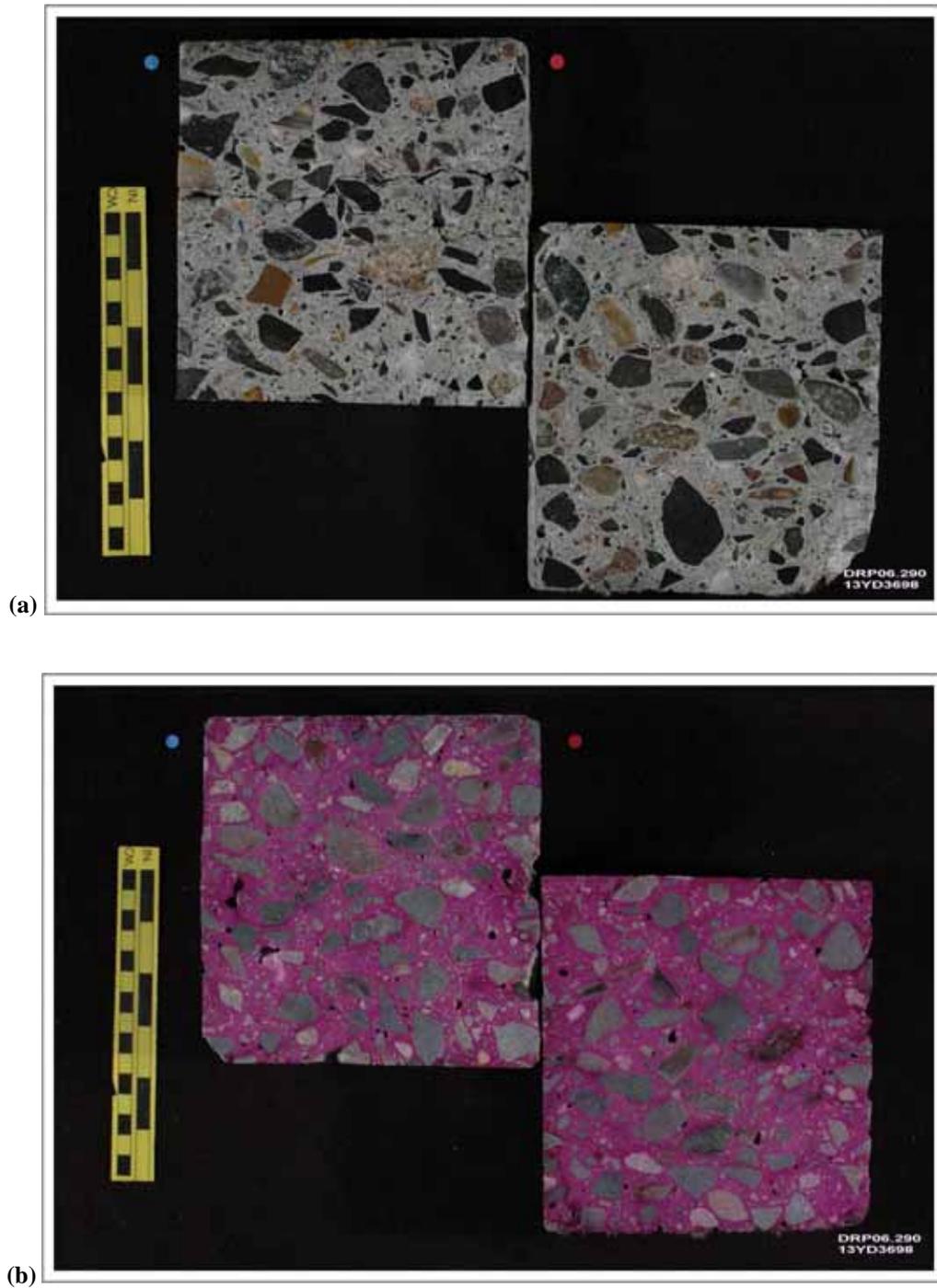


Figure B19. Core C9E. Photographs of (a) polished and (b) phenolphthalein-stained surfaces.

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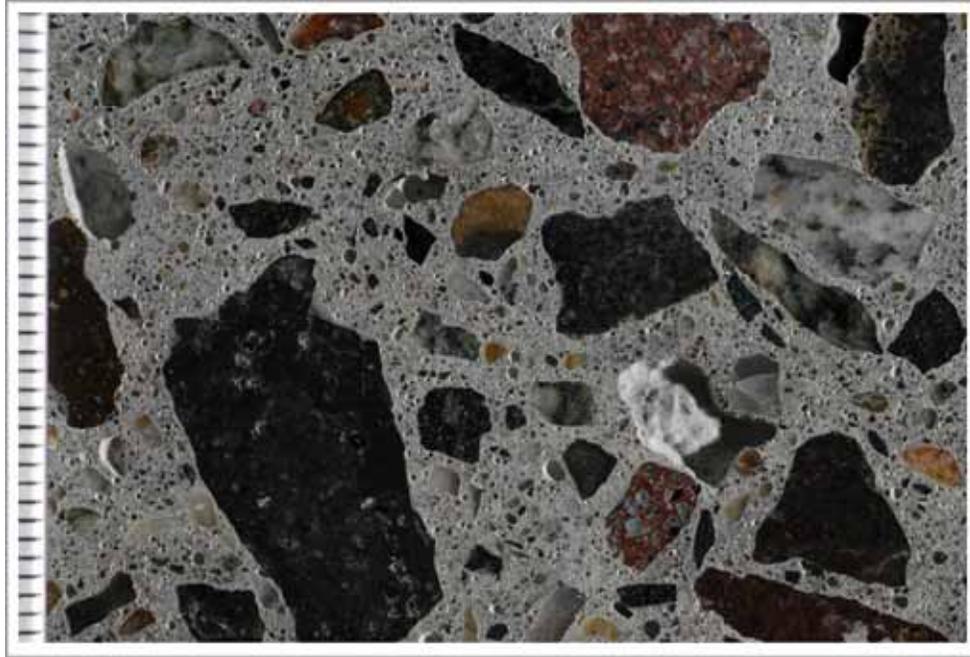


Figure C1. Core C1A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

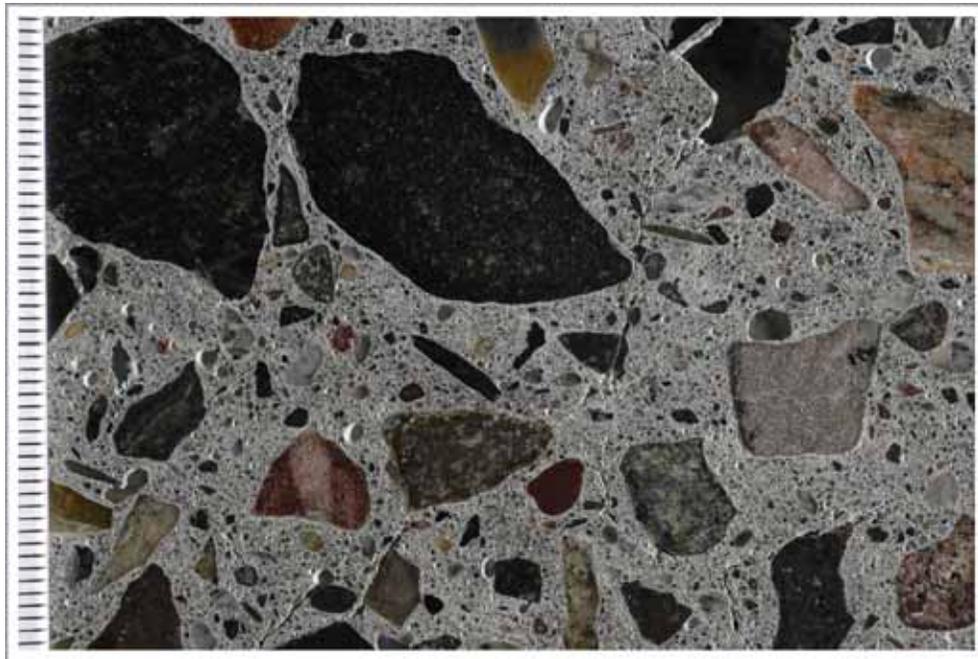


Figure C2. Core C2A. Photograph of polished surface showing overview of aggregate; scale in millimeters.



Figure C3. Core C3A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

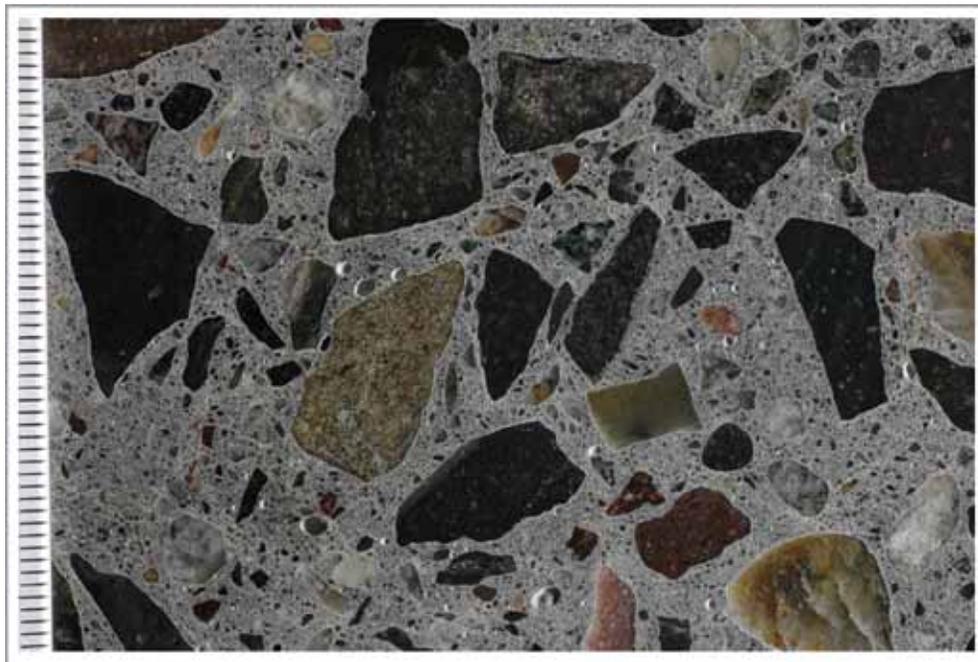


Figure C4. Core C4A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

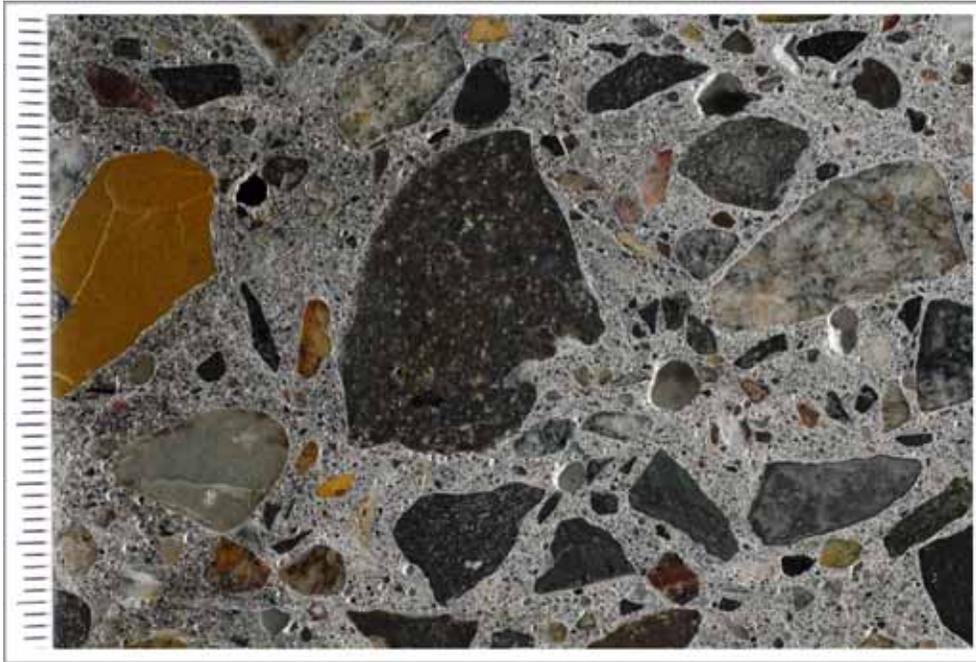


Figure C5. Core C5A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

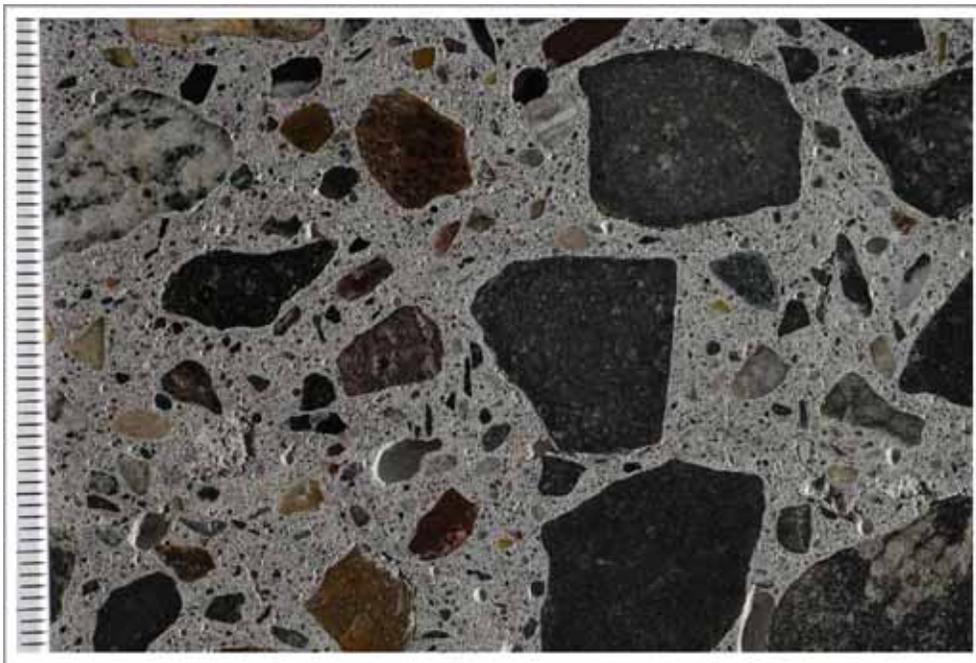


Figure C6. Core C6A. Photograph of polished surface showing overview of aggregate; scale in millimeters.



Figure C7. Core C7A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

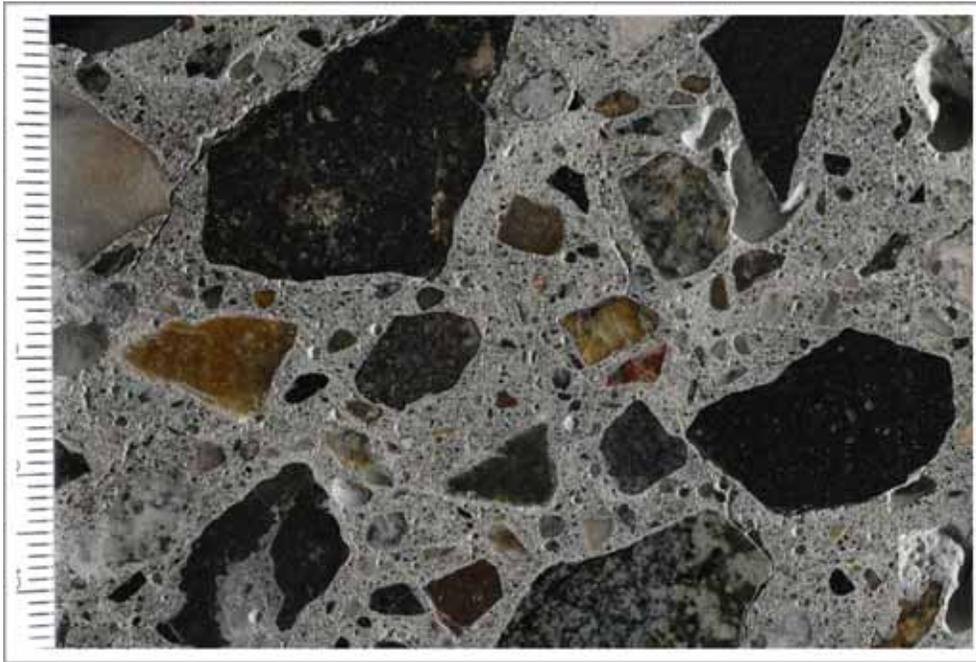


Figure C8. Core C8A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

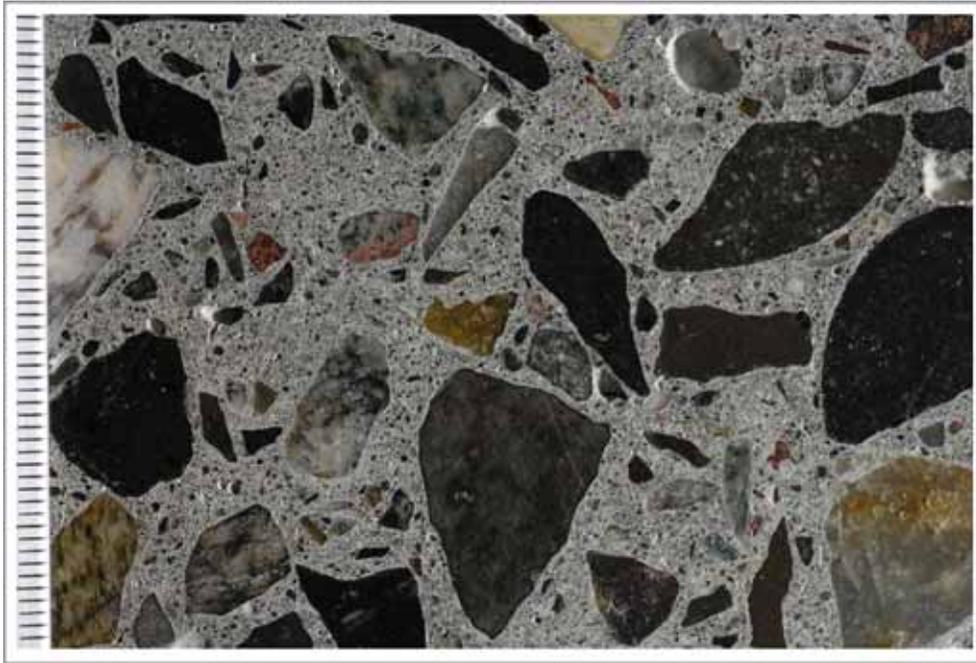


Figure C9. Core C9A. Photograph of polished surface showing overview of aggregate; scale in millimeters.

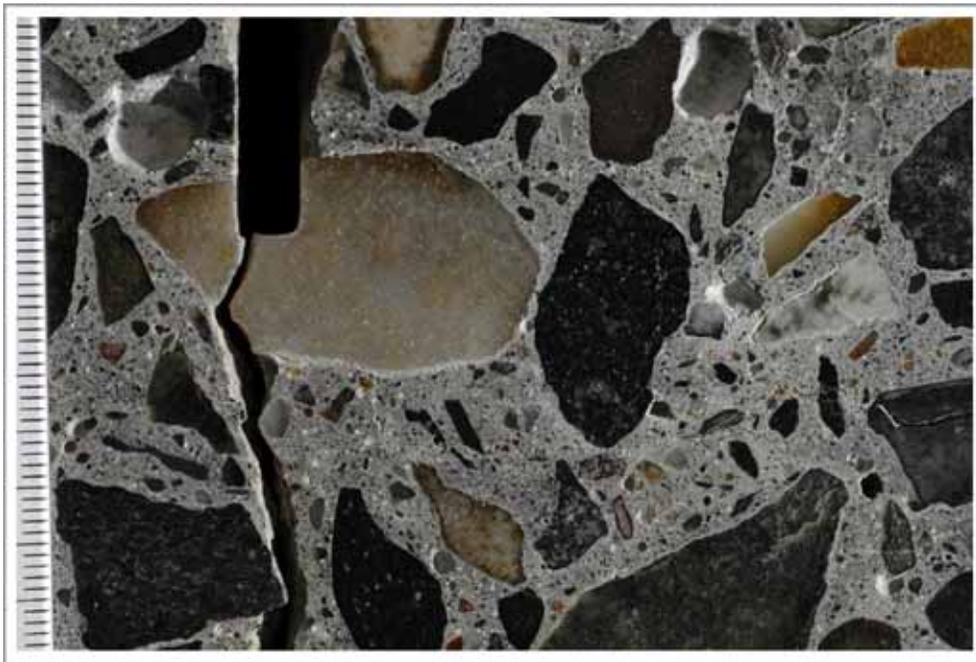


Figure C10. Core C10. Photograph of polished surface showing overview of aggregate; scale in millimeters.



Figure C11. Core C1E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

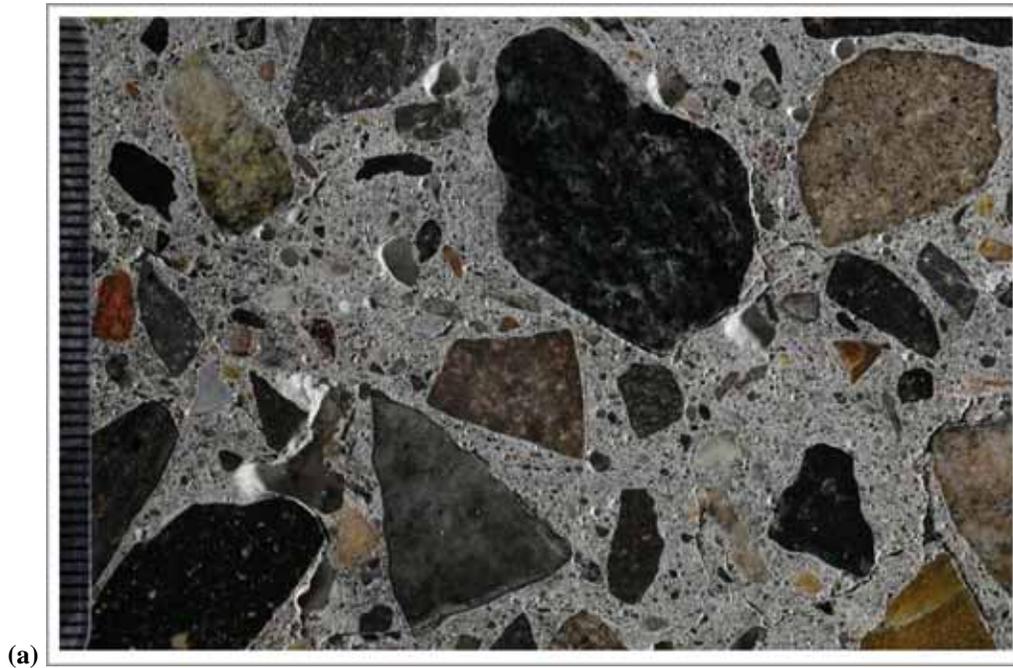


Figure C12. Core C2E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

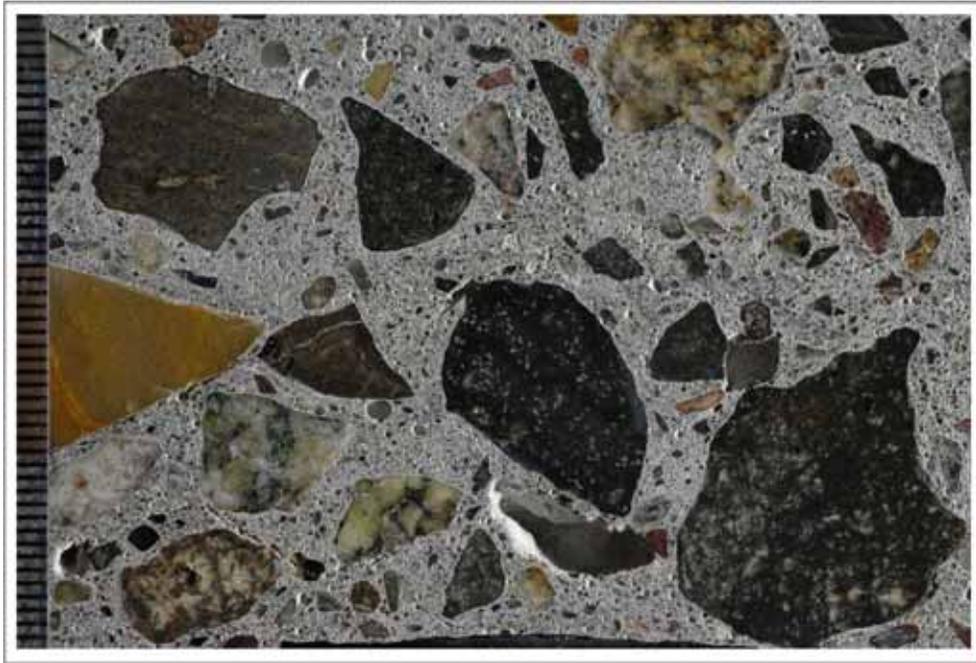


Figure C13. Core C3E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

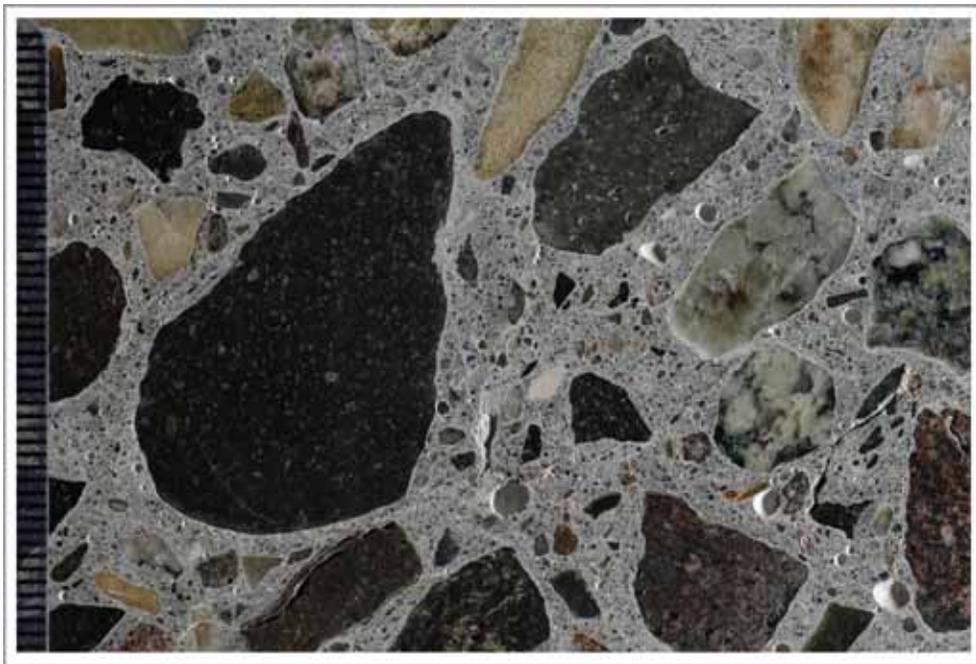


Figure C14. Core C4E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

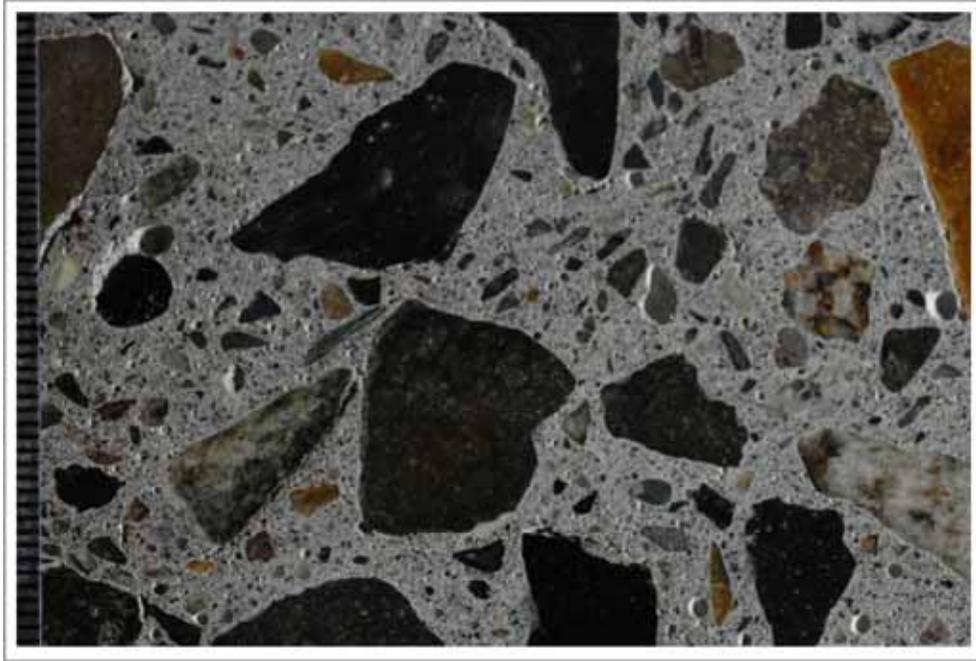


Figure C15. Core C5E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

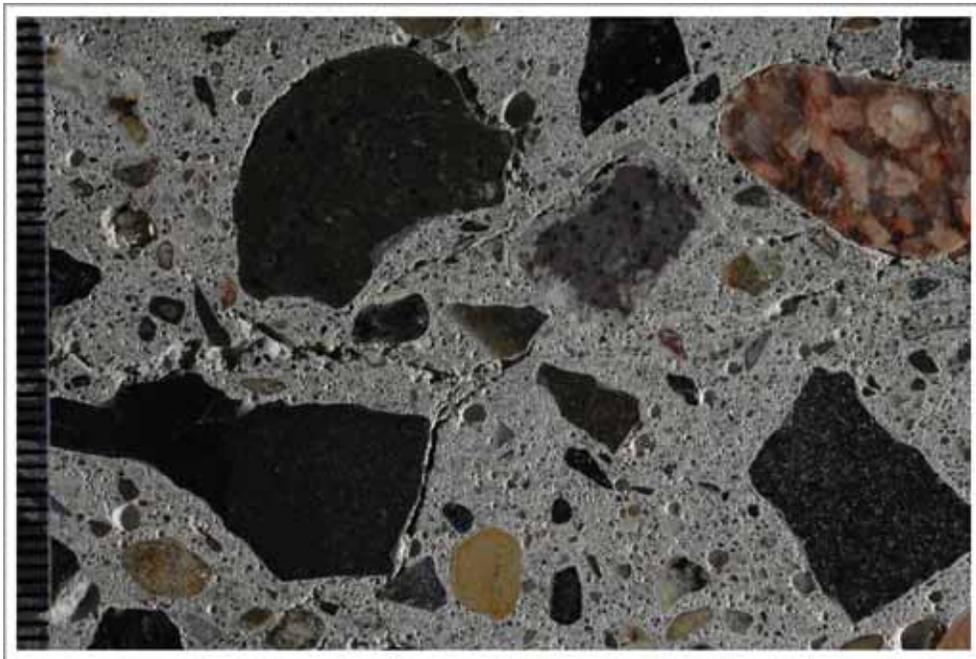


Figure C16. Core C6E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

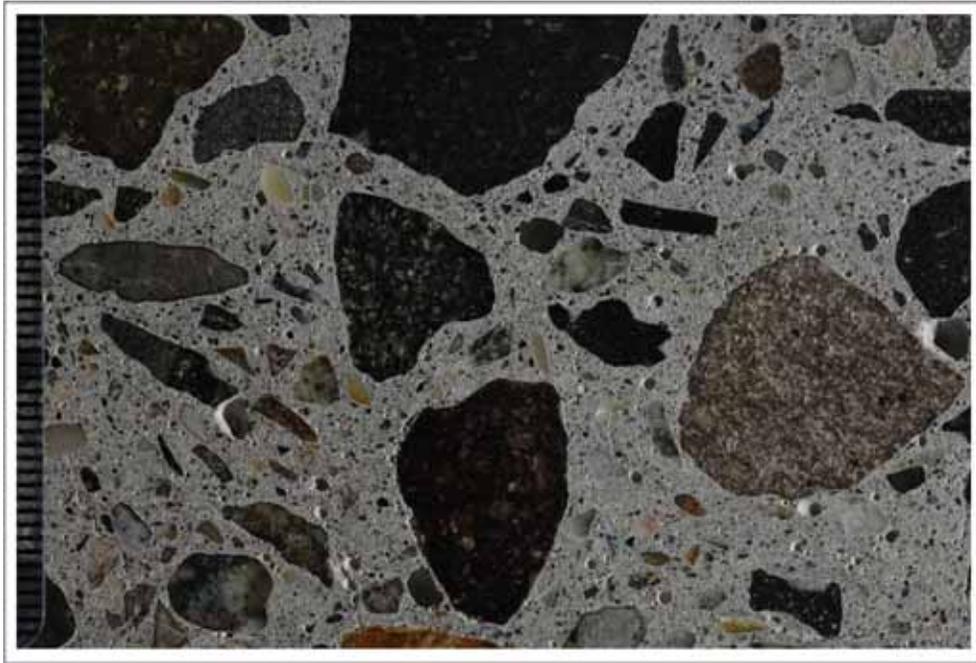


Figure C17. Core C7G. Photograph of polished surface showing overview of aggregate; scale in millimeters.

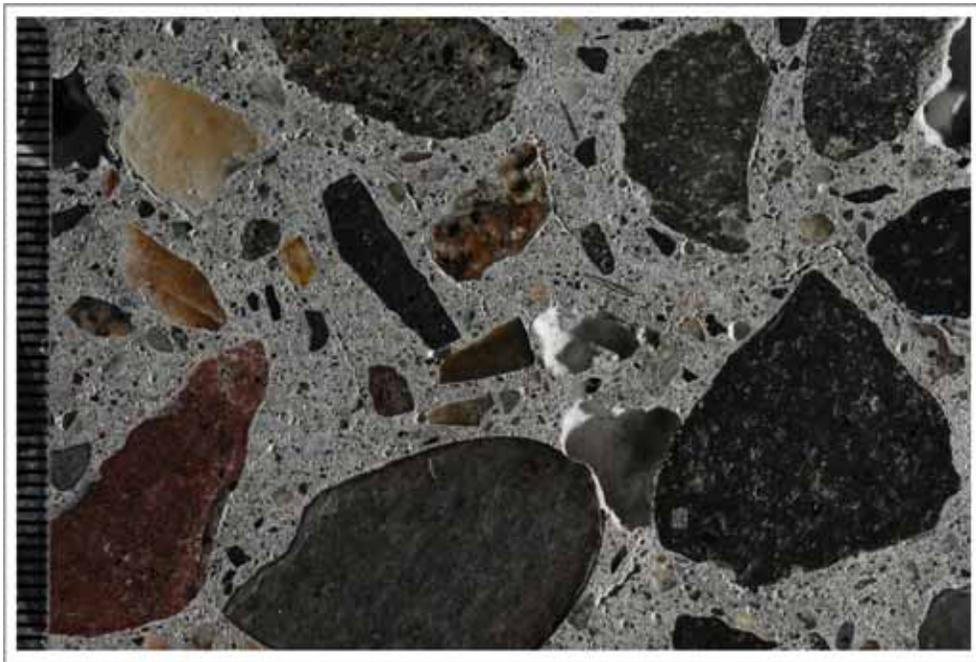


Figure C18. Core C8E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

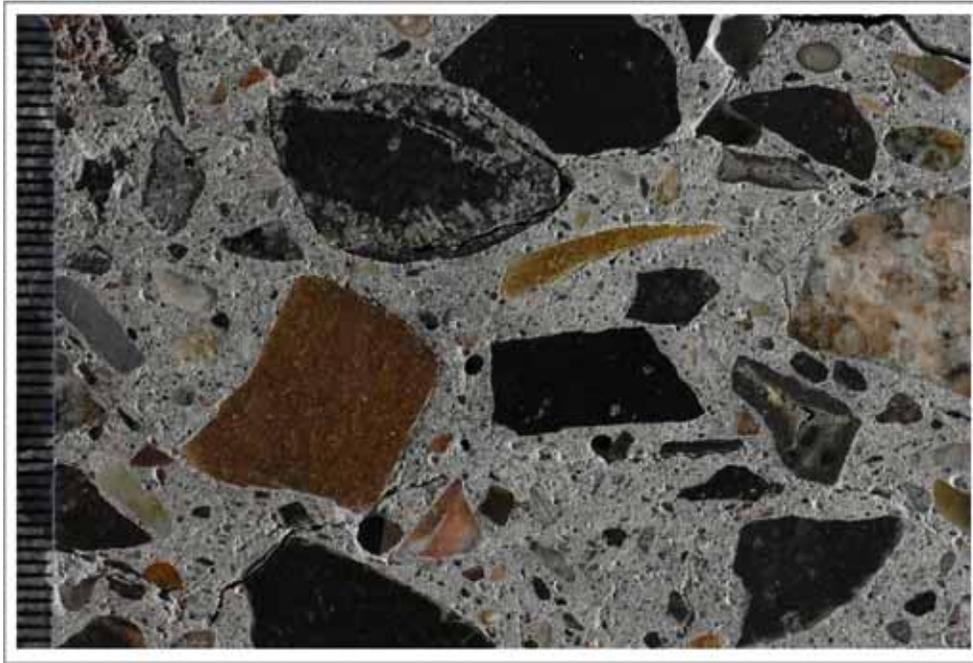


Figure C19. Core C9E. Photograph of polished surface showing overview of aggregate; scale in millimeters.

Table D1. Results of Damage Rating Index Evaluations for May 2006 Cores*

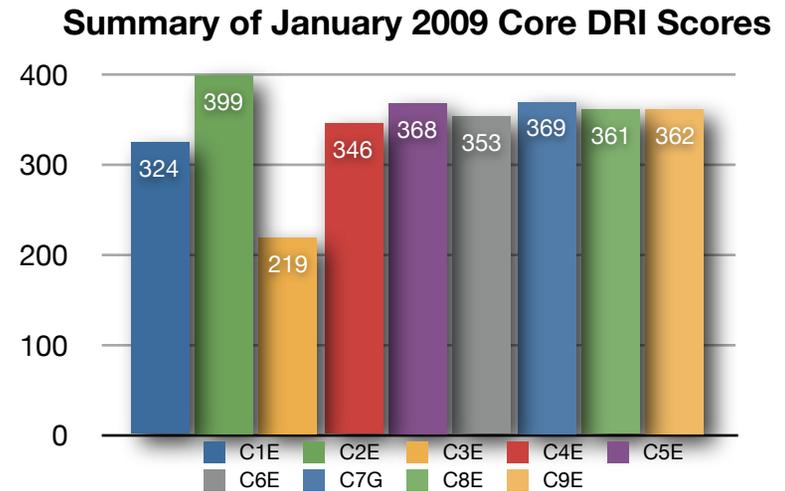
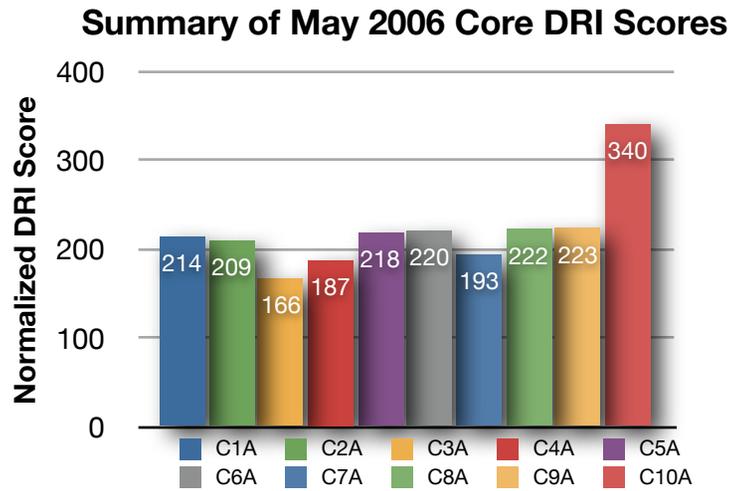
	CA w/ Frx	CA w/ Frx&Gel	CA Debond	CA Rxn Rim	FA w/ Frx	FA w/ Frx&Gel	FA Rxn Rim	FA Debond	Frx in Paste	Frx w/ Gel in Paste	Gel in Voids	Score	Area (cm ²)	Norm Score
C1A	19	10	6	5	15	25	19	6	36	32	11	321.25	150	214
C2A	18	12	2	2	13	31	22	3	52	23	11	313.75	150	209
C3A	23	5	2	3	16	37	17	1	20	24	12	249.5	150	166
C4A	24	10	3	4	15	32	33	0	23	30	4	281	150	187
C5A	34	14	4	4	21	42	13	1	41	24	9	327.5	150	218
C6A	7	14	1	1	7	36	7	0	82	13	11	330.25	150	220
C7A	26	11	0	0	22	57	20	0	35	15	14	290	150	193
C8A	19	3	1	1	16	55	22	2	59	17	19	333.25	150	222
C9A	31	16	3	7	32	45	21	3	49	17	15	335	150	223
C10A	10	9	2	1	9	43	7	1	54	69	15	510.5	150	340

*Abbreviations are as follows: CA = Coarse Aggregate, Frx = Fractures; Debond = Debonding; Rxn = Reaction; FA = Fine Aggregate; w/ = with

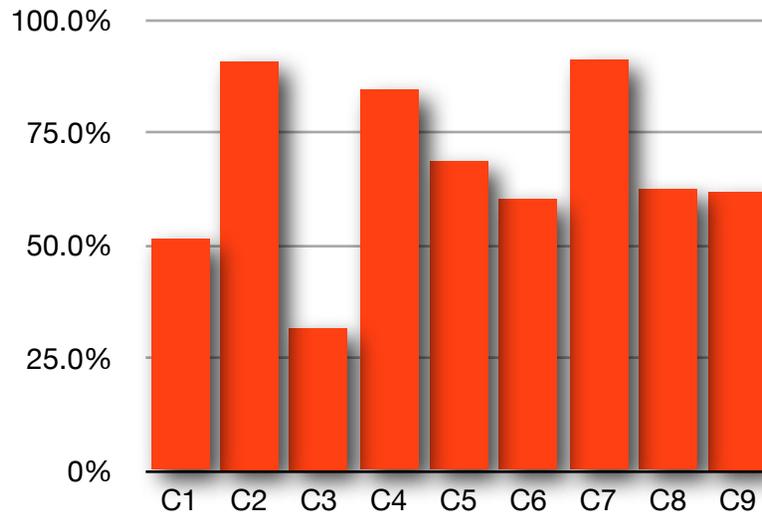
Table D2. Results of Damage Rating Index Evaluations for January 2009 Cores*

	CA w/ Frx	CA w/ Frx&Gel	CA Debond	CA Rxn Rim	FA w/ Frx	FA w/ Frx&Gel	FA Rxn Rim	FA Debond	Frx in Paste	Frx w/Gel in Paste	Gel in Voids	Score	Area (cm ²)	Norm Score
C1E	19	16	8	8	21	53	14	4	61	42	18	486.5	150	324
C2E	11	7	6	6	18	52	15	4	86	65	17	598.5	150	399
C3E	20	11	4	12	22	36	22	0	41	29	5	328.5	150	219
C4E	17	12	6	6	12	45	24	1	38	72	8	518.25	150	346
C5E	27	15	17	6	31	60	34	6	59	47	14	552	150	368
C6E	27	13	9	11	41	83	31	1	98	19	12	529.25	150	353
C7G	25	14	6	6	18	55	17	1	86	51	4	554	150	369
C8E	19	14	11	16	17	56	33	2	82	42	14	541.25	150	361
C9E	22	16	7	12	16	58	19	4	88	39	26	542.25	150	362

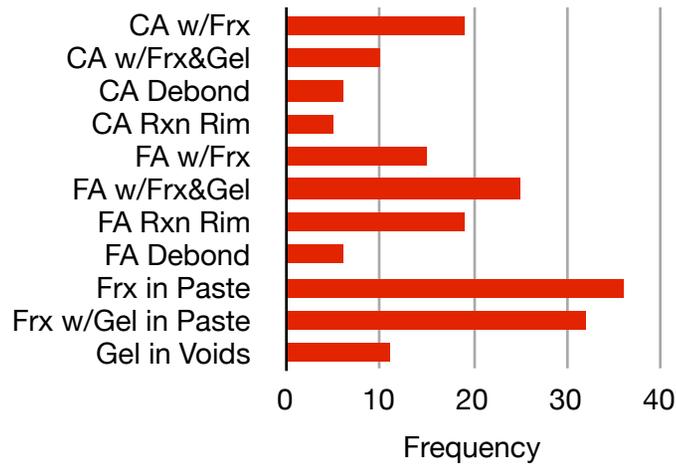
*Abbreviations are as follows: CA = Coarse Aggregate, Frx = Fractures; Debond = Debonding; Rxn = Reaction; FA = Fine Aggregate; w/ = with



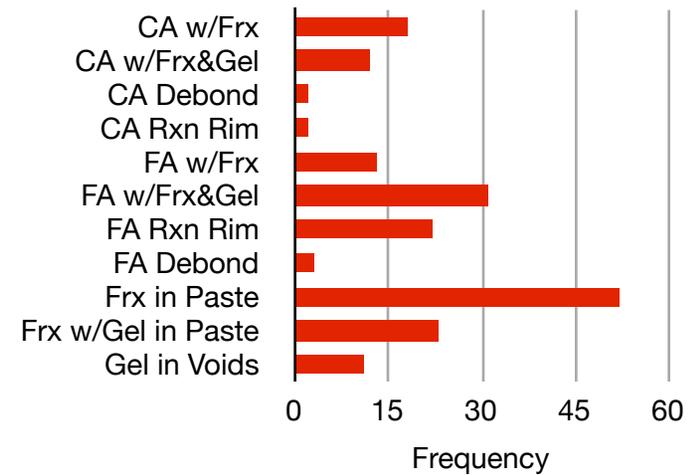
Summary of DRI Increase from May 2006 to January 2009



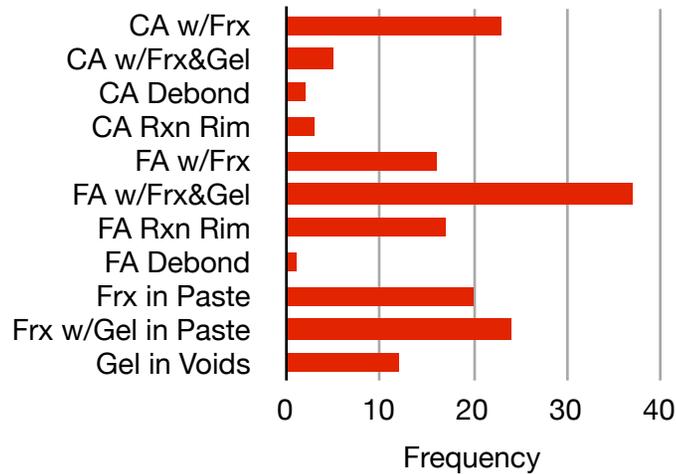
DRI Summary (C1A)



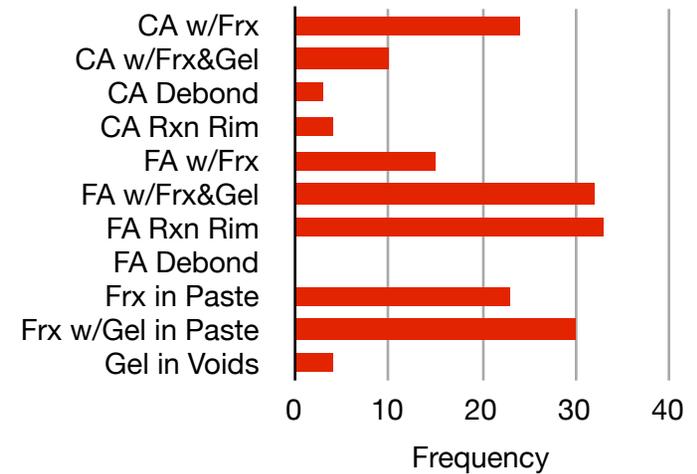
DRI Summary (C2A)

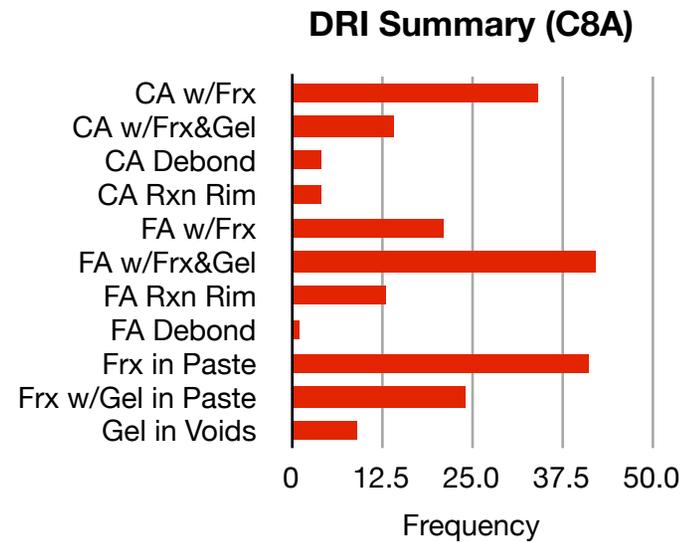
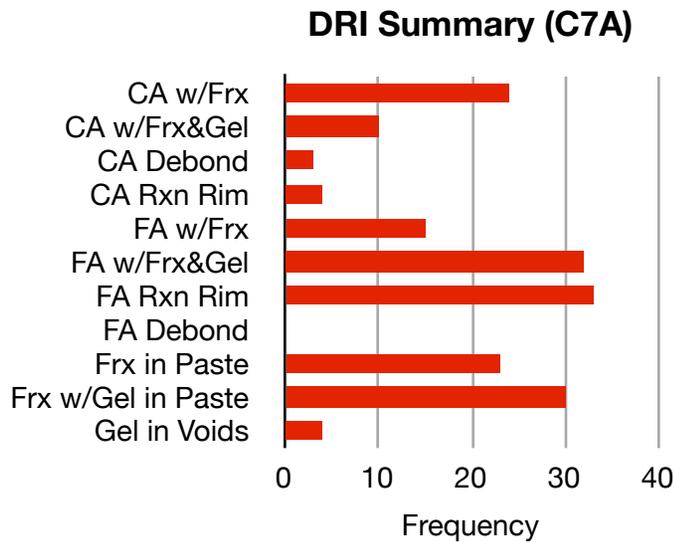
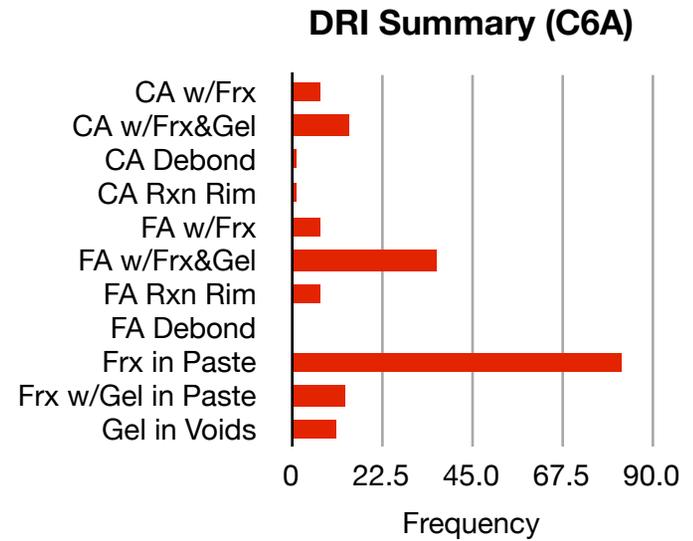
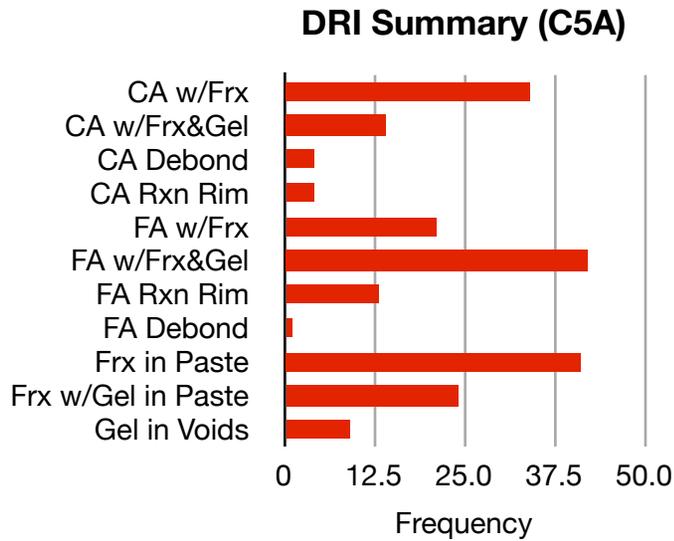


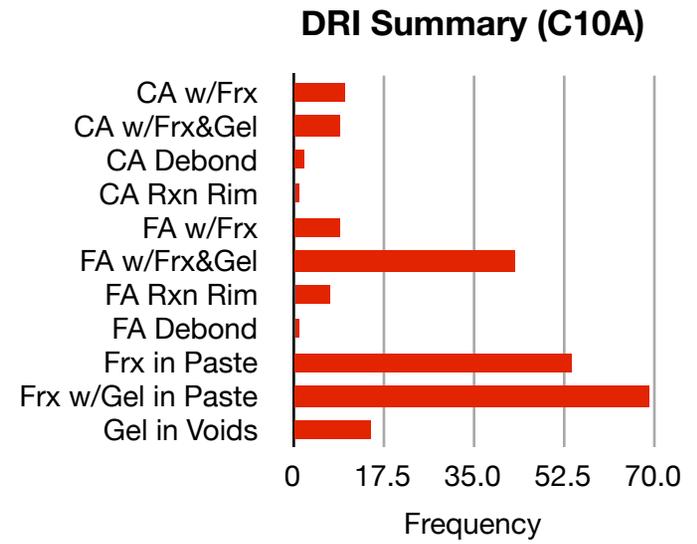
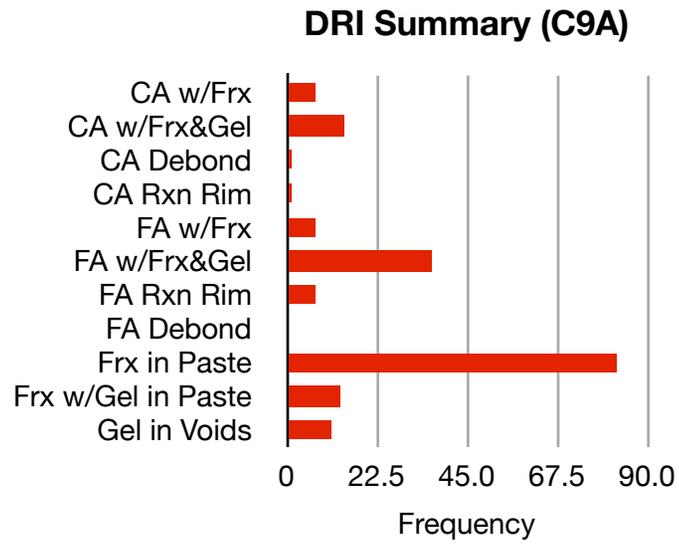
DRI Summary (C3A)



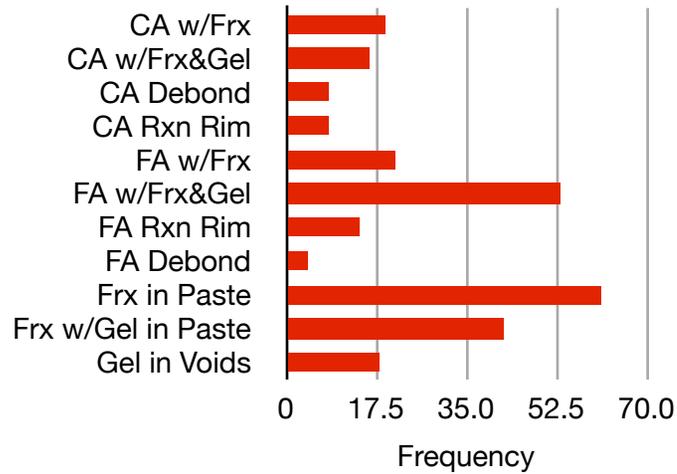
DRI Summary (C4A)



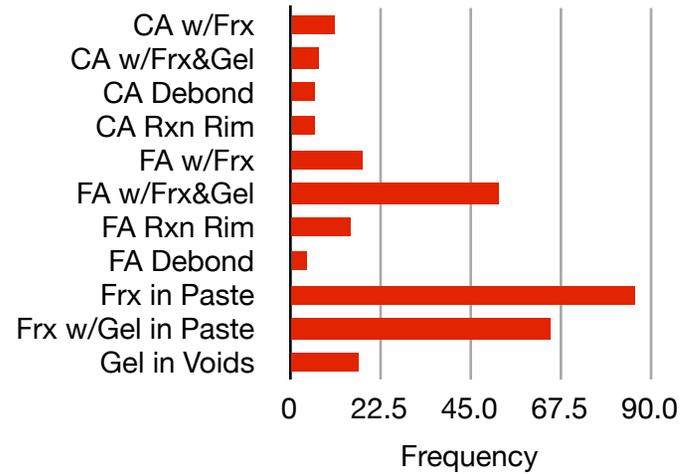




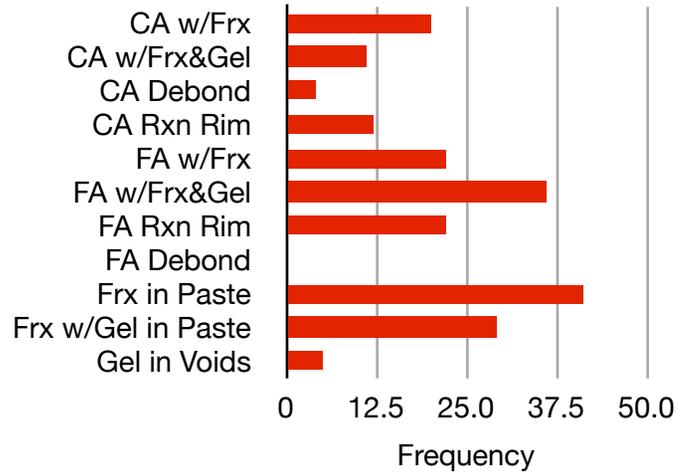
DRI Summary (C1E)



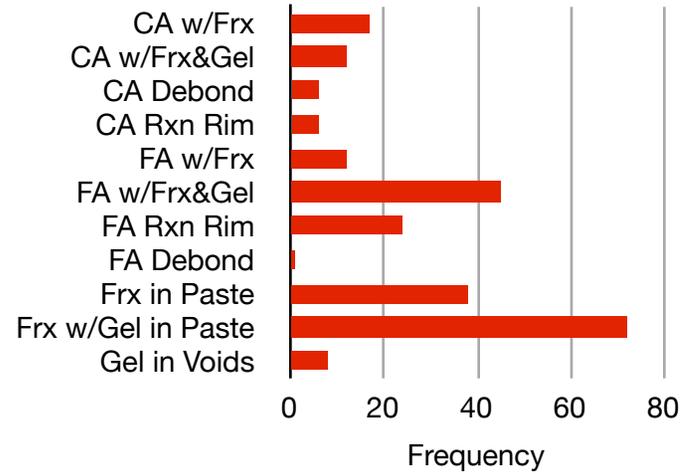
DRI Summary (C2E)



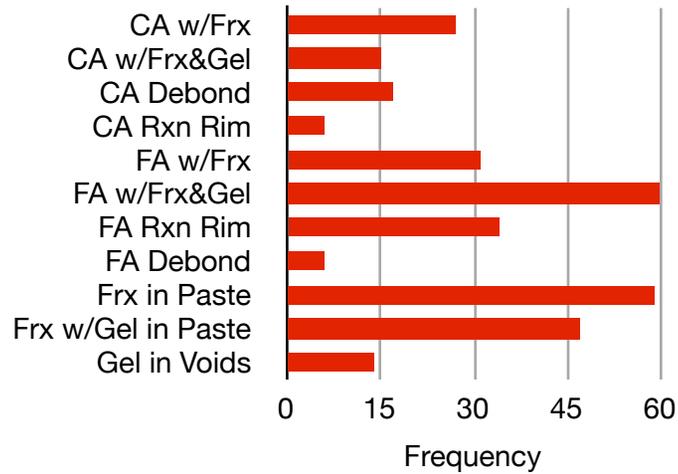
DRI Summary (C3E)



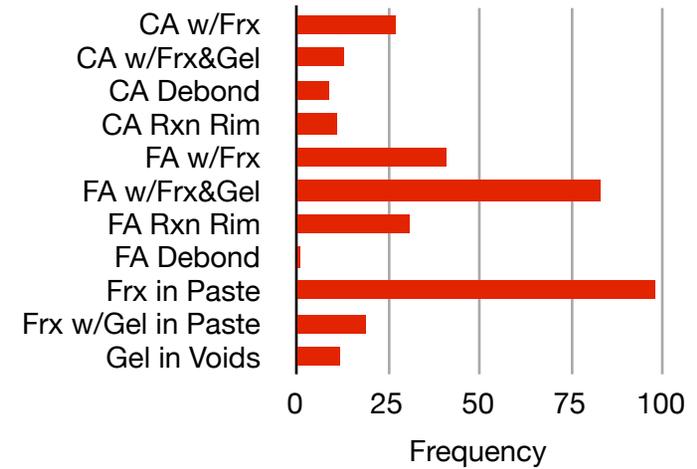
DRI Summary (C4E)



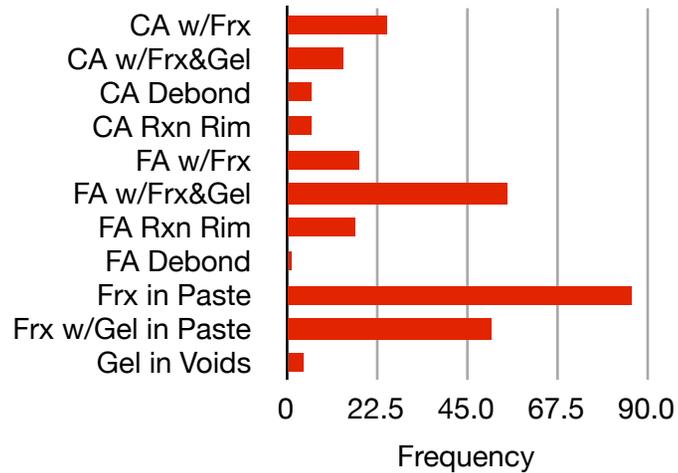
DRI Summary (C5E)



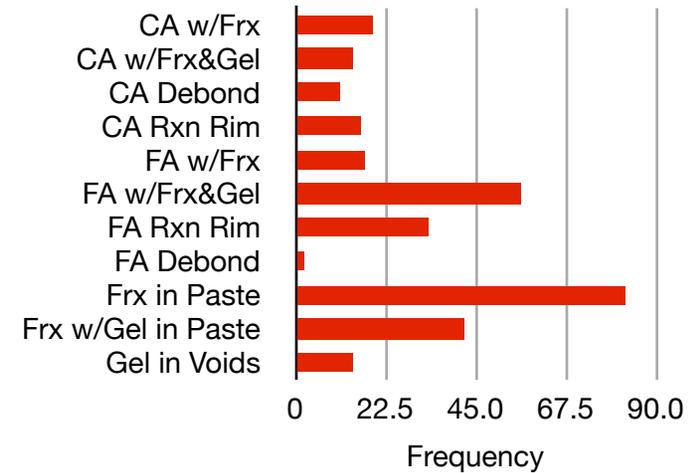
DRI Summary (C6E)

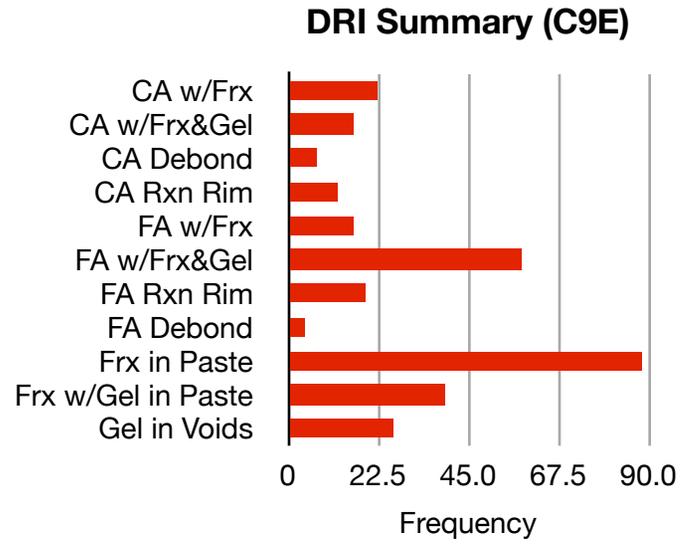


DRI Summary (C7G)



DRI Summary (C8E)





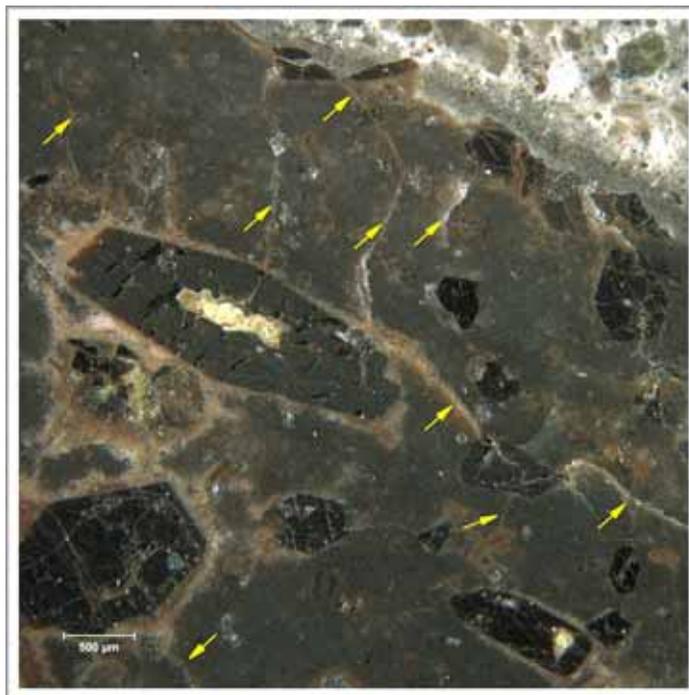


Figure E1. Reflected light photomicrograph of polished surface showing coarse aggregate particle with internal fractures (yellow arrows).

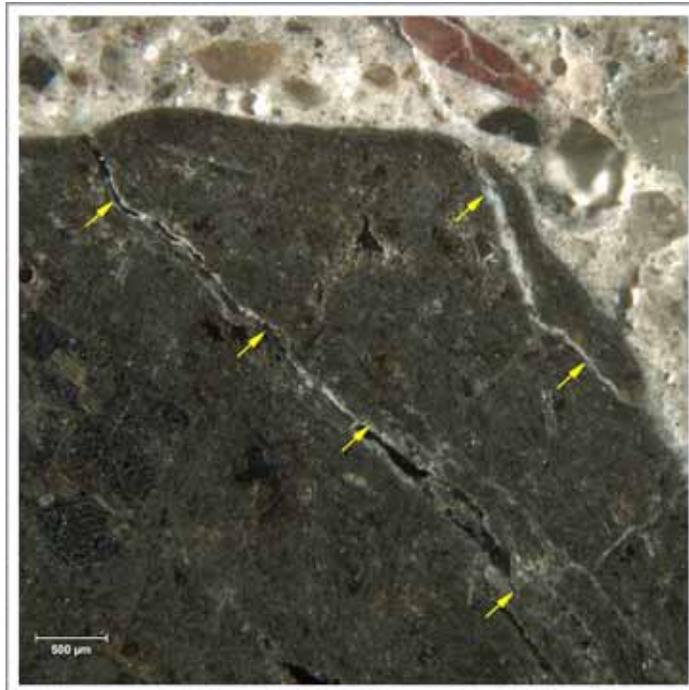


Figure E2. Reflected light photomicrograph of polished surface showing coarse aggregate particle with internal fractures that are filled with ASR gel (yellow arrows).

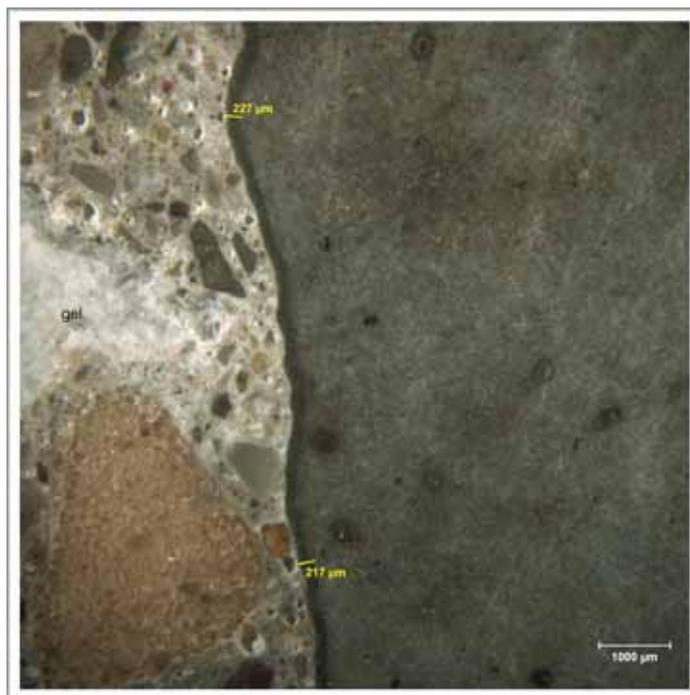


Figure E3. Reflected light photomicrograph of polished surface showing reaction rim (measured by yellow bars) on coarse aggregate particle.

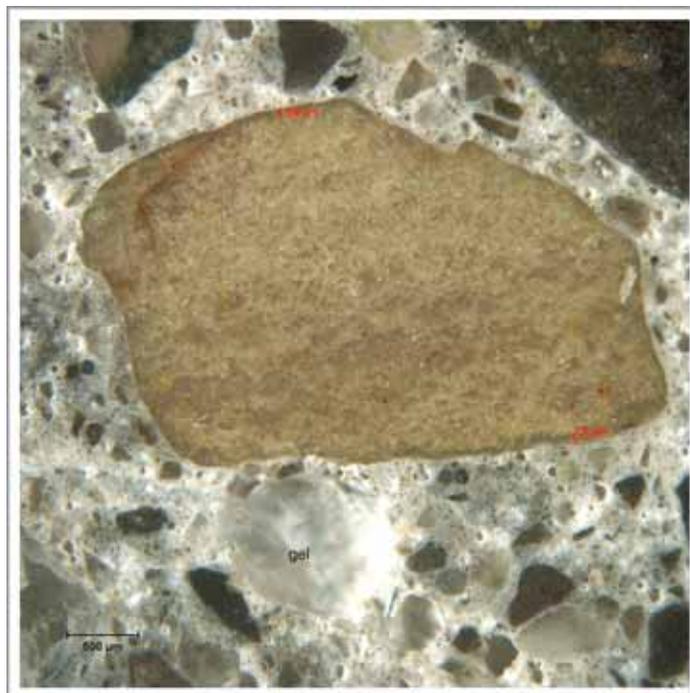


Figure E4. Reflected light photomicrograph of polished surface showing reaction rim (measured by red bars) on fine aggregate particle.

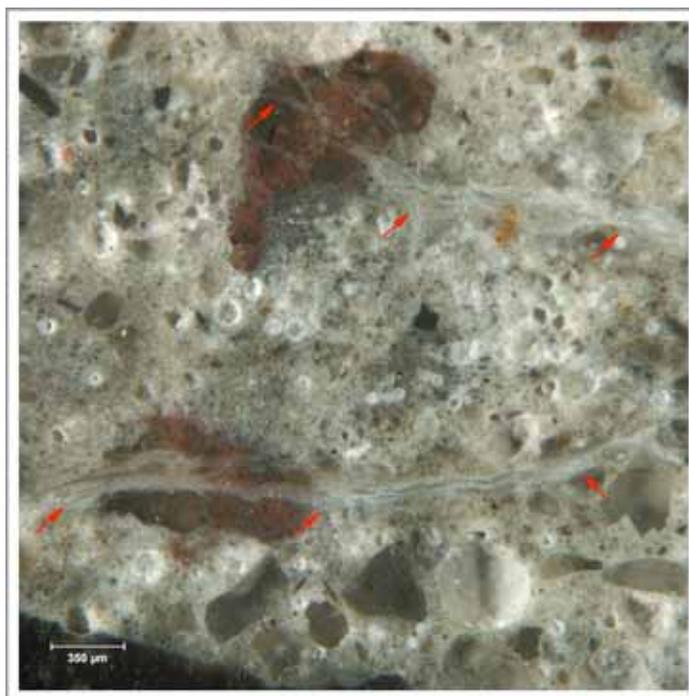


Figure E5. Reflected light photomicrograph of polished surface showing microcracks filled with ASR gel (red arrows) cutting through fine aggregate particles and the paste.



Figure E6. Reflected light photomicrograph of polished surface showing fine aggregate particle with microcracks filled with ASR gel (yellow arrows). Note gel in void next to the particle.

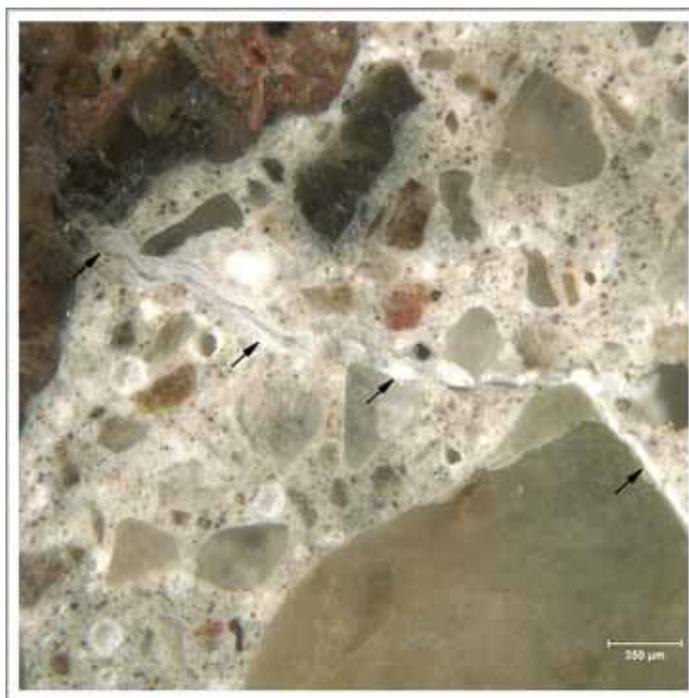


Figure E7. Reflected light photomicrograph of polished surface showing microcrack filled with ASR gel (black arrows) cutting through the paste.



Figure E8. Reflected light photomicrograph of polished surface showing void partially filled with clear ASR gel (yellow arrow).

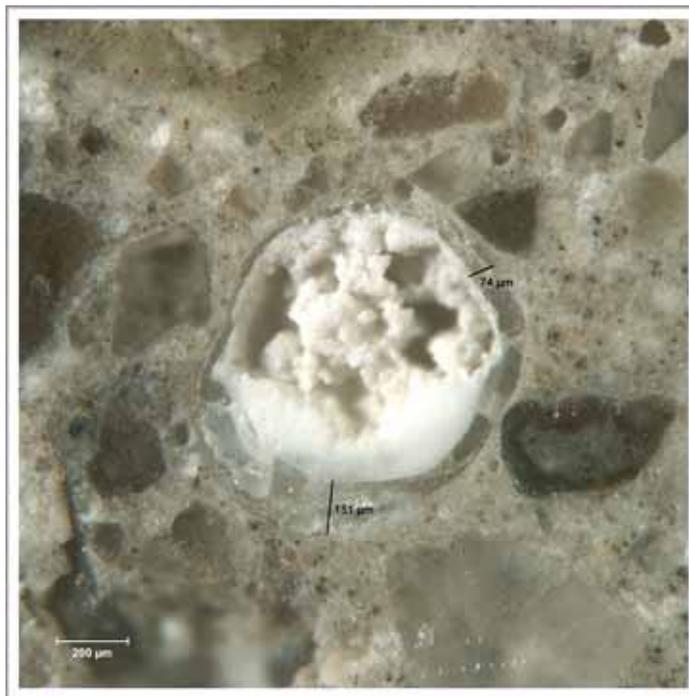


Figure E9. Reflected light photomicrograph of polished surface showing void rimmed by clear gel (width measured by black bars) and filled with milky white gel.

Appendix B

Ultrasonic Pulse Velocity (UPV) Test Results

UPV Test Results for "Before" and "After" Cores

"Before" Cores					"After" Cores					Percent Reduction	Surface Treatment
No.	UPV 1	UPV 2	UPV 3	AVG	No.	UPV 1	UPV 2	UPV 3	AVG		
C1-B	12335	12394	12409	12379	C1-E	11232	11244	11147	11208		
C1-C	12102	12102	12087	12097	C1-F	9974	10062	10091	10042		
C1-D	12861	12877	12909	12882							
AVG				12453	AVG				10625	14.68	Sodium Tartarate
C2-B	12302	12375	12346	12341	C2-E	10587	10566	10609	10587		
C2-C	12617	12648	12617	12627	C2-F	9530	9592	9592	9571		
C2-D	12405	12405	12375	12395							
AVG				12454	AVG				10079	19.07	Control - No Treatment
C3-B	13815	13834	13815	13821	C3-E	12545	12470	12426	12480		
C3-C	13926	13889	13907	13907	C3-F	11368	11392	11404	11388		
C3-D	14305	14403	14423	14377							
AVG				14035	AVG				11934	14.97	Lithium Nitrate
C4-B	14483	14463	14523	14490	C4-E	13333	13251	13317	13300		
C4-C	14823	14885	14906	14871	C4-H	13943	12998	13889	13610		
C4-D	14130	14149	14168	14149							
AVG				14503	AVG				13455	7.23	Siloxane
C5-B	13761	13780	13743	13761	C5-E	11036	11070	11082	11063		
C5-C	13708	13690	13679	13692	C5-F	10519	10572	10582	10558		
C5-D	13514	13496	13531	13514							
AVG				13656	AVG				10810	20.84	Lithium Nitrate plus Siloxane Sealer
C6-B	12500	12543	12590	12544	C6-E	10041	9818	9919	9926		
C6-C	12852	13743	12836	13144	C6-F	9718	9630	9552	9633		
C6-D	13066	13082	13018	13055							
AVG				12914	AVG				9780	24.27	Silane
C7-B	13947	13966	13947	13953	C7-G	10354	10231	10491	10359		
C7-C	13851	13795	14060	13902	C7-J	10719	10742	10798	10753		
C7-D	13520	13556	13520	13532							
AVG				13796	AVG				10556	23.49	Control - No Treatment
C8-B	NA	NA	NA		C8-E	10273	10232	10123	10209		
C8-C	12632	12617	12586	12612	C8-F	8936	8952	8867	8918		
C8-D	12648	12663	12663	12658							
AVG				12635	AVG				9564	24.31	Lithium Nitrate plus Silane Sealer
C9-B	12121	12887	12077	12362	C9-E	9068	9175	9217	9153		
C9-C	13717	13587	13532	13612	C9-F	10901	10877	10913	10897		
C9-D	12953	13004	12970	12976							
AVG				12983	AVG				10025	22.78	Boiled Linseed Oil

Appendix C

Manufacturer's Information for Surface Treatments



Chem-Crete PaviX[®] CCC100

Concrete Moisture Protection System For Airport, Highway & Bridge Structures

PRODUCT DESCRIPTION

Chem-Crete PAVIX CCC100 is a unique water-based chemical product for the moisture protection of large-scale concrete substrates against temperature and water associated problems such as thermal cracking, damage caused by repeated freeze and thaw cycles, chloride ion penetration, as well as alkali silica reactions.

Chem-Crete PAVIX CCC100 keeps treated concrete reasonably dry, thus helping to eliminate most water and moisture associated problems. Chem-Crete PaviX CCC100 provides three effective mechanisms for concrete protection in all weather conditions by formation of two types of crystals and water repellency. In the presence of moisture, one type of the crystals present in the product swells, therefore, blocking the pores completely. The second type of crystals absorbs the extra moisture on the surface of the first crystal preventing surface moisture on that crystal from diffusion to the concrete. These hydrophilic and hygroscopic properties provide double and durable protection against moisture penetration in concrete.



ADVANTAGES & BENEFITS

- Provides long lasting internal waterproofing and moisture blocking from positive and negative sides.
- Excellent repelling property preventing water, jet fuel and oil penetration intrusion from the surface.
- Resists aggressive chemicals such as acids, caustics Jet fuels and oil.
- Protects reinforcing steel bars against corrosion without any negative effect on existing steel cathodic protection.
- Enhances the adhesion property of joint sealant and concrete road markers.
- Reduces Alkali Silica Reactions (ASR), and eliminates silicate dusting.
- Prevents penetration of chloride ions from de-icing salts.
- Eliminates damage caused by repeated freezing and thawing cycles.

- Prevents concrete scaling.
- Increases concrete hardness.
- Seals and protects cracks up to 1/16th inch / 1.5 mm.

FIELDS OF APPLICATION

Chem-Crete PAVIX CCC100 can be used as a treatment and protection against water and moisture associated problems for all concrete and cementitious structures.

- | | |
|------------------|-------------------------|
| Airport Runways | Airport Taxiways |
| Aircraft Parking | Bridges |
| Tunnels | Concrete Roads-Highways |
| Parking Lots | Buildings |
| Sea Ports | Walkways |

PACKAGING

<u>Product</u>	<u>Packaging</u>
Chem-Crete PaviX CCC100	5 gal pail or 55 gal drum (18.93 L pail or 208 L drum)

TECHNICAL SPECIFICATIONS

Physical Properties:

Specific Gravity	1.1
Viscosity	2.4 centipoises
Freezing Point	28°F / -4°C
Boiling Point	219°F / 104 °C
Environmental Hazards	None
Color	Clear
Odor	None
Toxicity	None
Fumes	None
Flammability	None

Product Performance:

Chem-Crete PaviX CCC100 complies with the following standards:

ASTM STANDARDS:

ASTM C666-97 Standard Test Method for Resistance of Concrete to Rapid Freezing & Thawing.

ASTM C 1262-98 Standard Test Method for Evaluating the Freeze Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units.

ASTM C 672-98 Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.

ASTM C1218 Standard Test Method for Water-Soluble Chloride in Mortar and Concrete.

ASTM C1202-97 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.

ASTM D6489-99 Standard Test Method for Determining the Water Absorption of Hardened Concrete Treated With a Water Repelling Coating.

ASTM C944-99 Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method.

ASTM D4541-95 Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.

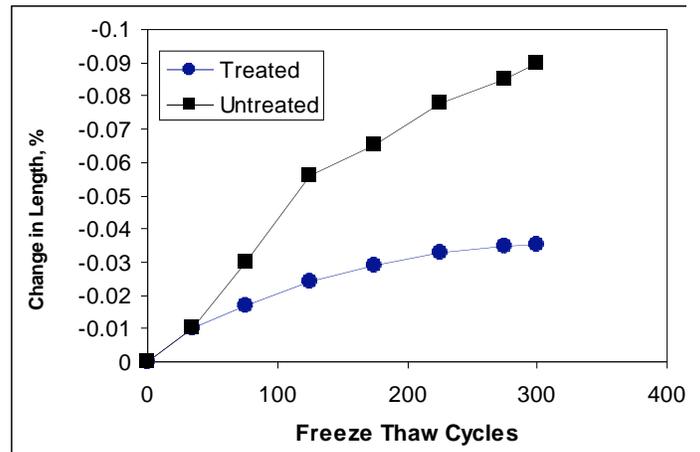
ASTM F609-96 Standard Test Method for Measuring Static Slip Resistance of Footwear Sole, Heel or Related Materials Using a Horizontal Pull Slipmeter (HPS).

ASTM E303-93 Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester.

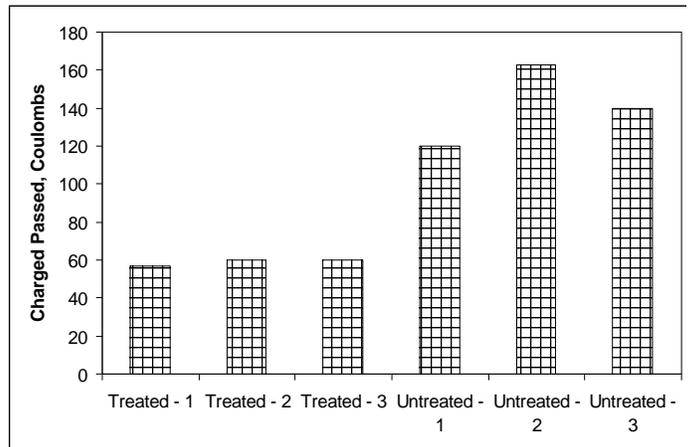
ASTM C 642-97 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.

ASTM C 457-98 Standard Test Method for Microscopical Determination of Parameters of the Air Void System in Hardened Concrete.

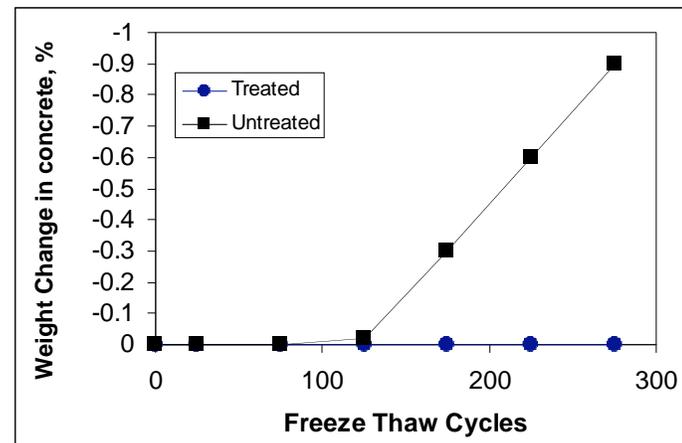
AASHTO T259-00 Resistance of Concrete to Chloride Ion Penetration.



Freezing & Thawing effect on treated & untreated concrete samples
ASTM C666-97



Chloride Ion Penetration tests on treated & untreated concrete samples
ASTM C1202-91 and AASHTO T259



ASTM C-666-97

Other Standards

ISO 2812-2:1993	Paints and varnishes -- Determination of resistance to liquids -- Part 2: Water immersion method
CSN 73 2578	Test for Water-tightness of Surface Finishes of Building Materials
CSN 73 1326	Determination of resistance to de-icing salts
GOST 12730.5-84	Concretes. Method for the determination of water tightness
GOST 10060-87	Concretes. Methods of frost resistance determination

APPLICATION

Concrete surfaces must be clean and sound prior to application of the product. Proper cleaning will open the surface pores and capillaries in order to enhance the penetration process. Compressed air can be used to remove dust and loose particles from the surface. Flushing the area to be treated with water can improve the cleaning process, however for heavily contaminated areas; special concrete cleaning agents such as Chem-Crete CONCLEAN CCC 060 can be used to remove dirt especially those contaminated with oil.

For large-scale applications, such as airport runways, it is recommended to spray the product using a heavy-duty commercial sprayer.

Coverage:

It is recommended to apply Chem-Crete PaviX CCC100 at an average rate of 150 to 200 ft²/gal (3.7 to 4.9 m² / lit) in one coat.

Limitations:

Do not apply Chem-Crete PaviX CCC100 in the following cases:

If temperature falls below 40°F (5°C).

Do Not Allow Product to Freeze.

To areas previously treated with sealing agents unless these sealers are removed by chemical or mechanical means.

STORAGE

Chem-Crete PaviX CCC100 must be stored under room temperature. Cold temperatures may cause the product to crystallize. Shelf life is ONE YEAR in its original unopened packaging.

Do Not Allow Product to Freeze.

SAFETY PRECAUTIONS

As with all construction chemical products, adequate precautions and care must be taken during usage and storage. Avoid direct contact with foodstuff, eyes, skin, and mouth. Any direct contact with skin, eyes, etc. should be washed thoroughly with clean running water and soap.

Always wear protective goggles and gloves. In case of eye contact, flush for 15 minutes with warm water. Keep out of reach of children.

TECHNICAL ASSISTANCE

Please contact International Chem-Crete Corporation for Technical Personnel.

WARRANTY

LIMITED WARRANTY: International Chem-Crete Inc. warrants that, at the time and place we make shipment, our materials will be of good quality and will conform to our published specifications in force on the date of acceptance of the order.

DISCLAIMER: The information contained herein is included for illustrative purposes only and, to the best of our knowledge, is accurate and reliable. International chem-crete Inc. is not under any circumstances liable to connection with the use of information. As International Chem-Crete Inc. has no control over the use to which others may put its products, it is recommended that the products be tested to determine the suitability for specific applications and/or our information is valid in a particular circumstances. Responsibility remains with the architect or engineer, contractor and owner of the design, application and proper installation of each product. Specifier and user shall determine the suitability of the product for specific application and assume all responsibility in connection therewith. MN/112007

Manufactured By:



International Chem-Crete Inc., 800 Security Row, Richardson, TX 75081, U.S.A

Tel: (972) 671-6477, Fax: (972) 238-0307

contactus@chem-crete.com

www.chem-crete.com

EUCO ARC TREATMENT

ALKALI SILICA REACTIVITY CONTROL PENETRATING SURFACE TREATMENT

DESCRIPTION

EUCO ARC TREATMENT is a lithium nitrate based, specially formulated, penetrating surface treatment designed to alleviate the expansive properties of concrete affected with alkali-silica reactivity (ASR). When reactive silica has sufficient alkalis and moisture, a chemical reaction occurs causing the formation of a gel which absorbs water and swells. This expansion will result in cracking and premature deterioration of concrete. EUCO ARC TREATMENT inhibits the ability of the gel from swelling, extending the life span of concrete.

PRIMARY APPLICATIONS

- Highways and bridges
- Airport runways
- Water treatment facilities
- Warehouses
- Parking garages
- Bases for high-power tension lines
- Ports and piers

FEATURES/BENEFITS

- Mitigates ASR expansion and cracking
- Reduces or eliminates ASR induced popouts
- Safe to handle
- Increases life span of concrete
- Delays expensive and costly concrete replacement

TECHNICAL INFORMATION

Physical Properties

Material.....	Lithium Nitrate
Specific gravity @ 68° F (20°C).....	1.20
Freezing point.....	1.4°F (-17° C)
pH.....	7.0 to 9.5
VOC content	0 g/L

PACKAGING

EUCO ARC TREATMENT is available in 5 gal (18.9 L) pails, 55 gal (208 L) drums, 275 gal (1041 L) totes, and bulk.

SHELF LIFE

2 years when stored above 32°F (0°C) in original, unopened container.

SPECIFICATIONS/COMPLIANCES

At this time there are no ASTM standards written for alkali-silica treatments. The following agencies have recognized EUCO ARC TREATMENT as the most effective choice for the mitigation of alkali-silica reactivity.

- US Army Corps of Engineers
- Federal Highway Administration (FHWA)
- Federal Aviation Administration (FAA)
- American Association of State Highway Transportation Officials (AASHTO)
- Several state departments of transportation



The Euclid Chemical Company

19218 Redwood Rd. • Cleveland, OH 44110
Phone: [216] 531-9222 • Toll-free: [800] 321-7628 • Fax: [216] 531-9596
www.euclidchemical.com

An **RPM** Company



DIRECTIONS FOR USE

Flood concrete surfaces by topical ponding or spray application to gain penetration. Coverage rates range from 3 to 9 gal/1000 ft² (11.4 to 34.1 L/ 92.90 m²), with 6 gal (22.8 L)/1000 sq.ft² (92.90 m²) the norm. Repeat applications may be necessary.

The treatment may also be applied by vacuum impregnation, pressure injection or electrochemical injection. Actual dosage is based upon the concrete volume to be treated.

Surface Preparation: The concrete surface should be clean, dry, and free of any contaminate or coating which may interfere with the penetration of EUCO ARC TREATMENT. Preparation methods include mechanical sweeping, power washing, and abrasive cleaning.

Consult with a Euclid Chemical representative regarding application, methods and frequency.

CLEAN-UP

Clean brushes, tools, equipment and flush sprayer with potable water immediately after use.

PRECAUTIONS/LIMITATIONS

- Keep from freezing.
- Due to a wide variety of conditions, consult your local Euclid Chemical representative to schedule a pre-job meeting.
- Store in a cool, dry area in a tightly sealed container. Keep separate from combustible, organic and oxidizable materials. Always reseal containers after use.
- In all cases, consult the Material Safety Data Sheet before use.

ADDITIONAL INFORMATION

Note: The product and application are covered by US Patents 5,985,011 and 5,837,315.

The Euclid Chemical Company and FMC Lithium have joined forces to distribute and market lithium-based products for controlling alkali-silica reactivity (ASR) to mitigate ASR-induced expansion in existing concrete. FMC has been developing technology based on research originally conducted under the Strategic Highway Research Program (SHRP).

Rev. 10.09

WARRANTY: The Euclid Chemical Company ("Euclid") solely and expressly warrants that its products shall be free from defects in materials and workmanship for one (1) year from the date of purchase. Unless authorized in writing by an officer of Euclid, no other representations or statements made by Euclid or its representatives, in writing or orally, shall alter this warranty. EUCLID MAKES NO WARRANTIES, IMPLIED OR OTHERWISE, AS TO THE MERCHANTABILITY OR FITNESS FOR ORDINARY OR PARTICULAR PURPOSES OF ITS PRODUCTS AND EXCLUDES THE SAME. If any Euclid product fails to conform with this warranty, Euclid will replace the product at no cost to Buyer. Replacement of any product shall be the sole and exclusive remedy available and buyer shall have no claim for incidental or consequential damages. Any warranty claim must be made within one (1) year from the date of the claimed breach. Euclid does not authorize anyone on its behalf to make any written or oral statements which in any way alter Euclid's installation information or instructions in its product literature or on its packaging labels. Any installation of Euclid products which fails to conform with such installation information or instructions shall void this warranty. Product demonstrations, if any, are done for illustrative purposes only and do not constitute a warranty or warranty alteration of any kind. Buyer shall be solely responsible for determining the suitability of Euclid's products for the Buyer's intended purposes.

EUCO-GUARD 100

SILOXANE WATER AND CHLORIDE REPELLENT FOR CONCRETE & MASONRY

DESCRIPTION

EUCO-GUARD 100 is a deep penetrating siloxane sealer designed to protect concrete structures, decks, pavements and surfaces against the adverse effects of de-icing salts, moisture, weathering and freeze damage. EUCO-GUARD 100 reacts chemically with the concrete to provide a highly effective chloride screen and water barrier. In addition to its ease of application, EUCO-GUARD 100 has the added versatility to be used on both new and old concrete surfaces. If a higher solids material is required, use EUCO-GUARD 200 (20% solids).

PRIMARY APPLICATIONS

- Parking structures
- Lane barriers & ramps
- Bridges
- Marine platforms
- Auto/truck repair bays
- Exterior concrete surfaces

FEATURES/BENEFITS

- Provides an efficient, continuous chloride barrier
- Blocks pores and capillaries for outstanding water repellency
- May be applied to new, cured concrete or old concrete
- Extremely high alkali resistance
- Dries to tack-free and skid-resistant surface
- Suitable for use over dry or damp (not saturated) concrete
- Full protection in one treatment, but may be reapplied later at any time
- Provides a low cost protection system over the life of a structure
- Protects reinforcing steel against the corrosive effects of surface absorbed chlorides and moisture
- Renders new concrete virtually free of surface scaling
- Retards deterioration of existing, distressed structures

TECHNICAL INFORMATION

Typical Engineering Data: The following results were developed under laboratory conditions.

Drying Time

Foot traffic 4 to 6 hrs

Wheel traffic..... 10 to 12 hrs

Type siloxane

Flash point..... 105°F (41°C)

EUCO-GUARD 100:..... 10% solids

EUCO-GUARD 200:..... 20% solids

Solvent mineral spirits

Appearance: EUCO-GUARD 100 is a clear, solvent based material. After placement and drying, the product has virtually no effect on the appearance of dry concrete. EUCO-GUARD 100 treated concrete will cause water to "bead" at the surface.

Test Specimens NCHRP#244 Test Method @21Days
4000 psi (27.6 MPa), 3" (76 mm) x 6" (152 mm) cylinders
5.25% air entrainment, 15% NaCl solution

Type	% Weight gain	Chloride screened	Repellency factor
Untreated	2.802%	—	—
Euco-Guard 100	0.212%	96%	92%

Test Specimens	ASTM C 642 Water absorption 24 hour results	ASTM C672 Scaling resistance

	% weight gain	water repellency factor	50 cycles	125 cycles
Untreated	4.85%	----	4 moderate to severe	5 severe scaling
Euco-Guard 100	0.364%	92%	0 to no scaling	0 to no scaling

PACKAGING

EUCO-GUARD 100 is packaged in 55 gal (208 L) drums and 5 gal (18.9 L) pails.

SHELF LIFE

2 years in original, unopened package.



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SPECIFICATIONS/COMPLIANCES

- EUCO-GUARD 100 will function as a 96% chloride screen when tested by NCHRP #244 criteria for Northern and Southern exposure.

COVERAGE

<u>Concrete Surface</u>	<u>Application Rate</u>
Troweled Smooth	125 to 150 ft ² /gal (3.1 to 3.7 m ² /L)
Broomed Textured	75 to 125 ft ² /gal (1.8 to 3.1 m ² /L)

Material Requirements: A one coat application using a coverage rate of 125 ft²/gal (3.1 m²/L) will require approximately 8 gal (30.3 L) of material per 1000 ft² (92.9 m²) of area. For exterior concrete with a textured finish, a coverage rate of 75 to 125 ft²/gal (1.8 to 3.1 m²/L) is required to achieve NCHRP #244 results. Higher coverage rates may be used depending on surface porosity and desired level of protection.

DIRECTIONS FOR USE

Surface Preparation (New Concrete): Surface should be well cured using water, wet burlap, polyethylene or curing paper. Surfaces must be free of all dirt and debris. All joint sealants and caulks should be in place before applying EUCO-GUARD 100. Where a curing membrane is required or desired for curing, only KUREZ DR VOX dissipating resin curing compound applied at 450 ft²/gal (11 m²/L) is permitted. When using KUREZ DR VOX, a high pressure water blast or clean-up with an aggressive scrubber is required at 45 days or longer after application of KUREZ DR VOX. The concrete surface should be dry for at least 24 hours for maximum penetration and best results.

Surface Preparation (Old Concrete): Remove all foreign substances that could prevent absorption-dirt, dust, tar, oil, etc. Pressure wash with water and cleaners where appropriate. Membranes of any kind must be removed.

Mixing: EUCO-GUARD 100 is a one component material which requires no pre-blending prior to use. The product should be used directly from the container.

Placement: Horizontal Surfaces - Flood surface using low pressure sprayer, roller, brush or broom. Broom or squeegee material around for even distribution. Let the surface absorb the EUCO-GUARD 100 solution and follow immediately with a second application before the surface dries. Redistribute any puddles or free-standing EUCO-GUARD 100. **Vertical Surfaces** - Apply by sprayer, roller or brush in two applications from the bottom up. Be sure to apply "wet-on-wet" as described for horizontal surfaces. To apply the sealer to concrete, use a 'pump-up' or airless sprayer for best results. A short nap roller or lambs wool applicator may also be used.

CLEAN-UP

Use mineral spirits or acetone to clean tools and equipment.

PRECAUTIONS/LIMITATIONS

- Use in a well ventilated area.
- Do not dilute EUCO-GUARD 100 with solvents or thinners.
- Protect metal, glass and other surfaces from overspray.
- Do not use at temperatures below 40°F (4°C).
- Do not use over saturated surfaces or curing membranes.
- Block all HVAC ventilation ducts which may distribute solvent odor.
- All joint sealants and caulks should be in place before applying EUCO-GUARD 100.
- EUCO-GUARD 100 is a solvent-based product with a distinct odor. When used in enclosed areas, or on extremely porous substrates, the solvent odor may dissipate slowly. If HVAC intake ducts will distribute solvent odor into adjoining occupied areas of the building, care should be taken to block these ventilation vents. If solvent odor is unacceptable, use a water-based product such as BARCADE WB 244.
- Do not allow to puddle. All product should penetrate the substrate with no surface build-up.
- Do not apply if rain is expected within 8 hours.
- This product does not prevent oil stains or discoloration from fallen tree leaves.
- In all cases, consult the Material Safety Data Sheet before use.

Rev. 10.09

WARRANTY: The Euclid Chemical Company ("Euclid") solely and expressly warrants that its products shall be free from defects in materials and workmanship for one (1) year from the date of purchase. Unless authorized in writing by an officer of Euclid, no other representations or statements made by Euclid or its representatives, in writing or orally, shall alter this warranty. EUCLID MAKES NO WARRANTIES, IMPLIED OR OTHERWISE, AS TO THE MERCHANTABILITY OR FITNESS FOR ORDINARY OR PARTICULAR PURPOSES OF ITS PRODUCTS AND EXCLUDES THE SAME. If any Euclid product fails to conform with this warranty, Euclid will replace the product at no cost to Buyer. Replacement of any product shall be the sole and exclusive remedy available and buyer shall have no claim for incidental or consequential damages. Any warranty claim must be made within one (1) year from the date of the claimed breach. Euclid does not authorize anyone on its behalf to make any written or oral statements which in any way alter Euclid's installation information or instructions in its product literature or on its packaging labels. Any installation of Euclid products which fails to conform with such installation information or instructions shall void this warranty. Product demonstrations, if any, are done for illustrative purposes only and do not constitute a warranty or warranty alteration of any kind. Buyer shall be solely responsible for determining the suitability of Euclid's products for the Buyer's intended purposes.

EUCO-GUARD S-40

WEATHERPROOFING SILANE SEALER

DESCRIPTION

EUCO-GUARD S-40 is a deep penetrating silane sealer designed to protect concrete structures, decks and pavements against the adverse effects of deicing salts, moisture, weathering and freeze-thaw damage. EUCO-GUARD S-40 reacts chemically with the concrete surface to provide a highly effective chloride screen and water barrier. EUCO-GUARD S-40 can be used on both new and old concrete surfaces.

PRIMARY APPLICATIONS

- Parking structures
- Lane barriers & ramps
- Bridges
- Marine platforms
- Auto/truck repair bays
- Exterior concrete surfaces

FEATURES/BENEFITS

- Provides an efficient, continuous chloride barrier
- Blocks pores and capillaries for outstanding water repellency
- May be applied to new, cured concrete or old concrete
- Extremely high alkali resistance
- Dries to tack-free and skid-resistant surface
- Suitable for use over dry or damp (not saturated) concrete
- Full protection in one treatment, but may be reapplied later at any time
- Provides a low cost protection system over the life of a structure
- Protects reinforcing steel against the corrosive effects of surface absorbed chlorides and moisture
- Renders new concrete virtually free of surface scaling
- Retards deterioration of existing, distressed structures

TECHNICAL INFORMATION

Typical Engineering Data: Developed under laboratory conditions.

Drying time foot traffic.....2 to 6 hrs
wheel traffic 10 to 12 hrs

Flash point 112°F (44°C)

Appearance: EUCO-GUARD S-40 is a clear, solvent based material. After placement and drying, the product has virtually no effect on the appearance of dry concrete. EUCO-GUARD S-40 treated concrete will cause water to "bead" at the surface.

NCHRP #244 Test Method @ 21 day Test Specimens:
3" (76 mm) x 6" (152 mm) cylinders, 4,000 psi (28 MPa) concrete, 5.25% air entrainment, 15% sodium chloride solution

	% Weight gain	Chloride screened	Repellency factor
Untreated	2.802%		
EUCO-GUARD S-40	0.212%	96%	92%

ASTM C 642 (Water absorption @ 24 hours)

	% Weight gain	Repellency factor
Untreated	4.85%	-----
EUCO-GUARD S-40	0.364%	92%

Solids content.....40%

Untreated	4.85%	-----
EUCO-GUARD S-40	0.364%	92%

ASTM C 672 (Scaling resistance @ 50 & 125 cycles)

	Untreated	EUCO-GUARD S-40
50 cycles	4 (moderate to severe)	0 (no scaling)
125 cycles	5 (severe scaling)	0 (no scaling)

SHELF LIFE

2 years in original, unopened container.

PACKAGING

EUCO-GUARD S-40 is packaged in 55 gal (208 L) drums and 5 gal (18.9 L) pails.

SPECIFICATIONS/COMPLIANCES

- EUCO-GUARD S-40 will function as a 96% chloride screen when tested by NCHRP #244 Series II and Series IV (southern exposure) criteria. Concrete treated with EUCO-GUARD S-40 shows excellent scaling resistance when tested per ASTM C 672. Independent test data available upon request.



The Euclid Chemical Company

19218 Redwood Rd. • Cleveland, OH 44110
Phone: [216] 531-9222 • Toll-free: [800] 321-7628 • Fax: [216] 531-9596
www.euclidchemical.com

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COVERAGE

Concrete Surface	Application Rate
Troweled Smooth	125 to 160 ft ² /gal (3.1 to 3.9 m ² /L)
Broomed Textured	75 to 125 ft ² /gal (1.8 to 3.1 m ² /L)

Material Requirements: A one coat application using a coverage rate of 125 ft²/gal (3.1 m²/L) will require approximately 8.0 gal (30.3 L) of material per 1000 ft² (93 m²) of area. Exact coverage rates are a function of surface porosity and density. For exterior concrete with a textured finish, a coverage rate of 75 to 125 ft²/gal (1.8 to 3.1 m²/L) is required to achieve NCHRP 244 results. Higher coverage rates may be used depending on surface porosity and desired level of protection.

DIRECTIONS FOR USE

Surface Preparation: Where curing membrane is required or desired for curing, only KUREZ DR VOX dissipating resin curing compound is permitted.

New Concrete: Surface should be well cured using water, wet burlap, polyethylene or curing paper. Surfaces must be free of all dirt and debris. All joint sealants and caulks should be in place before applying EUCO-GUARD S-40. If KUREZ DR VOX was used to cure the concrete, it must be completely cleaned off the surface before application of EUCO-GUARD S-40. The concrete surface should be dry for at least 24 hours for maximum penetration and best results.

Old Concrete: Remove all foreign substances that could prevent absorption-dirt, dust, tar, oil, etc. Pressure wash with water and cleaners where appropriate. Membranes of any kind must be removed.

Mixing: EUCO-GUARD S-40 is a one component material which requires no pre-blending prior to use. The product should be used directly from the container.

Placement: Horizontal Surfaces - Flood surface using low pressure sprayer, roller, brush or broom. Broom or squeegee material around for even distribution. Let the surface absorb the EUCO-GUARD S-40 solution and follow immediately with a second application before the surface dries. Redistribute any puddles or free-standing EUCO-GUARD S-40. **Vertical Surfaces** - Apply by sprayer, roller or brush in two applications from the bottom up. Be sure to apply "wet-on-wet" as described for horizontal surfaces.

CLEAN-UP

Use mineral spirits or acetone to clean tools and equipment.

PRECAUTIONS/LIMITATIONS

- Use in a well ventilated area.
- Do not dilute EUCO-GUARD S-40 with solvents or thinners.
- Protect metal, glass and other surfaces from over-spray.
- Do not use at temperatures below 40°F (4°C).
- Do not use over saturated surfaces or curing membranes.
- EUCO-GUARD S-40 is a solvent-based product with a distinct odor. When used in enclosed areas, or on extremely porous substrates, the solvent odor may dissipate slowly. If HVAC intake ducts will distribute solvent odor into adjoining occupied areas of the building, care should be taken to block these ventilation vents. If solvent odor is unacceptable, use a water-based product such as EUCO-GUARD VOX or CHEMSTOP WB.
- Do not apply if rain is expected within 8 hours.
- Do not allow to puddle. All product should penetrate the substrate with no surface build-up.
- This product does not prevent oil stains or discoloration from fallen tree leaves.
- In all cases, consult the Material Safety Data Sheet before use.

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LINSEED OIL TREATMENT

CONCRETE SEALER

DESCRIPTION

LINSEED OIL TREATMENT is a blend of boiled linseed oil and solvents. When applied in a thin coating to concrete surfaces, it protects them from winter damage due to freeze-thaw cycling and the effects of de-icing salts. Two applications of the oil compound will protect concrete and increase its resistance to winter damage.

PRIMARY APPLICATIONS

- Roads and bridge decks
- Parking ramps and curbs
- Sidewalks and driveways
- Concrete exposed to freeze/thaw cycles
- Exterior concrete surfaces

FEATURES/BENEFITS

- Deep penetration
- Salt protection
- Ease of application
- Rapid drying

TECHNICAL INFORMATION

Typical Engineering Data

The following results were developed under laboratory conditions.

Suitable for exposure to traffic:4 to 6 hours

Viscosity: 25 to 35 secs. #1 Zahn Cup

Percent Solids by Volume Min: 50%

Flash Point:Above 112°F (44°C) TCC

VOC Content <400 g/L

Drying Time: 2 hours, depending on humidity and other climatic conditions.

Appearance

LINSEED OIL TREATMENT is a light brown material which will slightly darken concrete.

PACKAGING

LINSEED OIL TREATMENT is packaged in 55 gal (208 L) drums, and 5 gal (18.9 L) pails.

SHELF LIFE

2 years in original, unopened container.

SPECIFICATIONS/COMPLIANCES

- Linseed Oil Portion meets ASTM D 260
- Mineral Spirits Portion meets ASTM D 235

COVERAGE

Troweled Smooth	300 ft ² /gal (7.4 m ² /L)
Broomed Textured	400 ft ² /gal (9.8 m ² /L)

Material Requirements

A two coat application using a coverage rate of 300 ft²/gal (7.4 m²/L) for each coat will require approximately 6.7 gal (25.4 L) of material per 1000 ft² (92.9 m²) of area.



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DIRECTIONS FOR USE

Surface Preparation: Concrete surfaces to receive treatment shall be clean, dry and free of oil, dirt, loose scale and any other contaminants. Surfaces shall be swept clean by hand or by mechanical means. Oil and grease shall be removed as completely as possible. New concrete shall cure at least twenty-eight (28) days prior to application. New concrete cured with wax, resin base or chlorinated rubber or other curing agents shall not be treated until such agents have completely weathered away, or been removed by other means.

Mixing: LINSEED OIL TREATMENT is a one component product which requires no pre-blending prior to placement. LINSEED OIL TREATMENT should be used directly from the container.

Placement: LINSEED OIL TREATMENT shall be applied sparingly in two coats, at the average rate of 300 ft²/gal (7.4 m²/L) per coat. Application may be done by medium nap paint rollers or garden sprayers, using a wide fan nozzle. The second coat may be applied as soon as the first coat is dry to touch. In warm, dry weather this requires only one to four hours, but in cool weather, drying times up to 24 hours may be required. The preferred time for application is late afternoon so that when the concrete cools, the compound penetrates deep into the pores. Further treatment is recommended in form of a single application annually on surfaces subject to de-icing chemicals and wear. This application rate shall be at a rate of 400 ft²/gal (9.8 m²/L).

CLEAN-UP

Mineral spirits should be used for cleaning equipment.

PRECAUTIONS/LIMITATIONS

- Flammable. Keep away from matches, cigarettes and fires.
- All rags soaked with the compound must be stored in air-tight covered steel drums.
- In all cases, consult the Material Safety Data Sheet before use.

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