INVESTIGATION OF CONCRETE SEALER PRODUCTS TO EXTEND CONCRETE PAVEMENT LIFE

By

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A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Science in Civil Engineering

Boise State University

May 2011

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

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Thesis Title: Investigation of Concrete Sealer Products to Extend Concrete Pavement Life

Date of Final Oral Examination: 25 February 2011

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The final reading approval of the thesis was granted by George Murgel, Ph.D., Chair of the Supervisory Committee. The thesis was approved for the Graduate College by John R. Pelton, Ph.D., Dean of the Graduate College.

ACKNOWLEDGEMENTS

This report includes the results of a study titled, “Laboratory Investigation of Concrete Sealer Products to Extend Concrete Pavement Life,” conducted by the Department of Civil Engineering at Boise State University, in cooperation with the Idaho Transportation Department. The author would like to thank Keith Nottingham, Inez Hopkins, Ned Parish, Dan Gorley, Spencer Hyde, and all personnel involved with sealer application and coring at the Idaho Transportation Department. In addition, a thank you to Phil Boysen and Adam Spiegelman of Boise State University for fabricating equipment used during testing. Thanks to Dave Elper and Dan Uldall of Kwik Bond Polymers. Thanks to Unitex chemicals. Thanks to Idaho Concrete Company for donating aggregates and admixtures. Thanks to the undergraduate assistants from Boise State University: Ryan Henry, Nihan Darnall, and especially Douglas Crowell. Finally, thanks to the supervisory committee: Dr. George Murgel, Dr. Arvin Farid, and Dr. Amy Moll of Boise State University.

ABSTRACT

Portland cement concrete pavements (PCCP) are susceptible to deterioration and decreased service life caused by the ingress of water. Water can dissolve and transport deleterious chemicals such as de-icing salts, carbon dioxide, dissolved oxygen, and sulfates into PCCPs through cracks and the concrete surface. These chemicals and water itself all have the potential to degrade PCCP by chemical and/or physical processes. Surface-applied concrete sealers have demonstrated the ability to increase service life of PCCPs by limiting the ingress of water and deleterious chemicals into concrete.

Concrete sealers are being increasingly used by the Idaho Transportation Department (ITD). However, little has been done in Idaho to establish either a long-term field observation program or to perform a comprehensive laboratory analysis and evaluation process of suitable compounds. Thus, before proper deployment and long term field evaluation of concrete sealers can be done, an extensive laboratory evaluation process of suitable compounds, laboratory sealer evaluation protocol development, and application/reapplication protocol development needs to be performed.

In this research, five surface-applied concrete sealer treatments were evaluated in the laboratory. The sealer treatments are as follows.

1. Silane (water repellent)
2. Epoxy (barrier coating)
3. High molecular weight methacrylate (HMWM) (barrier coating/pore blocker)

4. Silane basecoat with an epoxy topcoat (dual treatment)
5. Silane basecoat with a HMWM topcoat (dual treatment)

The treatments were evaluated in the following tests in the laboratory.

1. Water vapor transmission
2. Saltwater absorption
3. Chloride permeability
4. Sealer penetration depth or coating thickness
5. Resistance to alkali
6. Ultraviolet (UV) weathering and cyclic saltwater ponding
7. Freeze-thaw resistance

In addition, the same treatments were applied at four field locations near Boise in Southwest Idaho to initiate a long-term field study to be completed in phase II of this study. Only the initial water absorption performance (time zero) was evaluated using core samples in the laboratory. The duration of the initial phase of this study was insufficient for the analysis of the long-term (4 years +) performance of the field site applications.

The dual treatments comprised of a silane basecoat and an epoxy or HMWM topcoat consistently exhibited the best performance. Of single sealer treatments, the epoxy, silane, and HMWM had the best performance in descending order. Only the silane exhibited a consistently measurable depth of penetration and was the only treatment that had significant vapor transmission ability. The dual treatments also exhibited the least water absorption for the initial, time zero, field cores extracted from each of the four field sites. Dual treatments offer the advantage of a deep penetrating sealer (silane) combined

with a barrier coating type sealer (epoxy or HMWM) able to seal cracks to limit the ingress of water and chemicals. Dual treatments offer the best protection for PCCPs. If vapor transmission is of concern, the silane sealer's performance consistently surpassed threshold values recommended in the literature and would be recommended.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway Officials
ASTM	American Society for Testing and Materials
ASR	Alkali Silica Reaction
CON	I-184 Connector Field Site
CW	Caldwell Field Site
DOT	Department of Transportation
DRC	Drying Rate Coefficient
EB	Eisenmann Bridge Field Site
FTR	Freeze Thaw Ratio
HMWM	High Molecular Weight Methacrylate
ITD	Idaho Transportation Department
NCHRP	National Cooperative Highway Research Program
PCCP	Portland Cement Concrete Pavement
POE	East Boise Port of Entry Field Site
RCR	Relative Chloride Ratio
RH	Relative Humidity
SAR	Saltwater Absorption Ratio
UV	Ultra Violet light
UW	Unit Weight (mass)
WAR	Water Absorption Ratio
WJE	Wiss, Janney, Elstner Associates, Inc,

CHAPTER 1: INTRODUCTION

Purpose

Surface applied concrete sealers have demonstrated the potential to extend the service life of Portland Cement Concrete Pavement (PCCP) in the United States and internationally. However, little has been done in Idaho to establish either a long-term, field observation program to measure the sealer effects and impacts under true field conditions of Idaho or perform a comprehensive region specific laboratory analysis and evaluation process of suitable compounds. Thus, before proper deployment and long-term field evaluation of concrete sealers and their effects on the projected longevity of the pavements can be done under actual conditions of southwestern Idaho, development of testing protocol to evaluate sealer performance in the laboratory and field, an extensive laboratory evaluation of suitable compounds, and development of application protocols needs to be performed. This research is the initial phase of a comprehensive study to address these needs.

Research Problem

Water and chemicals dissolved in water contribute to the deterioration of PCCP used in roadways and bridge decks. The primary function of a concrete sealer is to limit the ingress of water and chemicals such as deicing salts. Alkali aggregate reactions, carbonation, reinforcing steel corrosion, sulfate attack, freeze/thaw, etc. are examples of deterioration processes enhanced by the presence of water in PCCP. Reducing the ingress of water/chemicals can potentially increase service life of PCCPs. There are

many different classes of sealer compounds and many brand specific formulations within each class. Also, climate, materials and construction methods differ from region to region across the United States and from country to country across the world. Sealing compounds that are successful in one region or country may not be effective or even useful in Idaho. Identification of general classes of compounds best suited for use in Idaho needs to be developed.

Over time, a variety of laboratory evaluation methods has been developed by manufacturers, transportation departments, and agencies to test sealer performance. Often, these test results cannot be directly compared between research efforts as the methods and sample preparation are not standardized or compatible. The laboratory evaluation process ideally allows for comparison of both historical and future results. Therefore, a laboratory testing method designed to mimic field conditions likely to be encountered in Idaho that also allows for comparison of past and future studies needs to be addressed.

Furthermore, the development of the laboratory tests to evaluate the effectiveness of field-applied compounds needs to be considered. Historically, many studies have not been able to duplicate the performance of laboratory determined best sealing compounds applied in a controlled environment when applied in the field on PCCP.

Scope

Through an extensive literature research and input from ITD personnel, three general concrete sealing classes of compounds were selected for evaluation in the study. Out of these three general classes, three individual compounds and two combinations identified

in the literature as being effective were selected for further study. The selected group of compounds included:

1. Silane (water repellent)
2. Epoxy (barrier coating)
3. High molecular weight methacrylate (HMWM) (barrier coating/pore blocker)
4. Silane basecoat with an epoxy topcoat (dual treatment)
5. Silane basecoat with a HMWM topcoat (dual treatment)

Comparative tests between the five concrete sealer treatments and control (untreated) samples were conducted in the laboratory to identify their performance. The tests selected to evaluate the performance were chosen or designed to mimic conditions likely encountered in Idaho including UV exposure, freeze-thaw cycling and exposure to two different roadway deicing salts. In addition, the same treatments were applied in the field at four sites in Southwestern Idaho to facilitate the long-term performance of the sealers at retarding crack formation.

This study discusses general classes of sealing compounds, although analyses are limited to using only one brand in each class of sealer. Hence, the test results do not represent the performance of all sealers within each class. It is likely that different formulations (brands) in each class will provide varying results. Further tests involving multiple brands of each class of sealers would facilitate the selection of the best products within each class. Moreover, treatments applied in the field will only have been in place for one year at the conclusion of this study. The necessary long-term evaluation (4+ years) is beyond the initial phase of the study.

CHAPTER 2: BACKGROUND/LITERATURE REVIEW

This chapter offers a background on surface applied concrete sealers and incorporates information discovered during the literature review. The literature review focused primarily on research performed after the 1994 National Cooperative Highway Research Program (NCHRP) Synthesis 209 *Sealers for Portland Cement Concrete Highway Facilities* by Philip D. Cady, which was an extensive summarization of work prior to the publishing date. Articles and technical reports were reviewed from resources comprising both domestic (United States) and foreign countries. Several studies by transportation agencies of states, such as California, Missouri, Minnesota, Kansas, South Dakota and Wisconsin, were studied and their results were considered in this project.

Background

Surface applied concrete sealers are designed to limit the ingress of water and chemicals into PCCP. By sealing a PCCP, processes dependent upon the exposure to water and chemicals deleterious to concrete or reinforcing steel can be reduced or inhibited. Water enters into concrete through pores or void space by capillary action, positive pressure, diffusion or most directly from seepage into surface cracks. While water is a necessary ingredient of concrete, its presence after the initial hydration and hardening has a potential to negatively affect the integrity of the concrete. Water readily dissolves and transports chemicals such as chlorides, sulfates, carbon dioxide, and

oxygen into concrete. These chemicals all have the potential to deteriorate concrete or reinforcing steel. In addition, alkali aggregate reactions can occur when the highly alkaline cement-paste reacts with silicate or dolomite crystals in aggregates in the presence of water, causing expansion and cracking. The pressure induced by freezing-thawing of water also adversely affects concrete durability. Maintaining concrete below a "critical moisture level" can eliminate freeze thaw deterioration (Basheer and Cleland 2006). Each of these deterioration mechanisms is enhanced by the presence of water. Through the use of concrete sealers, reduction of moisture can contribute to keeping these reactions or physical actions from reaching a "critical moisture level" that enables the deterioration process to begin or accelerate.

For newly constructed PCCPs, modern mix design greatly reduces the permeability of water and adequate air entrainment deters freeze-thaw pressure induced expansion. However, during the construction and placement of concrete decks, variability of durability between decks and within decks can be observed (Attanayake et al. 2006). Moreover, early age cracking can create cracks within newly placed concrete. Many PCCPs in Idaho are also exposed to de-icing salts during the winter. Limiting chloride exposure within PCCPs can increase its service life. By applying sealers on new construction, areas with reduced durability can be protected and additional protection can be provided for areas even with sound construction. The adoption of a sealing program could potentially increase overall PCCP service life.

Sealers applied to old concrete, in a low to moderate stage of deterioration, may also increase the service life, providing the mechanism causing the deterioration is not too far advanced. For example, if chloride induced corrosion from the use of deicing

salts is causing deterioration, sealing the PCCP will discourage further exposure, but the already present chloride can continue to cause damage. Chloride ingress is of primary concern for concretes with reinforcing steel. Corrosion of reinforcing steel results in an expansion pressure that causes cracking in concrete as well as deterioration of the structural steel. The chloride ions remains active in the corrosion process, once present as a continuous process, because chloride ions are not consumed as explained by the chemical reactions represented in Equation 2.1 and Equation 2.2 (Medeiros and Helene 2008).

$$Fe^{3+} + Fe^{2+} + 5Cl^{-} \xrightarrow{yields} FeCl_3 + FeCl_2$$

Equation 2.1 Reinforcing Steel Corrosion 1

For hydrolysis:

$$FeCl_3 + FeCl_2 \xrightarrow{yields} 5Cl^{-} + Fe(OH)_2 + Fe(OH)_3$$

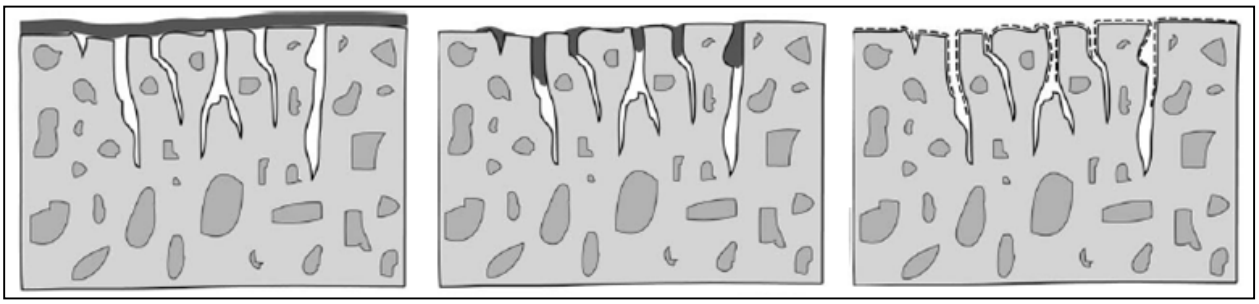
Equation 2.2 Reinforcing Steel Corrosion 2

After the second reaction, chloride ions remain free to react again. Consequently, the corrosion caused by chloride ions is one of the most dangerous and deleterious processes in reinforced concrete (Medeiros and Helene 2009). An additional example is alkali-silicate reactions (ASR) which can develop when the highly alkaline cement paste reacts with silica in aggregates in the presence of water to form alkali-calcium silica gel. The gel can swell causing expansion pressure which results in cracks in the concrete. A recent ASR study, involving the use of concrete sealers to mitigate ASR, found that regardless of the surface treatment, if ASR is advanced sealing has little benefit (Krauss et al. 2006). The results indicate that, regardless of the treatment, upward moisture migration from the sub grade to the bottom of the pavement is sufficient to support

continued ASR even in dry desert climates (Krauss et al. 2006). Concrete sealers can increase the service life of old PCCPs as long as they are applied to concrete surfaces not worse than a low to a moderate state of distress as defined by FHWA-RD-03-031 (Miller 2003).

Sealer Classes

Concrete sealers are typically classified into: (1) coating, and (2) penetrating sealers. However, penetrating sealers can be further defined by: (2a) pore blocking types or (2b) water repellents. Cady suggested that sealers be classified as a) barrier coating, b) pore blockers, and c) water repellents (Cady 1994). See Figure 2.1.



(a) Barrier Coating **(b) Pore Blocker** **(c) Water Repellent**

Figure 2.1 Sealer Types (Medeiros and Helene 2009)

Barrier coatings (Figure 2.1a) are compounds that generally have larger molecular size and higher viscosities than water repellent sealers and therefore have limited penetration into concrete decks. They are however, capable of penetrating and sealing larger cracks within concrete decks. Examples include epoxies, methacrylates, acrylics, urethanes etc. They rely on providing a complete surface barrier to water and chemicals. As primarily being surface coatings, their effectiveness at sealing decks is reduced by surface wear from traffic. Typically aggregate is applied on top of barrier coatings to

increase frictional properties and to improve wear rates. By diluting these products with a dispersant, deeper penetration depths can be achieved rendering the products as pore blocking/barrier coatings.

Pore blockers (Figure 2.1b) are penetrating compounds that fill the pore space of concrete without leaving a measurable surface coating. Silicates of lithium or sodium and linseed oil in solvent are common pore blockers. Silicates react with cement paste forming precipitates or gels that fill pore space reducing capillary suction. Silicates change surface properties of concrete by decreasing permeability, increasing hardness and overall increasing durability (LaRosa Thompson et al. 1997).

Water repellent sealers (Figure 2.1c) are penetrating sealers typically associated with organosilicon compounds like silanes and siloxanes. These compounds react with the cement paste leaving thin water-repelling coatings on the inside of pore walls that effectively exclude liquid water and undesirable ionic substances like chlorides (Cady 1994).

Sealers are also commonly referred to as deck sealers or crack sealers. A deck sealer is formulated to primarily seal the surface of PCCPs (water repellents and pore blockers) and may seal small cracks, while crack sealers (barrier coatings) are formulated to seal cracks and may provide some additional deck sealing capabilities.

Water Vapor Transmission

Vapor transmission can be an important sealer property. Barrier coating or pore blocking sealers can reduce the drying ability of a PCCP and especially bridge decks. Attanayake, et al explains the importance of breathability for bridge decks:

> "Most of the bridge decks are now constructed using stay-in-place forms. Other decks are cast on side-by-side box girders. Therefore, moisture transfer from concrete is only possible through the top surface of the deck. Consequently, covering the top surface of the deck with an impermeable layer or a penetrating type sealant that completely seals the pores can inhibit breathability causing adverse effects on its durability. Additionally, the pore blockers do not sufficiently penetrate into concrete due to larger molecular size (Cady 1994). There is a possibility that the sealed surface can be compromised by abrasion of vehicular traffic as well as exposure to ultraviolet radiation. For this reason, sealants that function as water repellents will last longer and are preferred for sealing concrete bridge decks (Attanayake et al. 2006)."

A barrier coating or pore blocking sealer can trap moisture present within PCCP should the PCCP absorb water. A minimum vapor transmission of 35% (relative to untreated concrete surfaces) is recommended (Cady 1994).

Available Testing Methods

Testing methods to evaluate the effectiveness of concrete sealers vary considerably. Most tests compare sealed versus unsealed samples. Many are, at least, partly based on the American Society for Testing and Materials (ASTM) or the American Association of State Highway and Transportation Officials (AASHTO) standards. One of the first comprehensive approaches to test concrete sealers was the NCHRP Report 244 *Concrete Sealers for Protection of Bridge Structures* (Pfeifer et al. 1981). This research focused primarily on the effects of sealers, limiting the ingress of water and chlorides. The study was conducted as a series of tests to explore different conditions encountered in field applications and exposures on surface applied concrete sealers. Series I and II tests focus on water and chloride transmission using different conditioning

regimes. Series III tests focus on varying application rates using the Series I and II methods. Series IV tests include a Southern Climate test mimicking the effects of Ultraviolet (UV) light exposure, while the Northern Climate test mimicked the effect of freeze-thaw cycling. Series II is likely the most commonly used approach to test sealers and allows for the most historical data. The test procedures most frequently cited as used among agencies polled were AASHTO T259 and NCHRP 244 Series II (Bush 1998).

Other methods have been developed by individual transportation agencies including for example, Oklahoma Department of Transportation OHD-L34 (ODOT 1982), and Alberta BT001 (Alberta 2000). AASHTO and ASTM standards such as AASHTO T260 (AASHTO 2005) and ASTM C666 (ASTM 2008) can be utilized to test sealed samples versus unsealed samples. With such a diverse range of tests combined with varying methods of sample preparation, direct comparison of results can be difficult from study to study and from laboratory to field performance. In a recent study Bush sites two sources of confusion:

1. Differences in performance observed in the laboratory and field applications
2. Differences in performance observed in various laboratory tests. The present confusion is further compounded since there is not a consensus as to which tests should be conducted to evaluate sealer performance in the laboratory (Bush 1998).

The Minnesota Department of Transportation (DOT) published a recent study in 2009 that details the most common testing methods used in the Midwest and demonstrates the diversity of testing methods (Johnson et al. 2009).

One of the primary recommendations of NCHRP Synthesis 209 is to develop a national standard testing specification for concrete sealers. This recommendation originates from the different testing methods that do not allow direct comparison of results. Variance in methods, sample preparation, application procedures etc. creates data that cannot be directly compared. In response to this recommendation, NCHRP 20-07 Task 235 (Krauss 2009) was completed in February 2009 by Wiss, Janney, Elstner Associates, Inc., the original agency authoring NCHRP 244. This research is currently under review and is expected to be included into AASHTO M224 *Standard Specification for Use of Protective Sealers for Portland Cement Concrete.* This research sent questionnaires to DOTs from every state in the U.S., Canadian Provinces, and European DOTs synthesizing sealer use, application techniques, testing methods etc. It offers a standard method of testing to address product qualification, product quality assurance, field application quality assurance and field assessment of reapplication needs and product performance. Many of the test procedures proposed are based upon existing methods to allow historical comparison. Adoption of a standard method of testing would facilitate creating a national database on concrete sealer products that would assist transportation agencies in product selection. In anticipation of the inclusion of this study into AASHTO M224, many of the tests selected for this study are based upon methods suggested in the proposed new standard.

Application Requirements

Many factors affect the success of concrete sealer performance as a result of application methods. Climatic conditions, concrete conditions, surface preparation, and application rates can all influence performance. Each concrete sealer has specific

application requirements and hence, adherence to manufacturer recommendations will likely provide the best results. Each manufacturer, in turn, may have differing application requirements even for the same class of compound further making comparisons of test results difficult.

Climatic conditions include temperature, wind, antecedent precipitation as well as forecasted precipitation. Most sealers are suggested to be applied between 4°C and 32°C at the concrete surface. Excessive wind can influence volatilization and curing rates. Moisture content at the surface is important as some sealers are not compatible with moisture during application. Several studies recommend a minimum of two days drying time after rain events or water pressure washing (Attanayake et al. 2006; Johnson et al. 2009). Sealers also need adequate curing time before precipitation events. Knowing antecedent and future weather is an important consideration for application, and following manufacturer application protocol is recommended.

The condition of concrete greatly affects sealer performance. Sealers are most effective on concretes with no more than a low to moderate state of deterioration. If a concrete is under advanced distress, sealers will be less effective. Age, water/cement ratio, chloride content, reinforcement corrosion potential, and service should be considered in accordance with manufacturer recommendations. Most product application instructions suggest new concrete has cured a minimum of 28 days before a sealer application. Several studies recommend sealers be applied at 3 to 6 months of age before chloride levels become high (Soriano 2003; Rahim et al. 2006).

Surface preparation activities prior to sealing the PCCP surface will be critical in the overall success of sealers. A crack sealer will likely be of little use, if the cracks are

full of dirt or debris. Similarly, if a concrete deck is excessively fouled, sealers will not have the best chance of success, because they will not be able to adhere properly to the surface. Sandblasting has the potential to open up pores in the concrete, and in turn, increases permeability. Silanes and siloxanes are best applied on new concrete or if the carbonated surface is removed from older concrete for the chemical to bond to the concrete surface. Silane and siloxane require the presence of normal alkalinity of the hydrated cement paste in the concrete substrate and moisture to produce the hydrolysis and condensation reactions that create the hydrophobic pore surfaces (Cady 1994). Many sealer manufacturers require or recommend shot blasting or pressure washing to prepare surfaces. In a bridge deck study in South Dakota where three bridges received different surface preparation consisting of sandblasting, power brooming and doing nothing prior to application, Soriano observed that penetration depths were similar for all three methods when using silane products. In fact, the sandblasted deck exhibited greater overall water penetration and in the absence of excessive debris, the "Do-Nothing" deck preparation appeared to provide the overall best sealer performance (Soriano 2003). Most sealers cover between 1.5-3 m^2/liter depending upon the condition of the surface, but for barrier coatings that require sand for frictional purposes, a sufficient quantity of sealer must be applied to allow for the sand to adhere to the sealed surface.

Service Life of Surface Applied Concrete Sealers

The longevity of surface applied concrete sealers varies dramatically depending upon traffic conditions, climate, PCCP conditions and the use of de-icing salts, studded tires, snowplowing and antiskid abrasives as well as, sealer material properties. In general, there is no consensus among agencies/researchers on how frequent PCCPs

should be sealed (Rahim et al. 2006). Reapplication needs can be generally based on wearing rates of PCCP versus depth of penetration. When the surface has worn to near the penetrated depth of the sealer, the sealer is no longer effective and would need reapplication. Another method involves measuring chloride diffusion rates if the goal of the sealer application is chloride protection. Once a sealer is no longer effective at reducing chloride diffusion, reapplication is necessary. Several studies offer methods to predict service life (Cady 1994; Rahim et al. 2006; Weyers 2005). However, actual service life will likely vary and field evaluation methods are limited. The expected durability for deck sealants typically ranges from five years to 15 years, while crack sealants are usually expected to remain effective from five years up to the life of the structure for some products (Pincheira et al. 2005).

Historical Use in Idaho

Most sealer use in Idaho has been on bridges. However, 32 km of Interstate 84 in both East and Westbound lanes near Mountain Home was sealed with High Molecular Weight Methacrylate (HMWM) in the summer of 2009. This PCCP was experiencing distress related to alkali-silica reactions (ASR), and HMWM was applied in an effort to increase its service life. A long term field evaluation program has yet to be established.

Recent Department of Transportation Studies

Kansas DOT published a study in 1998 that focused on HMWM and epoxy healer sealers as crack sealers (Meggers 1998). Sealers were applied on bridge decks and analyzed over 3 years using concrete cores for chloride content. Field results were inconclusive and a laboratory component of the study was initiated. The field trials found that some areas that were sealed actually had increased concentrations of chlorides

and that sealers could potentially trap chlorides in the bridge decks (Meggers 1998). It was theorized that rain events could potentially "wash" chloride salts out of the bridge decks reducing chloride content in unsealed sections. This theory is supported by Megger's experiment:

> "Meggers (1998) ran 12 beams which contained high chloride concentrations under tap water to simulate the excessive wetting that happens during spring and summer. Seven of the 12 beams showed a significant decrease in chloride levels. This was due to the tap water leaching out the chloride ions (Johnson et al. 2009)."

Penetration depths were also varied and the author suggested that the optimum sealer would be the one with a relatively low viscosity, 0.5 Pa.sec. or less, tensile elongation of 10% or more and a tensile strength of at least 8 MPa (Meggers 1998).

In 2005, the Wisconsin DOT funded a study of multiple brands of concrete deck and crack sealers (Pincheira et al. 2005). Thirteen deck sealers evaluated in this research were made of organosilicone products, silane and siloxanes, with various dispersants (Pincheira et al. 2005). The deck sealants were evaluated using AASHTO T259 (AASHTO 2006) and also contained a freeze-thaw component using alternating cycles of freezing and thawing. Chloride content was evaluated using AASHTO T260 (AASHTO 2005). The study categorized the sealer performance into three groups. Sealants that offered the best performance were assigned to Performance Group Category I, those that offered a moderate level of protection were assigned to Performance Group Category II, and those that offered the least amount of protection were assigned to Performance Group Category III (Pincheira et al. 2005). The crack sealers were gravity fill HMWM, epoxy

and urethane. Cracks of various widths were sealed and evaluated using tensile splitting techniques. Once again, the crack sealers were separated into three performance groups.

California DOT published the results of a research effort in 2006 using HMWM, used extensively in California on bridge decks (Rahim et al. 2006). The objectives were to review previous research using concrete sealers, to study the effectiveness of using methacrylate as a sealer and to develop guidelines for the use of HMWM and other sealers (Rahim et al. 2006). This report offers a history of the use of HMWM and consolidates penetration depths, application conditions, and application procedures of various studies. The study recommends that HMWM be applied on new decks between 3-6 months of age. For older decks, attention to surface preparation recommendations will offer the best protection. The study also often refers to the use of silane sealers for penetrating and sealing decks and small cracks followed by a topcoat of HMWM to seal larger cracks.

In 2009, Minnesota DOT funded a study performed by The University of Minnesota (Johnson et al. 2009). This study was conducted to evaluate the current state of use of surface applied concrete sealers. It offers a summary of laboratory and field testing methods used by transportation agencies primarily in the Midwest and results of recent studies. It also provides recommendations on testing methods, product selection, and product application.

CHAPTER 3: SELECTION OF COMPOUNDS

Surface applied concrete sealers are available in a variety of classes and brand specific formulations. Cady in 1994 identified 409 concrete sealer products through 169 manufacturing firms that produce them and recognized that the list was far from complete (Cady 1994). The purpose of this chapter is to provide background information on the method used to select sealer classes for use in the study and to provide more information about selected sealer properties.

Selection of Compounds

The selection of compounds for use in this study was based on commonly used products discovered in the literature review, NCHRP Synthesis 209 Table 8: Ranking of concrete sealers by laboratory tests, developing a selection matrix, and input from ITD personnel. The literature review revealed the most common deck or water repellent sealers are silane or siloxane (Johnson et al. 2009; Meggers 1998; Pincheira et al. 2005). Crack sealers or barrier coatings were HMWM, epoxy and the occasional use of urethanes (Johnson et al. 2009; Meggers 1998; Pincheira et al. 2005). Pore blockers were linseed oil and silicates.

NCHRP Synthesis 209 Table 8 ranks generic sealer types based on laboratory tests reported from a survey (Cady 1994). Several of the ranked compounds are not commonly used anymore in the United States. Examples are gum resin, stearate,

chlorinated rubber, and silicone. Chlorinated rubber use has been diminished due to environmental concerns, gum resins revealed little use in the literature review, stearates are susceptible to UV exposure, and silicones have historically not performed well in laboratory and field tests. Removing these compounds from the rankings reveals the best ranked sealers in a descending order: Dual Systems (silane/top coat epoxy or HMWM), Urethane, Silane, Epoxy, Siloxanes, Acrylics (methacrylates), Linseed Oil, and Silicates. Cady recommended taking extreme care in interpreting the results of these rankings as there are significant levels of variability and rankings represented average performance (Cady 1994).

A selection matrix for concrete sealers was developed to aid in the selection of compounds, (see appendix A). Criteria selected were based primarily on concrete substrate conditions including age, water/cement ratio, traffic exposure, cracks, water exposure, service life, and vapor transmission. In addition, recoating ability was considered as some compounds are not able to be applied over existing sealers. Sealers are grouped together in the following classes: silane/siloxane, epoxy/urethane, acrylics (methacrylates), linseed oil, dual systems, and silicates. Performance was evaluated by a scale from 1 to 3 where 1=poor, 2=fair and 3=good. Values assigned in the matrix were based upon the information garnered from the literature review and are open to discussion. The rankings are displayed in Table 3.1 below where 1 = highest and 5 = lowest.

Table 3.1 Selection Matrix Rankings

Silane Siloxane	Epoxy Urethane	Acrylic (HMWM)	Linseed Oil	Dual Systems	Silicates
4	2	2	5	1	5

Development and the results of the selection matrix revealed that certain type of sealers are used for specific applications. For example if a concrete is new, a silane would be a longer lasting solution as barrier coatings would likely wear off with vehicular traffic while a silane would provide a longer wearing surface. Likewise, a barrier coating/crack sealer would provide crack sealing capabilities for a cracked, older concrete. Dual systems offer the benefits of sealing the pavement deck and sealing cracks and, as a result, have the highest rankings.

The rankings of the selection matrix and NCHRP Synthesis 209 Table 8 were presented and discussed with ITD personnel in a meeting. From the list of compounds, five treatments were selected for evaluation:

1) Silane
2) Epoxy
3) High Molecular Weight Methacrylate (HMWM)
4) Silane base and HMWM topcoat (Dual System)
5) Silane base and Epoxy topcoat (Dual System)

Selected Sealer Properties

Silane

This organosilicone compound is classified as water repellent deck sealer that penetrates into concrete and reacts with the cement paste forming a thin hydrophobic coating in pore spaces (see Figure 2.1c). The correct nomenclature for this class of

substance is alkyl trialkoxy silane where “alkyl” refers to the organo-fucntional group, R, part of the molecule responsible for water repellent properties and “trialkoxy” pertains to the three silicon functional groups R’O (Cady 1994). See Figure 3.1.

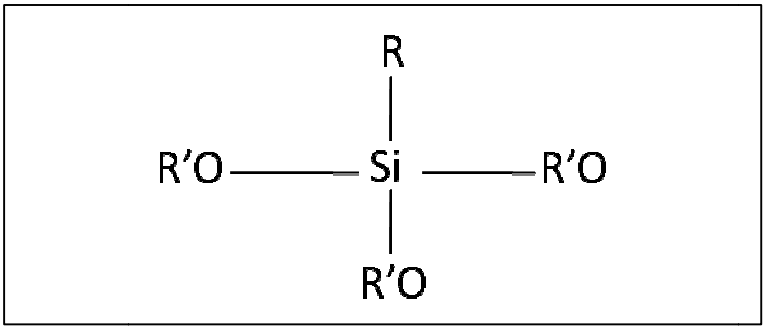


Figure 3.1 Alkyl Trialkoxy Silane

The R or “alkyl” group can be a straight chained or branched hydrocarbon that provides the hydrophobic properties of the sealer. Soriano concluded that silane sealers should incorporate alkyl groups larger than methoxy and ethoxy groups as their concrete bridge deck surface sealing materials (Soriano 2003). Larger molecules potentially provide more water repellency. The coating renders the concrete hydrophobic by leaving an exposed hydrocarbon (R) on the surface that reduces the contact angle of water droplets to the concrete surface while the alkoxy groups bond to the inorganic concrete surface see Figure 3.2 and Figure 3.3 below.

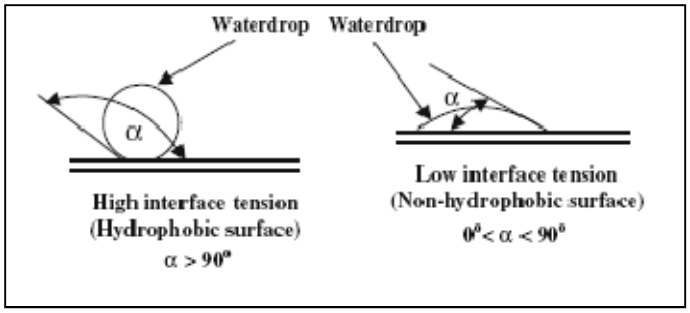


Figure 3.2 Silane Contact Angle (Medeiros and Helene 2008)

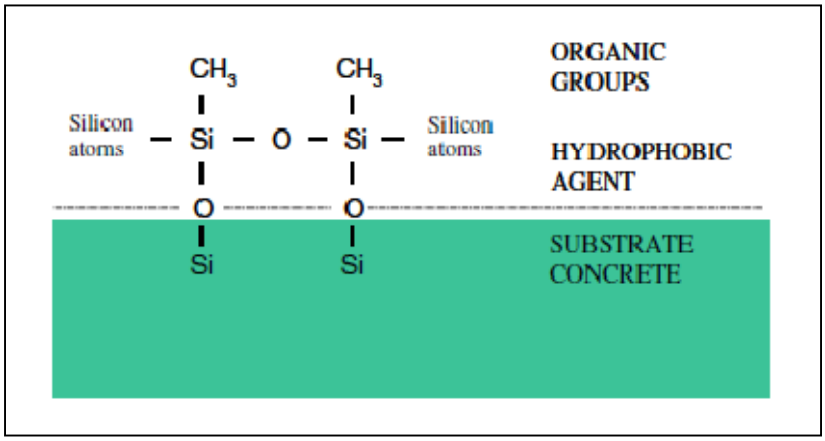


Figure 3.3 Chemical Bond of Silane to Concrete (Medeiros and Helene 2008)

The advantage of this type of sealer is the ability to transmit water vapor trapped within the concrete into the atmosphere while limiting the ingress of liquid water into the concrete. Also, they can achieve penetration depths up to 6mm to reduce the effect of surface wear on sealing quality. They are, however, limited in use for sealing cracks larger than 0.6mm (Wenzlick 2007). Hydrophobic agents are efficient only in non-saturated conditions where the main transport mechanism is capillary suction (Medeiros and Helene 2008).

Siloxane is another option for water repellent sealers. Siloxane is composed of chains of silane molecules. Silane molecules are smaller than siloxane and typically achieve deeper penetration depths. Silanes are more volatile than siloxanes.

Silane/siloxane can be diluted with water or solvents such as alcohols. Silane/siloxane content should be at least 40% and are available up to 100%. Results of the 2009 Minnesota DOT study suggest that: (i) silane products typically outperform siloxane products, (ii) water-based products are not suitable for reapplication, and (iii) solvent-based products typically outperform water-based products (Johnson et al. 2009). Silane gels are commercially available that can potentially reduce the amount of silane that volatizes during application, resulting in deeper penetration depths.

Epoxy

There are many formulations of epoxy used in conjunction with concrete repair and preservation. The formulations referred to in this study are categorized as "healer sealers" or "gravity-fill" and are typically diluted to a low viscosity in order to penetrate cracks. Epoxy is classified as a barrier-coating or pore blocker depending upon viscosity, and hence, penetrating ability. These are two component systems comprised of a bisphenol (A) epoxy resin mixed with an epichlorohydrin (B) usually in a 1:1 ratio.

Aggregate is often broadcast on the surface to improve frictional properties after application. These sealers are often referred to as crack sealers. The ACI 224.1R-93 (1998) states: "low viscosity monomers and resins can be used to seal cracks with surface widths of 0.03 mm to 2 mm by gravity filling (Rahim et al. 2006). Epoxy's tensile strength, compressive strength and elongation properties allow the compound to seal cracks that expand and contract from thermal changes and vehicular loading. Epoxies also can be used in overlays mixed with aggregates although these formulations have typically higher viscosities and do not penetrate as effectively into small cracks.

High Molecular Weight Methacrylates (HMWM)

HMWMs are barrier coatings with some penetrating ability. HMWMs are a three-component system (monomer resin, initiator, and promoter) that requires extra precaution during mixing, because a violent reaction may occur if the initiator and promoter are mixed first or improperly (Soriano 2003). Alternate formulations may exist that reduce the hazard potential. HMWMs are ultraviolet light resistant polymers. They have low viscosities (about that of water) and can penetrate dry concrete without using a carrier or solvent (100% solids content) (Cady 1994). They are effective crack-sealers and are typically applied as such, however, due to the low viscosity; they can penetrate and seal concrete decks. Like epoxies, aggregate is usually broadcast after application before curing to increase frictional properties of the barrier coating. HMWMs are susceptible to surface wear from vehicular traffic and typically do not penetrate as deep as silane sealers into concrete due to their larger molecular size.

Dual Systems

Dual systems or combination systems are comprised of a silane base coat followed by an epoxy or HMWM top coat. Silane is applied and allowed to cure, then the top coat is applied. This method provides sealing of the concrete deck and cracks. As the top coat wears off, the deck remains sealed from the penetrating silane and the cracks remain sealed offering potentially the most protection for PCCP.

CHAPTER 4: APPROACH AND METHODS

In this chapter, a laboratory and field testing plan developed and presented to ITD during a quarterly meeting for approval is discussed. ITD specifically requested that the tests be based upon existing methods, preferably ASTM or AASHTO standards to be used to compare previous and future studies. As mentioned before, the laboratory testing series is based upon a draft of NCHRP 20-07 Task 235 that was completed in February 2009 by Wiss, Janney, Elstner Associates, Inc (WJE) (Krauss 2009). This research is currently under review and is expected to be included into AASHTO M224 *Standard Specification for Use of Protective Sealers for Portland Cement Concrete* after validation. By adopting a standard method as proposed, the results of this study could be compared with future sealer research and will contribute to the development of a national database on concrete sealers.

Laboratory Testing

The laboratory testing plan focused on testing the prequalification of universal properties of concrete sealers. Universal properties necessary for all sealers include vapor transmission properties, resistance to water and chloride ion penetration, and resistance to outdoor weathering and alkali found in concrete (Krauss 2009). Tests to evaluate these properties include:

1) Water vapor transmission
2) Saltwater absorption

3) Chloride permeability
4) Sealer penetration depth or coating thickness
5) Resistance to alkali
6) Ultraviolet (UV) weathering and cyclic saltwater ponding

The tests are all performed in series using 10 cm cube samples with the exception of the UV weathering and cyclic saltwater ponding that uses a 30.5 cm by 30.5 cm by 7.6 cm slab sample. The WJE testing method suggests methods to cast, cure, prepare and seal samples. Following a standard method of sample preparation provides the consistency required for the comparison with other research using similar methods. After sealing, samples are run sequentially through the testing series to determine the performance compared to unsealed samples. Figure 4.1 adapted from WJE details the testing series below and each major test will be discussed individually.

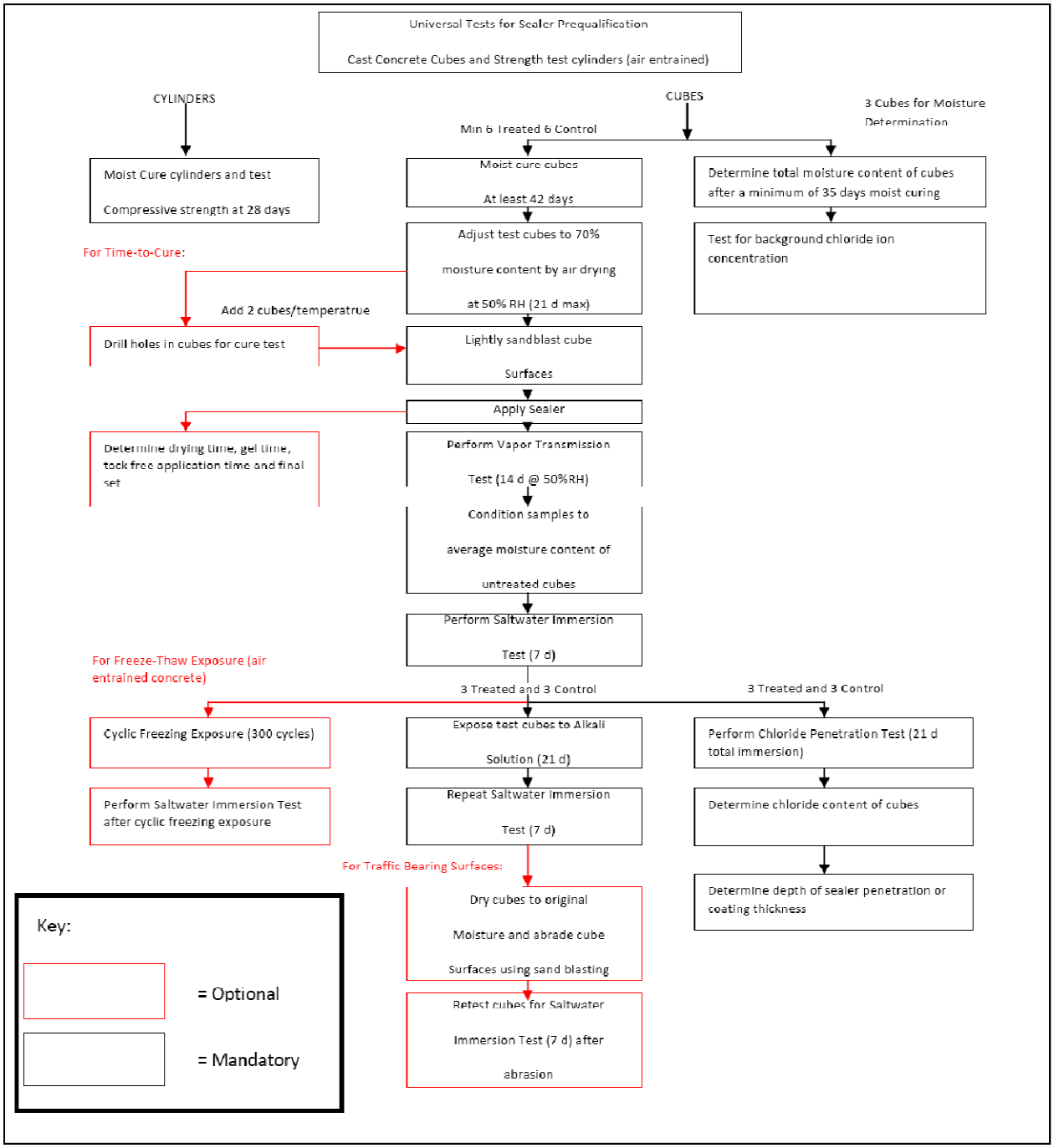


Figure 4.1 Flow Chart for Prequalification Testing (Krauss 2009)

In addition to the universal tests, a freeze-thaw exposure test was conducted to simulate the effect of freeze-thaw cycling encountered in Idaho. The testing method is

based on an initial 7-day saltwater absorption test followed by 300 cycles of freeze-thaw and a final 7-day saltwater absorption test.

Casting Samples

To simulate PCCP used in Idaho, laboratory samples were cast using an ITD mix design. The mix design is based on ITD's *Standard Specifications for Highway Construction* as displayed in Table 4.1 below.

Table 4.1 ITD PCCP Mix Design (ITD 2010)

Concrete Class in MPa (28 Day)	Minimum Cement Content kg/m³	Max. Water Cement Ratio	Slump mm	Air Content Percent
31.0	392	0.44	50 mm max.	4-7

Appendix B contains information regarding aggregate gradations (coarse and fine), casting dates, slump, air content, compressive strength, moisture capacity, age of sample at time of use, admixture properties, and ratio of coarse to fine aggregates. Aggregates were selected from local sources utilized in the Boise area and were donated by *Idaho Concrete Company*. Cement used is *Ashgrove* type I/II which is typical of cement specifications in ITD's roadway design manual. *BASF MICRO AIR*® air entrainment is used to meet the 409 specification for air content. Specimens were cast and cured in accordance with AASHTO T126. For each batch: slump, air content, and 28 day compression strength (3 cylinders per batch) were determined for quality control assurance. In total, 27 batches of concrete were cast with an average compressive strength of 39.4 MPa for 78 cylinders. Typically samples that did not reach the required

compressive strength had forming issues such as incomplete rodding or convex tops/bottoms as other samples from the batch met the requirements.

The number of samples required for the testing series was selected as 6 samples for each sealer tested and 6 control samples. In addition one sample from each batch was used to determine the moisture capacity. Additional samples may be required if the time to cure test is performed, which was beyond the scope of this study.

Conditioning

A common discrepancy between sealer tests is the adjusted moisture content of samples. For example, the Oklahoma DOT absorption test follows ASTM C642 and oven dries samples to a constant weight (no moisture); while the NCHRP Series 244 dries samples for 5 days at 50% relative humidity (RH) (Bush 1998). A sample, that has no moisture, will likely gain more mass; while a sample conditioned for a general time period may not be duplicated consistently. The initial moisture content of the concrete in the NCHRP 244 test cannot be controlled which is not a desirable feature for laboratory test methods (Johnson et al. 2009). The method offered by WJE conditions samples to 70% moisture content to promote more consistent results.

Samples were cured a minimum of 42 days and not more than 6 months in a water bath at 25°C. Samples were then conditioned in an environment chamber at 23°C and 50% RH to reach a moisture capacity of 70%. To determine the moisture content, one sample from each batch was removed from the water bath, towel dried and weighed to determine the saturated surface dry weight (W_{ssd}). The sample was then oven dried to a constant weight (W_{od}) at 95°C. The total moisture capacity (M_{ssd}) was determined by Equation 4.1.

$$M_{ssd} = ((W_{ssd} - W_{od})/W_{od}) * 100 \ \ in \ \% \ by \ weight$$

where:

M_{ssd} = Total moisture capacity

W_{ssd} = Weight saturated surface dry

W_{od} = Weight oven dried

Equation 4.1 Total Moisture Capacity (Krauss 2009)

Cumulative samples from each batch were averaged to obtain the mean total moisture capacity ($M_{ssd\text{-}m}$). Samples for the testing series were then removed from the water bath and the saturated surface dry weight ($W_{ssd\#}$) was determined for each sample. To determine the target weight representing 70% moisture content for each sample, the oven dry weight ($W_{od\#}$) is estimated using Equation 4.2.

$$W_{od} = \frac{W_{ssd}}{1 + \left(\frac{M_{ssd-m}}{100}\right)} \ in \ grams$$

where:

W_{od} = Weight oven dried

W_{ssd} = Weight saturated surface dry

$M_{ssd\text{-}m}$ = Mean weight saturated surface dry

Equation 4.2 Oven Dry Weight (Krauss 2009)

Then, the target weight ($W_{t\#}$) after conditioning at 50% RH was determined by Equation 4.3.

$$W_t = \left(0.70 * (W_{ssd} - W_{od})\right) + W_{od\#}$$

where:

W_t = Target weight

Equation 4.3 Target Weight (Krauss 2009)

Samples were conditioned to approximately the target weight value. Samples were then slightly sandblasted prior to sealing.

Application

Sealing consisted of complete immersion in silane for 2 minutes to ensure all surfaces were sealed. The applied sealer mass was determined by weighing the container before and after immersion. Application for the epoxy and HMWM consisted of one coat sealing five faces of the six faced cubes with a brush allowing 24 hours of curing followed by sealing of the sixth face. The epoxy and HMWM were mixed according to manufacturer recommendations. The weight of the sealer applied (W_{sa}) was measured by weighing the container, sealer, and brush (epoxy and HMWM) before and after application. The application rates were calculated by determining the volume (liter) per surface area (m^2) using the manufacturers reported specific gravity, mass applied, and surface area of a 10 cm cube. Mean application rates for all treated cube samples are listed in Table 4.2 below.

Table 4.2 Mean Sealer Application Rates for Cube Samples

		Dual System			Dual System		
	Silane	HMWM	Silane	HMWM	Epoxy	Silane	Epoxy
Application Rate (m^2/liter)	4.8	5.9	4.4	5.4	5.3	4.6	4.8
Manufacturer Recommended (m^2/liter)	2.5-3	2-3	2.5-3	2-3	3.7-4.9	2.5-3	3.7-4.9

The application rates were typically under the recommended rates of the manufacturers. The manufacturer application rates are average rates and are in part accounting for material filling cracks. The relatively smooth surface of the samples would likely differ than surfaces of PCCP in the field and would theoretically require less sealer to be applied. It is possible however, that the application rates that were less then recommended could have influenced the results. All laboratory sealed surfaces appeared to be "wet" until sealer was cured during application. For the silane, complete immersion for a constant time allows for all surfaces to be treated evenly and comparable if using different compounds. For the brush applied HMWM and Epoxy, the vertical surfaces of the cubes were challenging to apply. Application of more sealer would "run off" the vertical sides of the cubes and not adhere to the cubes. While treating the "sixth side (bottoms)" of the cubes after 24 hours of curing, a second coat was applied to all surfaces. A limited amount of material would adhere before "running off." Application of a second coat only increased the coating thickness and does not further penetrate into the samples.

Water Vapor Transmission

Water vapor transmission for sealed samples was gravimetrically determined and compared with unsealed samples using the WJE method. The method proposed by WJE is based on the NCHRP 244. Vapor transmission measured using the WJE method differs from the one using the NCHRP 244 method, in that vapor transmission is measured prior to saltwater immersion testing to ensure that all samples (treated and untreated) are at the same moisture content. Immediately after sealing, samples were placed in an environment chamber at 23°C and 50% RH for 14 days. Samples were weighed at 0 (W_0), 7 (W_7), and 14 (W_{14}) days. The water loss due to vapor transmission is the measured difference between the 14th and 7th day in the assumption that volatile components of sealers will have evaporated in the initial 7 days (Krauss 2009). The water loss due to vapor transmission is determined by Equation 4.4.

$$VT_{treated}\ or\ VT_{untreated} = \frac{W_7 - W_{14}}{168hr * 0.062m^2}\ in\ g/(m^2 * hr)$$

where:

VT = Vapor transmission, treated or untreated cubes

W = Weight at 7 or 14 days

Equation 4.4 Vapor Transmission (Krauss 2009)

Then the mean value is determined for treated ($VT_{treated\text{-}m}$) and untreated ($VT_{untreated\text{-}m}$) samples of the same type. Then the mean drying rate coefficient (DRC) was calculated by Equation 4.6.

$$DRC = \left(\frac{VT_{treated-m}}{VT_{untreated-m}}\right) * 100 \ \ in\ percent\ (\%)$$

where:

DRC = Drying rate coefficient

VT_{-m} = Vapor transmission mean for treated and untreated samples

Equation 4.5 Drying Rate Coefficient (Krauss 2009)

The DRC represents a treated sample's vapor-transmission-ability compared to the untreated samples vapor-transmission-ability. The untreated samples are expected to lose more moisture than sealed samples. Prior to the next test (saltwater immersion), the sealed samples are oven dried to the moisture content of the unsealed samples to ensure starting the next test at the same moisture content as the untreated samples. To determine the target weight for the sealed samples, first the weight of the cured sealer applied is determined by Equation 4.6.

$$W_{csa} = N_s * W_{sw} \ \ in\ grams$$

where:

W_{csa} = Weight of cured sealer applied (g)

N_s = Non-volatile content from ASTM D5095 for silane/siloxanes and ASTM D2369 for other sealers

W_{sw} = Wet weight of sealer applied (g)

Equation 4.6 Weight of Cured Sealer Applied (Krauss 2009)

The W_{sw} value can be prone to error as a portion of the W_{sw} inevitably drips from the sample cubes after application. Then, the moisture content of the untreated cubes following vapor transmission (M_{cvt}) is calculated using Equation 4.7.

$$M_{cvt} = \left(\frac{W_{14-untreted} - W_{od}}{W_{od}}\right) * 100 \; as \; percent \; (\%)$$

where:

M_{cvt} = Moisture content after vapor transmission test

$W_{14\text{-}untreated}$ = Weight of untreated sample after vapor transmission test

W_{od} = Weight of oven dried sample (Equation 4.2)

Equation 4.7 Moisture Content After Vapor Transmission Test (Krauss 2009)

Thereafter, the mean value for the control cubes is calculated. Then the target weight for each treated sample is determined by Equation 4.8.

$$W_{t2} = W_{od} * \left(1 + \frac{M_{cvt-m}}{100}\right) + W_{csa} \; in \; grams$$

where:

W_{t2} = Target weight of treated samples after vapor transmission test

$M_{cvt\text{-}m}$ = Moisture content after vapor transmission test

W_{od} = Weight of oven dried sample (Equation 4.2)

Equation 4.8 Target Weight After Vapor Transmission Test (Krauss 2009)

The samples are then dried to approximately the target weight, determined in Equation 10, in an oven at 60°C. Samples are now prepared for the next test in the series.

Saltwater Absorption

This test measures a sealer's ability to limit the ingress of water and chlorides and is based on the NCHRP 244 testing series II. In this study, only the gravimetric determination of absorption was tested. Chloride content was beyond the resources available for this study and was reserved for the analysis of the results of the UV/Saltwater weathering test. In the testing series, all samples were tested for 7-day saltwater absorption.

The weight of each sample (W_{i0}) is measured prior to immersion. Samples are then immersed in 15% (by weight) sodium chloride solution maintained at laboratory temperatures. Fluid levels are maintained an inch above the top surface of each sample and samples are placed on glass rods so that all surfaces are exposed. Samples are removed after 7 days rinsed, towel dried and weighed (W_{i7}). The weight gained (ΔW_7) during immersion is calculated using Equation 4.9.

$$\Delta W_{i7} = \left(\frac{W_{i7} - W_{i0}}{W_{i0}}\right) * 100 \ \ as\ percent\ at\ 7\ days$$

where:

ΔW_{i7} = Weight gained during 7-days of immersion

$W_{i0\ or\ i21}$ = Weight at 0 or 7 days

Equation 4.9 Weight Gain 7-Day Saltwater Absorption Test (Krauss 2009)

The mean weight gain for both the treated and untreated samples is then calculated. The Saltwater Absorption Ratio (SAR) is calculated representing the absorption of the treated cubes in relation to the untreated cubes using Equation 4.10.

$$SAR_7 = \left(\frac{\Delta W_{i7-treated-m}}{\Delta W_{i7-untreated-m}}\right) * 100 \ \ as\ percent\ at\ 7\ days$$

where:

SAR_7 = Saltwater absorption ratio (%) at 7 days

$\Delta W_{i7\text{-}treated\text{-}m}$ = Mean weight gain (g) of treated samples at 7 days

$\Delta W_{i7\text{-}untreated\text{-}m}$ = Mean weight gain (g) of untreated samples at 7 days

Equation 4.10 Saltwater Absorption Ratio 7-Day (Krauss 2009)

After the 7-day saltwater absorption, three samples from all sealer types and the control underwent a 21-day total saltwater absorption, and the remaining three samples from each treatment underwent the alkali resistance test. The saltwater absorption

samples are then weighed at 14-day (W_{i14}) and 21-day (W_{i21}). The weight gain at 14-day (ΔW_{14}) and 21-day (ΔW_{21}) are calculated using Equation 4.11 and Equation 4.12.

$$\Delta W_{i14} = \left(\frac{W_{i14} - W_{i0}}{W_{i0}}\right) * 100 \ \ as\ percent\ at\ 14\ days$$

Equation 4.11 Weight Gain 14-Day Saltwater Absorption Test (Krauss 2009)

$$\Delta W_{i21} = \left(\frac{W_{i21} - W_{i0}}{W_{i0}}\right) * 100 \ \ as\ percent\ at\ 21\ days$$

where:

$\Delta W_{i14\ or\ i21}$ = Weight gained (g) during 14 or 21 days of immersion

$W_{i0,\ 14\ or\ i21}$ = Weight at 0, 14 or 21 days

Equation 4.12 Weight Gain 21-Day Saltwater Absorption Test (Krauss 2009)

The SAR was calculated for both time periods using Equation 4.13 and Equation 4.4.

$$SAR_{14} = \left(\frac{\Delta W_{i14-treated-m}}{\Delta W_{i14-untreated-m}}\right) * 100\ as\ percent\ at\ 14\ days$$

Equation 4.13 Saltwater Absorption Ratio 14-Day (Krauss 2009)

$$SAR_{21} = \left(\frac{\Delta W_{i21-treated-m}}{\Delta W_{i21-untreated-m}}\right) * 100\ as\ percent\ at\ 21\ days$$

where:

$SAR_{14\ or\ 21}$= Saltwater absorption ratio (%) at 14 or 21 days

$\Delta W_{i14\ or\ i21\text{-}treated\text{-}m}$ = Mean weight gain (g) of treated samples at 14 or 21 days

$\Delta W_{i14\ or\ i21\text{-}untreated\text{-}m}$ = Mean weight gain (g) of untreated samples at 14 or 21 days

Equation 4.14. Saltwater Absorption Ratio 21-Day (Krauss 2009)

Alkali Resistance

The alkali resistance test determines a sealer's performance when encountered with an alkaline environment. This test is based on the Alberta BT002 method and

follows the WJE method. The Alberta highway agency believes that this test is important since after they introduced the test, several products that were on their approved list failed and had to be dropped (Krauss 2009).

After the initial 7-day salt water absorption, the remaining samples (3 from each sealer type and 3 controls) are soaked for 21-days in a 5.6 g/l potassium hydroxide solution at laboratory temperature of 25° C. The samples are covered by one inch of solution and supported on glass rods to ensure all surfaces are exposed. After 21 days, the samples are removed, towel dried, and dried in an oven at 60°C until they reached the initial weight (W_{i0}) of the saltwater absorption test. The samples then underwent a second 7-day saltwater absorption test. At the conclusion of the second saltwater absorption, the mean weight gain (ΔW_{i7}) for each treatment and control is determined. The saltwater absorption ratio after alkali exposure (SAR_{ALKALI}) is calculated using Equation 4.15.

$$SAR_{Alkali} = \left(\frac{\Delta W_{i7-treated-alk-m}}{\Delta W_{i7-untreated-alk-m}}\right) * 100\ as\ percent\ at\ 7\ days$$

where:

SAR_{Alkali} = Saltwater absorption ratio (%) after alkali exposure at 7 days

$\Delta W_{i7\text{-}treated\text{-}alk\text{-}m}$ = Mean weight gain (g) of treated samples after alkali exposure at 7 days

$\Delta W_{i7\text{-}untreated\text{-}alk\text{-}m}$ = Mean weight gain (g) of untreated samples after alkali exposure at 7 days

Equation 4.15 Saltwater Absorption Ratio After Alkali Exposure (Krauss 2009)

Weathering and Saltwater Resistance

This test determines the performance of a sealer when exposed to alternating cycles of UV exposure and saltwater ponding. The results compare the percent chloride absorption reduction from untreated with treated samples. The intent of weathering testing is to determine if the sealer remains effective after cyclic wetting, drying, and exposure to ultraviolet radiation (Krauss 2009). It is based on the NCHRP 244 Series IV Southern Climate Test and modified by WJE (Krauss 2009). Modifications were reducing the ponding cycle from 100 hours to 24 hours, which reduced the total testing time from 24 weeks to 14 weeks. Test data show that chloride from saltwater is rapidly absorbed into dry concrete during the first 24 hours of ponding then, the rate of chloride penetration slows and is controlled by diffusion after the concrete voids are filled with water, and the concrete becomes saturated (Krauss 2009).

Samples for this test are cast as 30.5 cm by 30.5 cm by 7.6 cm concrete slabs using the same mix design and casting procedures as the 10 cm cubes. Three samples are cast per sealer treatment plus three control samples in three separate batches for a total of

18 slabs. Conditioning consists of demolding at 24 hours followed by storage in plastic bags with wet cotton towels for 21 days. Thereafter, the formed (bottom) surface is then lightly sand blasted and then stored for 6 days in an environment chamber at 23°C and 50% RH. At an age of 28 days, the samples are removed from the environment chamber and sealed. Sealers are brush applied to the sand blasted surface. The applied amount of sealer is measured by weighing the sealer container and brush before and after application. Only one coat is applied for each sealer in this study. The mean application rates are displayed in Table 4.3 below.

Table 4.3 Mean Application Rates for Slab Samples

		Dual System			Dual System		
	Silane	HMWM	Silane	HMWM	Epoxy	Silane	Epoxy
Application Rate (m^2/liter)	6.5	5.3	6.4	5	5.2	6.2	5.3
Manufacturer Recommended Rate (m^2/liter)	2.5-3	2-3	2.5-3	2-3	3.7-4.9	2.5-3	3.7-4.9

These rates were similar to the cube sample application rates. All sealers were "puddling" on the slabs and additional material applied would run off of the samples. Refer to the prior discussion on application rates regarding the discretion between manufacturer rates vs. rates applied in this study.

After sealers are applied, the samples are placed back in the environment chamber and conditioned at 23°C and 50% RH. At 35 to 41 days, the sides of the samples are sealed with epoxy to eliminate the lateral moisture movement. Acrylic dikes, 2.5 cm tall, are applied with silicone to the treated/untreated surface to allow for saltwater ponding, see Figure 4.2.

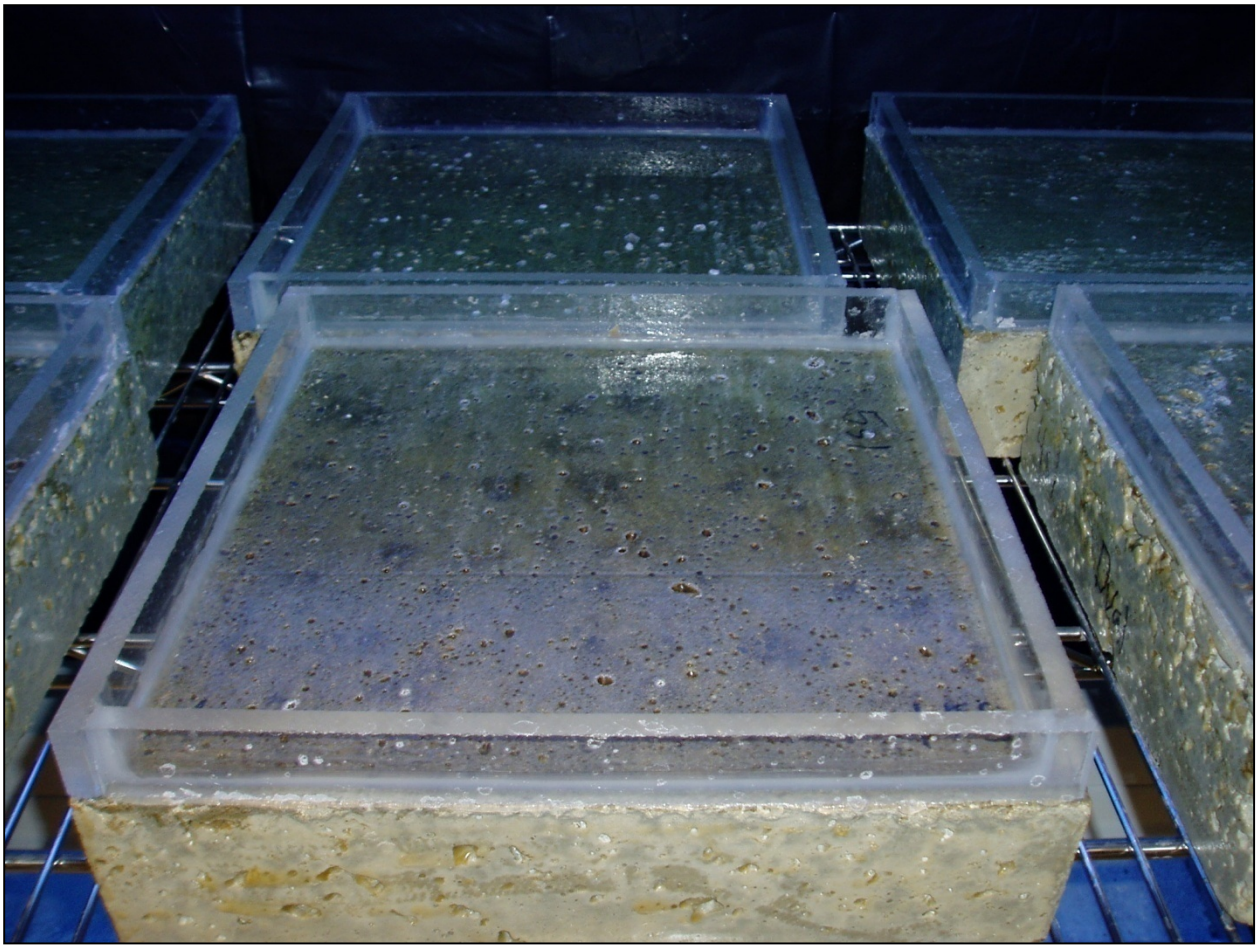


Figure 4.2 Prepared Slab Samples

Ponding started at day 42. Samples are ponded to a 12.8 mm of depth with 15% Sodium Chloride solution by weight for 24 hours on a Monday. Samples are drained, rinsed with tap water, and exposed to a UV cycle for 48 hours from Tuesday to Wednesday. Samples are ponded with saltwater for 24 hours starting on Thursday. On Friday, the samples are exposed to a UV cycle for 72 hours until Monday. This week long cycle is repeated for 14 weeks. The UV cycle is simulated using 122 cm long fluorescent fixture with 40 watt ultraviolet lamps (W-F40BL, GE part #10526) suspended 15.25 cm above the slabs as recommended by WJE. The UV chamber was maintained at

laboratory temperature (approx. 23°C) during this study which is different than the method suggested by WJE, where the temperature is 37.8°C during the UV cycle.

At the conclusion of 14 weeks, each sample is wet cored using a 3.5 cm diamond coring bit. Samples are immediately placed in an oven at 60°C and dried for 24 hours. Each sample is, then, sliced with a diamond saw, run dry, to produce samples from 6.4 mm to 12.7 mm, 15.9 mm to 22.2 mm, 25 mm to 31.8mm, and 34.9 mm to 41.3 mm. Samples from each depth are pulverized and screened to pass a standard #50 sieve.

Chloride content is determined at each depth using AASHTO T260 using the *Acid Soluble Chloride Ion Content Method 1: Potentiometric Titration* (AASHTO 2005). A Cole Parmer Chloride Ion Electrode Model#: 27504-08 is utilized to record milivolt readings during the titration. For each sample, 3 grams of material is added to a 250 ml beaker and 10 ml of distilled water is added to bring the sample into solution. Concentrated nitric acid is added (3 ml) and mixed allowing for a minimum of 5 minutes of acid digestion. The total volume is then increased to >50 ml by adding 40 ml of hot distilled water. Methyl Orange indicator (5 drops) is added to ensure sufficient acidity indicated by a sustained pale red color. A watch glass covers the beaker and is brought to a rolling boil for 1 minute. The solution is then vacuum filtered through a #41 over #40 *Whatman* filter paper. The filter and solid residual is washed with hot distilled water and vacuum filtered until the volume is approximately 150 ml. The solution was then transferred to a clean 250 ml beaker, covered with a watch glass and allowed to cool to room temperature. The electrode is checked for accuracy by checking the slope prior to each use using the method outlined in the electrode manual. Then for each sample, 3ml of Ionic Strength Adjuster (5 M $NaNO_3$) and 4 ml of 0.01 normality NaCl solution is

added. Then standard 0.01 normality $AgNO_3$ is added in 0.10 ml increments recording the millivoltmeter (mV) readings after each addition (titration). The titration is continued to at least 40 mV beyond the equivalence point (inflection point-approximately 305 mV). The percent chloride is calculated using Equation 4.16.

$$Cl^- = \frac{3.5453(V_1N_1 - V_2N_2)}{W}\ in\ percent(\%)$$

where:

V_1 = endpoint in ml of $AgNO_3$

N_1 = normality of $AgNO_3$

V_2 = volume of NaCl solution added in ml

N_2 = normality of NaCl

W = mass of original concrete sample in grams

Equation 4.16 Percent Chloride Concentration (AASHTO 2005)

The percent chloride is then converted to kg of Cl/m^3 of concrete by Equation 4.17.

$$C_n = Percent\ Cl\left(\frac{UW}{100}\right)\ in\ (\frac{kg}{m^3})$$

where:

C_n = Chloride ingress in slice n for each depth minus the baseline chloride concentration in oven dried untested cubes (kg/m^3)

UW = Unit mass of concrete per cubic meter

Equation 4.17 Chloride Ingress Concentration (AASHTO 2005)

The unit mass (UW) is assumed to be 2323 kg/m^3 for all samples in this research. The total chloride ingress (TC) was calculated for each sample using Equation 4.18.

$$TC = \left(\frac{C_1 + C_2}{2}\right) * (d_2 - d_1) + \left(\frac{C_2 + C_3}{2}\right) * (d_3 - d_2) + \left(\frac{C_3 + C_4}{2}\right) * (d_4 - d_3) \ in\ kg/m^2$$

where:

TC = Total chloride content (kg/m^2)

C_n = Chloride ingress in slice n for each depth minus the baseline chloride concentration in oven dried untested cubes (kg/m^3)

d_n = The midpoint depth of slice n for each sample (m)

Equation 4.18 Total Chloride Content (Krauss 2009)

The mean total chloride ingress for the treated and untreated cubes is calculated. The relative chloride ratio (RCR) as a percent of the untreated control samples is calculated using Equation 4.19.

$$RCR = \left(\frac{TC_{treated-m}}{TC_{untreated-m}}\right) * 100\ \ in\ percent\ (\%)$$

where:

RCR = Relative chloride ratio (%)

$TC_{treated\text{-}m}$ = Mean total chloride content in treated cubes (kg/m^2)

$TC_{untreated\text{-}m}$ = Mean total chloride content in untreated cubes (kg/m^2)

Equation 4.19 Relative Chloride Ratio (Krauss 2009)

Depth of Penetration

This test determines the extent at which, a sealer penetrates into concrete. The method suggested by WJE is used (Krauss 2009). First, the cube samples are split in half by placing the cubes in a compression testing apparatus with two 9.5 mm diameter steel rods centered on the top and bottom of the cube faces. Using compression, the cubes are split in half. Thereafter, for penetration depth, one half of the cube is immersed in red food coloring for 30 seconds, and then, is allowed to dry. The penetration depth is

determined by examining the dye-treated surface and measuring the depth of sealer penetration at 10 mm intervals within the center 5 cm of each treated face. A hand lens is used to measure to the nearest 1mm. The average, minimum and maximum penetration depths are calculated. Care should be taken to avoid measurement affected by aggregate particles. Coating thickness was not measured in this study.

Effect of Freeze-Thaw Exposure on Sealed, Air-Entrained Concrete

Surface applied concrete sealers are exposed to freeze-thaw cycling when applied to PCCPs in Idaho. WJE offers a method to evaluate sealer performance based on determining the difference in performance from an initial 7-day saltwater absorption test and a final 7-day saltwater absorption test after 300 cycles of freeze-thaw exposure based on AASHTO T161 Procedure A (AASHTO 2008). This method does not include measuring length change of the samples as in AASHTO T161. Cube samples (10 cm) are cast, conditioned and sealed as mentioned above using 4 samples for each treatment and control. An initial 7-day saltwater absorption test is performed. Then 300 cycles of freezing-thawing is performed in an environment chamber. A *Cincinnati Sub Zero* Model #: ZH-16-2-H/AC environment chamber was used in this research. In AASHTO T161 Procedure A, samples are submerged in water for the freeze-thaw cycling and are not surrounded by more than 3.2 mm of water (AASHTO 2008). The nominal freezing and thawing cycle of this method consists of alternately lowering the temperature of the specimens from 4 to -18° C and raising it from -18 to 4°C in not less than two nor more than five hours (AASHTO 2008). For this study, the alternating cycles are performed in 4 hours, 2 hours freezing and 2 hours thawing. At every 100 cycles the samples are rinsed, towel dried and weighed. In addition, the visible evidence of distress for each

cube is rated on a scale from 0 to 5 using the Deterioration Rating Scale presented in Table 4.4 below.

Table 4.4 Concrete Deterioration Rating Scale (Krauss 2009)

Scale	Title	Characteristics
0	No scaling	No evidence of deterioration
1	Light scaling	Loss of cement paste around larger of fine aggregate particles or minor fine cracking of the coating. No delamination or loss of coating and no course aggregate particles exposed. Only minor loss of cement paste or coating around edges of sample or at surface voids.
2	Moderate scaling.	Loss of mortar with coarse aggregate particles exposed or clearly visible. Cracking, local delamination or loss of coating integrity in local areas. Loss of mortar or coating around edges of sample or surface voids may be present.
3	Heavy scaling	Loss of mortar around coarse aggregate particles which protrude above adjacent mortar remaining. Loss of bond and loss of coating material exposing areas of the concrete.
4	Severe scaling	Loss of concrete (loss of coarse aggregate particles) and cracking of concrete. Includes cracking and disintegration of coarse and fine aggregate particles. Major cracking or loss of coating integrity.
5	Failure	Fracture or disintegration of specimen into two or more pieces.

At the conclusion of the freeze thaw cycling, the weight loss expressed as percentage of original weight is calculated using Equation 4.20.

$$\Delta W_{FT} = \left(\frac{W_{FT0} - W_{FT}}{W_{FT0}}\right) * 100 \;\; as\ percent\ (\%)$$

where:

ΔW_{FT} = Weight loss after freeze-thaw cycling (%)

W_{FT0} = Weight before freezing and thawing exposure (g)

W_{FT} = Weight after freezing and thawing exposure (g)

Equation 4.20 Weight Loss Freeze Thaw Test (Krauss 2009)

The mean weight loss percentage for the treated and untreated are calculated to determine the freeze-thaw weight loss ratio (FTR) using Equation 4.21.

$$FTR = \left(\frac{\Delta W_{FT-treated-m}}{\Delta W_{FT-untreated-m}}\right) * 100 \ \ as\ percent\ (\%)$$

where:

FTR = Freeze-thaw weight loss ratio (%)

$\Delta W_{FT\text{-}treated\text{-}m}$ = Mean weight loss after freeze-thaw cycling for treated samples (%)

$\Delta W_{FT\text{-}untreated\text{-}m}$ = Mean weight loss after freeze-thaw cycling for untreated samples (%)

Equation 4.21 Freeze Thaw Weight Loss Ratio (Krauss 2009)

Samples are, then, dried in an oven at 60°C until reaching their target weight before the first saltwater absorption test less the weight lost during the cyclic freezing exposure. Thereafter, a final 7-day saltwater absorption test is performed. The mean weight gain for the treated and untreated samples is calculated. The saltwater absorption ratio after freezing-thawing (SAR_{FT}) is calculated using Equation 4.22.

$$SAR_{FT} = \left(\frac{\Delta W_{i7-treated-FT-m}}{\Delta W_{i7-untreated-FT-m}}\right) * 100 \ \ as\ percent\ (\%)\ at\ 7\ days$$

where:

SAR_{FT} = Saltwater absorption ratio 7-day after freeze-thaw cycling (%)

$\Delta W_{i7\text{-}treated\text{-}FT\text{-}m}$ = Mean weight gain of treated samples after 7-day saltwater immersion (%)

$\Delta W_{i7\text{-}untreated\text{-}FT\text{-}m}$ = Mean weight gain of untreated samples after 7-day saltwater immersion (%)

Equation 4.22 SAR After Freezing and Thawing Test (Krauss 2009)

Field Testing

As mentioned in the scope, the field testing component of this research is limited in duration. The same sealer treatments were applied in the field as applied in the laboratory. The selected sealer treatments were applied in September 2009. Only one

year has elapsed. As a result, only the initial cores were analyzed for water absorption in this report. Due to the time and expense associated with taking core samples, only one sample per treatment (panel) and one control were extracted at each field site (6 cores per field site) initially. The cores were extracted in November of 2009 by ITD's drilling rig. The depth of penetration of sealant for the silane sealed panels will be determined in the next phase of the study by splitting the initial cores and measuring the penetration depth. This was not performed in this study in order to keep the cores intact for future comparison. Cores will be taken annually for the next several years as part of the next phase of the study to evaluate sealer performance over time. Ideally, a minimum of three core samples from each treated panel and at least two unsealed core samples should be taken for quality assurance/quality control purposes from each location.

For all field sites, surface preparation consisted of hand sweeping followed by using a leaf blower to remove dirt and debris. The field sites were selected primarily with safety and traffic disruption concerns in mind, in order for safe sealer application. Secondarily, the selected locations had a range of concrete age and use patterns. ITD personnel selected the four sites in and around Boise, Idaho. See Appendix E for diagrams of each field site.

Caldwell

The Caldwell site is located on West bound I-84 mile post 27.143, GPS=N43°40”31.1” W116°41’04.0” in a traffic lane that is part of an on ramp onto the interstate. Figure 4.3 illustrates the Caldwell Site (abbreviated CW).

Figure 4.3 Caldwell Site

This PCCP is older, well polished from traffic wear, and in a low state of distress. Silane was applied on Panels CW3, CW4 and CW5 on September 23, 2009 under dry antecedent moisture conditions and a surface temperature of 18°C. Approximately 4.7 liters of silane was applied to each of the three panels measuring approximately 13.4 m^2 each. The following day, epoxy (Panels CW1 and CW4) and HMWM (Panels CW2 and CW3) were applied at 18°C using 5.7 liters for each panel measuring approximately 13.4 m^2. Sand was broadcast on the panels for friction.

I-184 Connector

The Connector site (abbreviated CON)is located on the I-184 Connector where the Fairview onramp joins the Connector immediately prior to the Curtis road Bridge, GPS=N43°37’07.4” W116°14’23.8”. Figure 4.4 illustrates the Connector Site.

Figure 4.4 I-184 Connector Site

This site is located on the shoulder and not in a traffic lane. It is however, exposed to plowing and de-icing salts. This site has a relatively new PCCP in no discernable state of distress. Each panel measures approximately 14 m^2. Silane was applied on Panels CON3, CON4 and CON5 on September 23, 2009 with dry antecedent moisture conditions and a surface temperature of 27°C using 4.7 liters per panel. The following day, epoxy and HMWM were applied to Panels CON1 and CON4 and Panels

CON2 and CON3, respectively at 29°C using 5.7 liters for each panel. Sand was broadcast on the panels for friction.

East Eisenman Bridge

The East Eisenman Bridge site (abbreviated EB) is located East of Boise, GPS N43°30'26.9" W116° 08'32.3". Figure 4.5 illustrates the East Eisenman site.

Figure 4.5 East Eisenmann Bridge Site

Panels are located on the bridge abutments and are in traffic lanes although, traffic is low. This site has a relatively new PCCP in no discernable state of distress. Each panel is irregularly shaped (parallelogram). Silane was applied on Panels EB3 (8 liters), EB4 (8 liters) and EB5 (6.2 liters) on September 23, 2009 under dry antecedent moisture conditions and a surface temperature of 35°C. The following day, epoxy (Panels EB1

and EB4) and HMWM (Panels EB2 and EB3) were applied at 37.8°C. The following amounts of sealers were applied: 8 liters of epoxy to Panel EB1, 9.5 liters of HMWM to Panel EB2, 7.9 liters of HMWM to Panel EB3, and 9.5 liters of epoxy to Panel EB4. Sand was broadcast on the panels for friction. The application temperatures (35 °C) were approaching the upper limit of manufacturer recommendations (37.8°C).

East Boise Port of Entry

The East Boise Port of Entry site (abbreviated POE) is located at the Westbound Port of Entry, GPS=N43°25'56.7" W116°03"26.5". Figure 4.6 illustrates the East Boise Port of Entry site.

Figure 4.6 East Boise Port of Entry

Panels are located in a traffic lane with heavy truck traffic at low speeds. This is a relatively old PCCP that is in a moderate to severe state of distress with considerable oil staining. Each panel is approximately 12.5 m^2. Silane was applied on Panels POE3, POE4 and POE5 (4.25 liters each) on September 23, 2009 under dry antecedent moisture conditions and a surface temperature of 37.8°C. The following day, epoxy (Panels POE1 and POE4= 4.7 liters) and HMWM (Panels POE2 and POE3 = 5.7 liters) were applied at 37.8°C. Sand was broadcast on the panels for friction. The application temperatures were at the upper limit of manufacturer recommendations.

Water absorption

Laboratory analysis for the field sites consisted of evaluating core samples for water absorption using the method offered by WJE in Annex 2 of their report (Krauss 2009). This method is based on Alberta Infrastructure BT005 (Alberta 2000). This is a 24-hour gravimetric determination of a sealers ability to limit the ingress of water. As mentioned before, a minimum of three core samples for each treatment should be analyzed, although the initial cores only represented one sample of each treatment. Core samples are suggested to be 7.6 cm in diameter and need to be a minimum of 5 cm in length. Comparison is made between the absorption of the sealed end and non-sealed end of each core. The non-sealed end acts as the control surface. There are two methods suggested in Alberta BT005: Method A (Non-Traffic Bearing Surfaces) and Method B (Traffic –Bearing Surfaces). The methods differ in that Method B performs an additional 24 hour water immersion after sandblasting the sealed end of the sample to mimic the affects of traffic wear. For the initial cores, Method A was performed as sandblasting the sealed surfaces would have damaged the cores for visual comparison of subsequent cores in the next phase of the study.

Sample Preparation

Field cores are trimmed to 5 cm in length from the sealed surface using a wet diamond saw. The non-sealed saw cut end is lightly sandblasted to open pores plugged from saw cutting. Samples are then oven dried at 70°C by starting the samples in a cold oven and gradually raising the temperature 10°C every hour. Samples are dried until reaching a constant mass representing a 24 hour change of less than 0.2%. The round sides of the cores are, then, sealed with paraffin wax, although for future tests it is

recommended to use 2 coats of epoxy as paraffin can melt, if the samples need to be oven dried after the initial immersion. Immediately prior to immersion in water, the mass (W_0) of each core is weighed.

Method A

The sealed end of each core is immersed in tap water for 24 hours. The cores are supported on glass rods so that the depth of water is approximately 1.3 cm from the sealed end. At 24 hours, the samples are towel dried and weighed. The weight gain is recorded. If the samples have gained more than 2 grams, then they are dried in an oven at 50°C to within 2 grams of the pre-immersion weight (W_0). Otherwise, the samples are ready for immersion. The immersion is repeated for the unsealed end of each core and the weight gain in 24 hours of immersion is calculated. The water absorption ratio is then calculated using Equation 4.23.

$$WAR = \left(\frac{\Delta W_C - \Delta W_S}{\Delta W_C}\right) * 100 \ \ as\ percent\ (\%)$$

where:

WAR = The water absorption ratio (%)

ΔW_C = Weight gain of unsealed end of the core (g)

ΔW_S = Weight gain of the sealed (exposed surface) end of the core (g)

Equation 4.23 Water Absorption Ratio (Krauss 2009)

It should be noted that the WAR differs from the SAR calculated in previous tests in that the mass of water absorbed by the treated sample is subtracted from the mass absorbed by the control sample in the numerator. In the SAR, the mass of water absorbed by the treated sample is the numerator.

Method B

This method is similar to Method A, except the sealed surface is sandblasted to mimic traffic abrasion. Method B exactly follows Method A until prior to immersion of the unsealed end of the core. Instead, for penetrating sealers, the sealed surface is sand blasted evenly to remove 5.5 grams +/- 0.5 grams. For non penetrating sealers (pore blocking or barrier coating), the unsealed control cores are sandblasted at the exposed face until removing 5.5 grams +/- 0.5 grams while recording the weight of sand used to obtain this weight change. This can be accomplished by weighing the sand used before and after reaching the target weight. Then, the same mass of sand is used to sandblast the barrier coating or pore blocker sealed face. The 24 hour immersion test is repeated using the sandblasted sealed face and the weight gain is calculated. Thereafter, a 24 hour immersion of the unsealed end of the core is performed and the weight gain is calculated. The WAR is calculated before and after abrasion using Equation 4.23 and Equation 4.24 respectively.

$$WAR_{abraded} = \left(\frac{\Delta W_C - \Delta W_{SA}}{\Delta W_C}\right) * 100 \ \ as\ percent\ (\%)$$

where:

$WAR_{abraded}$ = Water absorption ratio after abrasion (%)
ΔW_C = Weight gain of unsealed end of the core (g)
ΔW_{SA} = Weight gain of the abraded sealed (exposed surface) end of the core (g)

Equation 4.24 WAR After Abrasion (Krauss 2009)

As mentioned before, the $WAR_{abraded}$ differs from the *SAR* calculations (Equations 4.10, 4.13-4.15).

CHAPTER 5: ANALYSIS OF RESULTS

Laboratory

Vapor Transmission Test

In this study, four separate trials using six samples for each treatment for a total of 24 samples per treatment were evaluated for vapor transmission using the method suggested by WJE. The results are displayed in Table 5.1.

Table 5.1 Cumulative Vapor Transmission Test Results

	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
Mean[a]	0.28	0.22	0.08	0.04	0.08	0.08
Maximum[a]	0.42	0.33	0.13	0.09	0.14	0.12
Minimum[a]	0.09	0.08	0.02	0.01	0.02	0.03
Std. Dev.[a]	0.11	0.09	0.03	0.03	0.03	0.03
DRC(%)	100.00	80.64	28.12	15.67	29.24	28.48

[a]Values in g/(m^2hr)

The drying rate coefficient (DRC) represents the vapor transmission relative to the moisture transmitted by control samples. Several studies suggested that sealers used on PCCPs should have a minimum DRC of 35% (Cady 1994; Rahim et al. 2006). Other than the silane sealer, none of the sealers exhibited the minimum DRC as recommended. Epoxy and HMWM sealers are not known for their ability to transmit moisture and the recommended minimum DRC may not apply, if the PCCP is able to release moisture through other avenues than the sealed surface. For the dual treatments, the silane did not

seem to greatly reduce the breathability of the epoxy or HMWM. Table 5.2 compares the DRC for the individual trials below.

Table 5.2 Mean DRC (%) Results for Vapor Transmission Trials 1-3

Trial	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
1	100	77.8	33.4	20.4	39.6	34.1
2	100	77	27.4	21.5	27.1	27.1
3	100	85	25.7	25.4	24.3	23.8
4	100	86	25.1	24.5	27.2	34.7
Average	100	81.5	27.9	23	29.6	29.9

Potential errors could be attributed to differences in air circulation within the environment chamber.

Salt Water Absorption Test

Six trials were conducted using 3 samples per treatment per trial. Trials 1, 2, 3, and 6 were evaluated using 15% by weight sodium chloride and Trials 4 and 5 were evaluated using a magnesium chloride deicing salt. The magnesium chloride tests were conducted, as magnesium chloride deicing salt is also used by ITD on PCCPs in Idaho. The complete results are displayed in Appendix D and are summarized below.

The moisture content of the treated samples was adjusted to match the moisture content of the untreated samples. This is important, since the SAR is the ratio of the treated to the untreated cubes. If the samples have significantly different moisture contents then the ratio is compromised. The moisture content for each sample was calculated using Equation 5.1.

$$M_c = \left(\frac{W_{i0} - W_{od}}{W_{od}}\right) * 100 \ \ as\ percent\ (\%)$$

where:

M_c = Moisture content

W_{i0} = Weight prior to saltwater immersion (g)

W_{od} = Weight oven dried (g)

Equation 5.1 Moisture Content (Krauss 2009)

The values of the moisture contents of each treatment prior to the saltwater immersion are detailed in Table 5.3. In general, the adjusted moisture contents for each trial were within 0.5% of the control samples.

Table 5.3 Moisture Content (%) Prior to Saltwater Immersion

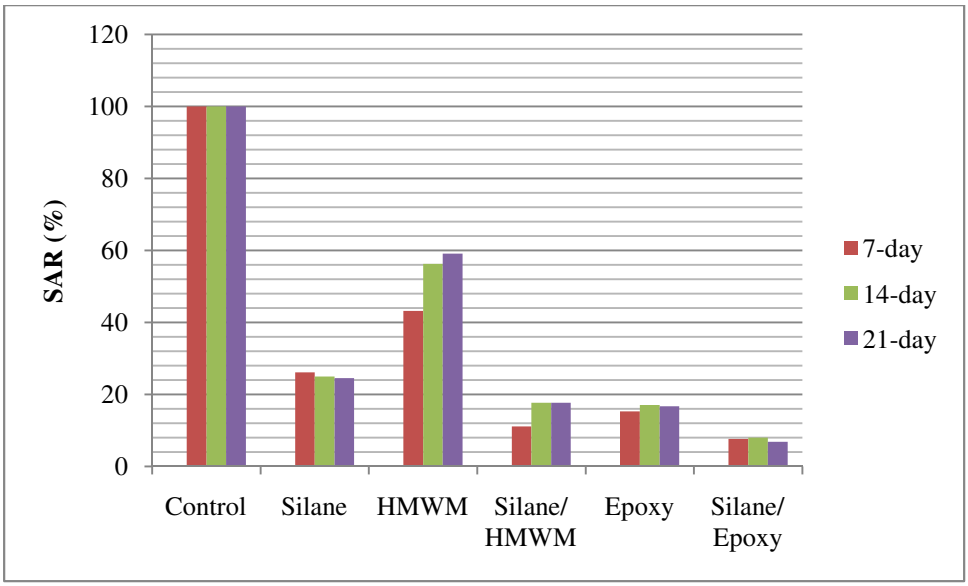
Trial	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
1	3.07	2.95	3.25	3.01	3.40	2.68
2	3.51	3.39	3.49	3.66	3.57	3.29
3	3.11	3.20	3.27	3.36	3.47	3.42
4	3.43	3.46	3.53	3.37	3.38	3.55
5	3.48	3.30	3.57	3.68	3.32	3.40
6	3.29	3.24	3.25	3.15	3.21	2.87
Average	3.32	3.26	3.39	3.37	3.39	3.20

Sodium Chloride 15% by Weight

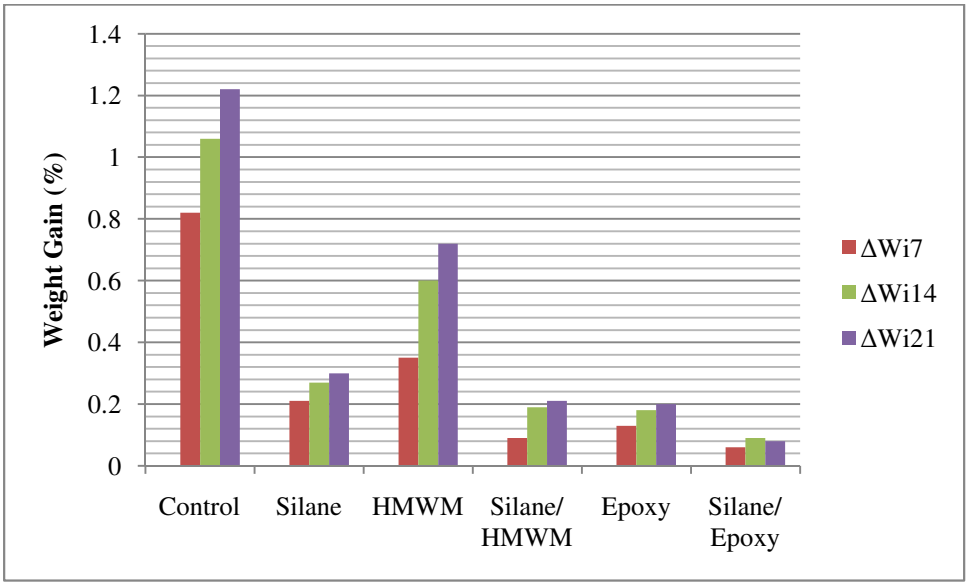
The mean SAR at weekly intervals and the percent weight gain ($\Delta W_{i\#}$) for trials 1, 2, 3 and 6 (using sodium chloride) are displayed in Table 5.4. Graph 5.1 displays the SAR over the 21-day immersion and Graph 5.2 displays the percent weight gain.

Table 5.4 Mean SAR (%) and Weight Gain (%) for Trials 1,2,3, and 6

	SAR				Percent Weight Gain		
Treatment	0-day	7-day	14-day	21-day	ΔW_{i7}	ΔW_{i14}	ΔW_{i21}
Control	0	100	100	100	0.82	1.06	1.22
Silane	0	26	25	25	0.21	0.27	0.3
HMWM	0	43	56	59	0.35	0.6	0.72
Silane/ HMWM	0	11	18	18	0.09	0.19	0.21
Epoxy	0	15	17	17	0.13	0.18	0.2
Silane/ Epoxy	0	8	8	7	0.06	0.09	0.08



Graph 5.1 Mean SAR Trials 1, 2, 3, and 6



Graph 5.2 Mean Weight Gain Trials 1, 2, 3, and 6

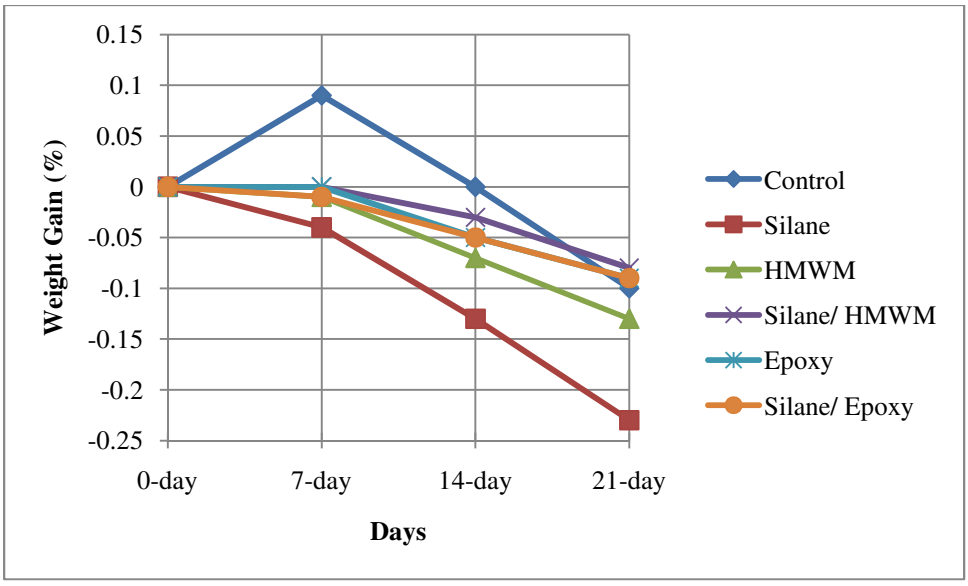
ITD has a material specification for waterproofing concrete materials that requires a percent reduction of water weight gain versus control of 75% using the NCHRP 244 series II with a duration of 21 days (ITD 2010). This test is based on the NCHRP 244 Series II test as explained above. The weight gain versus control can be calculated by

subtracting the SAR for each treatment from 100%. All treatments other than the HMWM met this specification in this study.

Dual or combined treatment systems have great potential for sealing PCCPs. The best performer was the dual treatment using a silane followed by a top coat of epoxy. The significantly improved performance of the silane/HMWM compared with the HMWM displays the benefit of using dual or combined treatments.

Magnesium Chloride

The results of the magnesium chloride tests from Trials 4 and 5 were inconclusive. The same saltwater absorption methods were used with a solution of magnesium chloride deicing salt at full strength in place of the sodium chloride solution. In this experiment, all samples including the control samples lost mass as demonstrated by Graph 5.3.



Graph 5.3 Mean Weight Gain (%) Saltwater Absorption Magnesium Chloride

In contrast, all samples gained mass using sodium chloride. This is a very important observation that needs to be investigated in the next phase of this project. One

possible explanation is that the concentrated magnesium chloride solution caused water vapor loss in the samples to the solution. This would explain how the silane treatment lost the most mass as the silane easily transmits water vapor. The control sample initially gained mass and then demonstrated a steep mass decline in the final week. The full strength solution was tested to mimic how the compounds are applied in the field. In hindsight, use of a diluted solution would better represent field conditions as the solutions are rapidly diluted when applied over ice or after additional precipitation falls on the solution. A recent de-icer study assumed a dilution of 100 to 3, which is the underlying assumption for the de-icer corrosivity test method established by the Pacific Northwest Snowfighters Association (Shi et al.). Additional tests could be conducted in the next phase of the study using a diluted solution to provide a comparison whether the dilution effect alters the vapor transport.

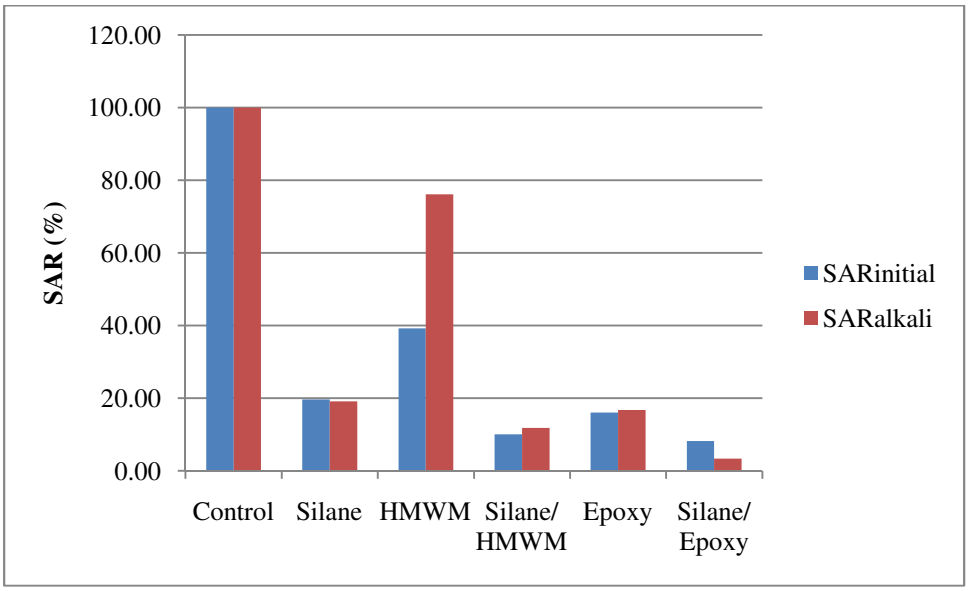
Ideally, the chloride content should be measured using AASHTO T260 after a 21-day saltwater absorption test. This was beyond the resources for the initial phase of the study but would likely provide additional pertinent sealer performance. Chloride analysis was reserved for the UV Exposure/Saltwater ponding tests during this phase of the study.

Alkali Resistance Test

Alkali resistance testing was performed on Trials 1, 2, 3, and 6 and was not performed using the samples treated with magnesium chloride. A total of 12 samples for each treatment were analyzed in Trials 1, 2, 3, and 6. The results are displayed in Table 5.5 and Graph 5.4 below.

Table 5.5 Mean SAR Before and After Alkali Exposure

	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
SARinitial	100.00	19.65	39.24	10.08	16.08	8.27
SARalkali	100.00	19.15	76.15	11.87	16.76	3.37
SARalkali/ SARinitial	1.00	0.97	1.94	1.18	1.04	0.41



Graph 5.4 Mean SAR Before and After Alkali Exposure

The ratio of SAR_{alkali}/ $SAR_{initial}$ displayed in Table 5.5 demonstrates the effect of an alkaline environment on sealer performance. The alkaline environment did not affect the silane treatment. Interestingly, alkali exposure reduced the SAR for the silane/epoxy treatments. The HMWM experienced a notable increase in SAR.

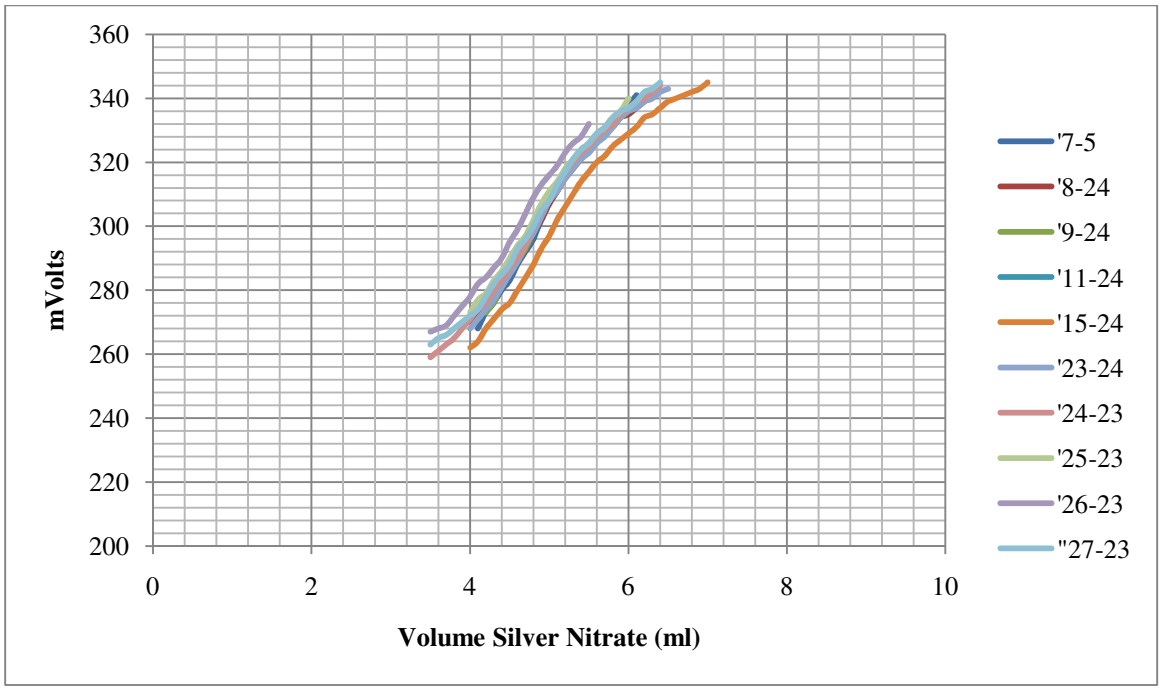
Weathering and Saltwater Resistance Test

Three separate 14 week trials using 3 samples per treatment were conducted in this research. Due to time and budgeting constraints, only samples from Trial 2 were

analyzed for chloride content at the time of this report. The remaining Trials will be processed in the next phase of the study. Three separate samples from each type of treatment in Trial 2 were analyzed. The chloride content of the concrete before ponding was determined by sampling ten random cubes from multiple batches of concrete that utilized the same mix-design, aggregates, cement, and water source. The percent chloride (Equation 4.16) and the titration curves are displayed in Table 5.6 and Graph 5.5 below for the raw concrete. The mean raw concrete chloride content was 0.01 % or 0.23 kg/m^3 assuming a unit weight for concrete of 2323 kg/m^3.

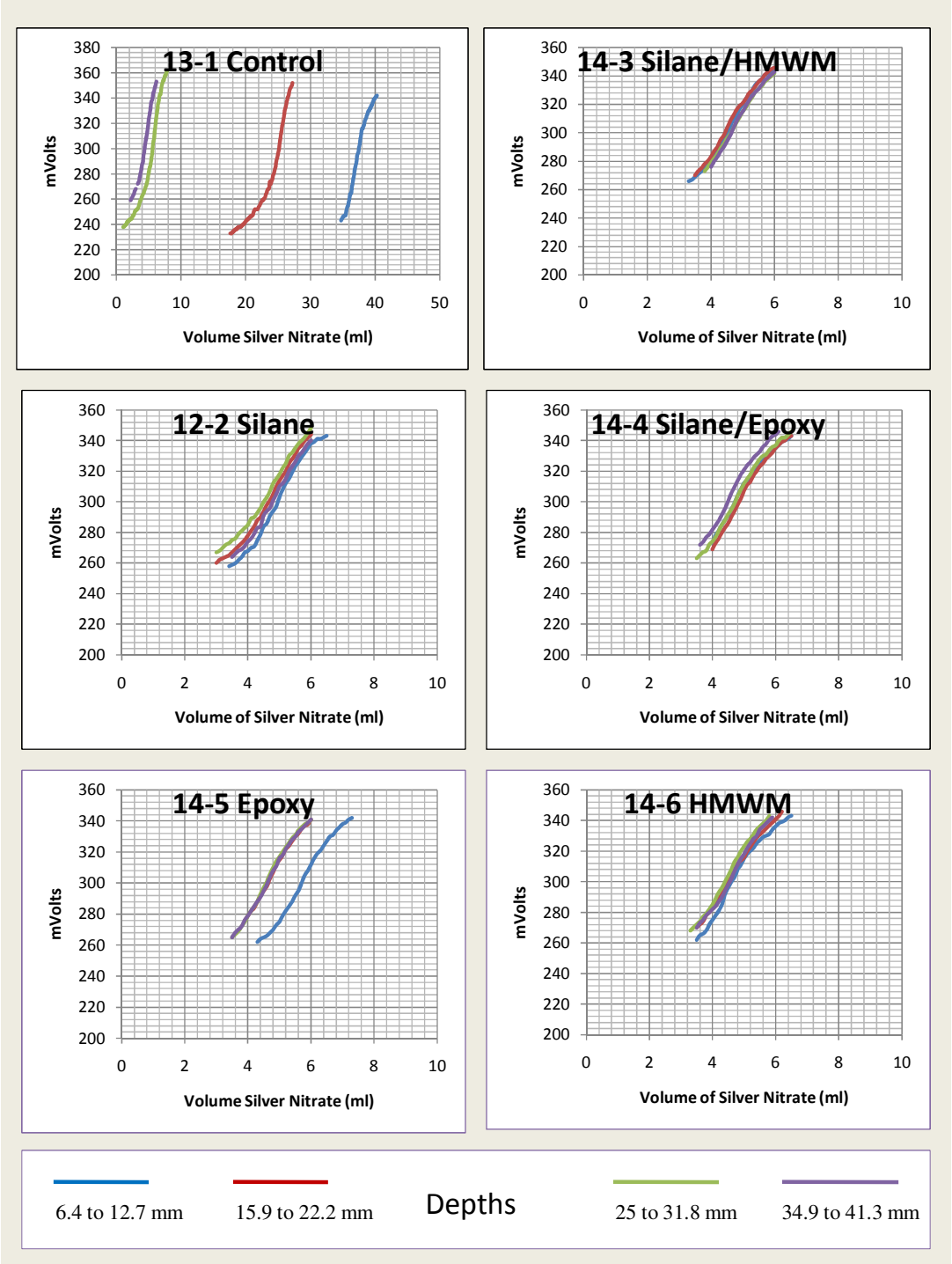
Table 5.6 Raw Concrete Chloride Calculations

	Sample									
	7-15	8-24	9-24	11-24	15-24	23-24	24-23	25-23	26-23	27-23
V_{AgNO3} (ml)	4.9	4.9	4.9	4.9	5.1	4.9	4.8	4.8	4.7	4.9
N_{AgNO4}	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
V_{NaCl} (ml)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
N_{NaCl}	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
W (g)	3.002	3.004	3.002	3.003	3.003	3.001	3.002	3.004	3.001	3.003
Cl (%)	0.010	0.010	0.010	0.010	0.013	0.010	0.009	0.009	0.008	0.010
		Mean Cl (%)		0.010						



Graph 5.5 Raw Concrete Chloride Titration Curves

Typical titration curves for the five different treatments and control samples at the conclusion of the test for Trial 2 are displayed in Graph 5.6.



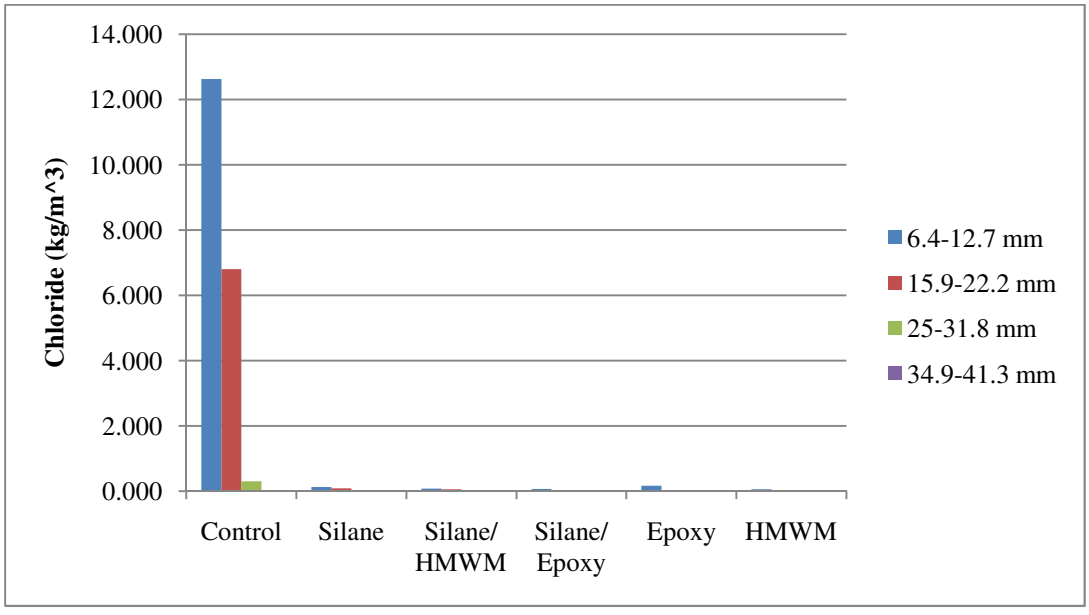
Graph 5.6 Typical Chloride Titration Curves Using AASHTO T260

Comparison of the raw chloride samples (Graph 5.5) and the treated samples titration curves at the conclusion of the tests (Graph 5.6), demonstrates the lack of

chloride penetration in treated samples. The graphs are very similar; chloride content is at or very near baseline values for treated samples regardless of type. Control samples absorbed chloride significantly from 6.4 mm to 22.2 mm, limited absorption from 25 mm to 31.8 mm and no absorption from 34.9 mm to 41.3 mm. The mean chloride concentrations are displayed in Table 5.7 and Graph 5.7.

Table 5.7 Chloride Content in Concrete from Weathering/Saltwater Resistance Test (kg/m^3)

Depth	Control	Silane	Silane/ HMWM	Silane/ Epoxy	Epoxy	HMWM
6.4-12.7 mm	12.624	0.128	0.082	0.072	0.165	0.063
15.9-22.2 mm	6.806	0.091	0.063	0.035	0.035	0.035
25-31.8 mm	0.304	0.026	0.035	0.008	0.007	0.007
34.9-41.3 mm	0.000	0.000	0.000	0.017	0.000	0.007



Graph 5.7 Chloride Content in Concrete from Weathering/Saltwater Resistance

The mean relative chloride ratio (Equation 4.19) and mean total chloride content (Equation 4.18) are displayed in Table 5.8.

Table 5.8 Relative Chloride Ratio and Total Chloride Weathering/Saltwater Resistance

	Control	Silane	Silane/ HMWM	Silane/ Epoxy	Epoxy	HMWM
RCR (%)	100	1.308	0.994	0.651	0.924	0.577
TCw (kg/m2)	0.1277	0.0017	0.0013	0.0008	0.0012	0.0007

The TCw is the total amount of chloride in the depth profile sampled from 6.4 mm to 41.3 mm. As the chloride content in the treated samples were at or near raw concrete levels, variation in the results is possible. For instance, the HMWM shows less TC_w than the silane/HMWM sample. In all other tests, the dual treatment performed better than the HMWM.

The RCR demonstrates that regardless of treatment type, the concrete sealers selected were at or near a 99% reduction of chloride absorbed. Concrete sealers demonstrate the ability to significantly decrease chloride absorption in PCCP and have the potential to protect PCCP from reinforcing steel from corrosion due to de-icing salts.

Depth of Penetration

Only silane samples exhibited discernable penetration depths and were the only samples measured. The epoxy and HMWM only had measurable penetration where surface voids were located. The coating thickness for epoxy and HMWM was not measured in this study. In total, 144 measurements were made on 6 different silane treated cube samples. *McCormick* brand red food coloring was used as the dye. The results are displayed in Table 5.9 and an illustration of a silane penetration is displayed in Figure 5.1.

Table 5.9 Penetration Depth of Silane

Treatment	Mean (mm)	Max (mm)	Min (mm)	Total Measurements (quantity)
Silane	3.66	9.00	2.00	144.00

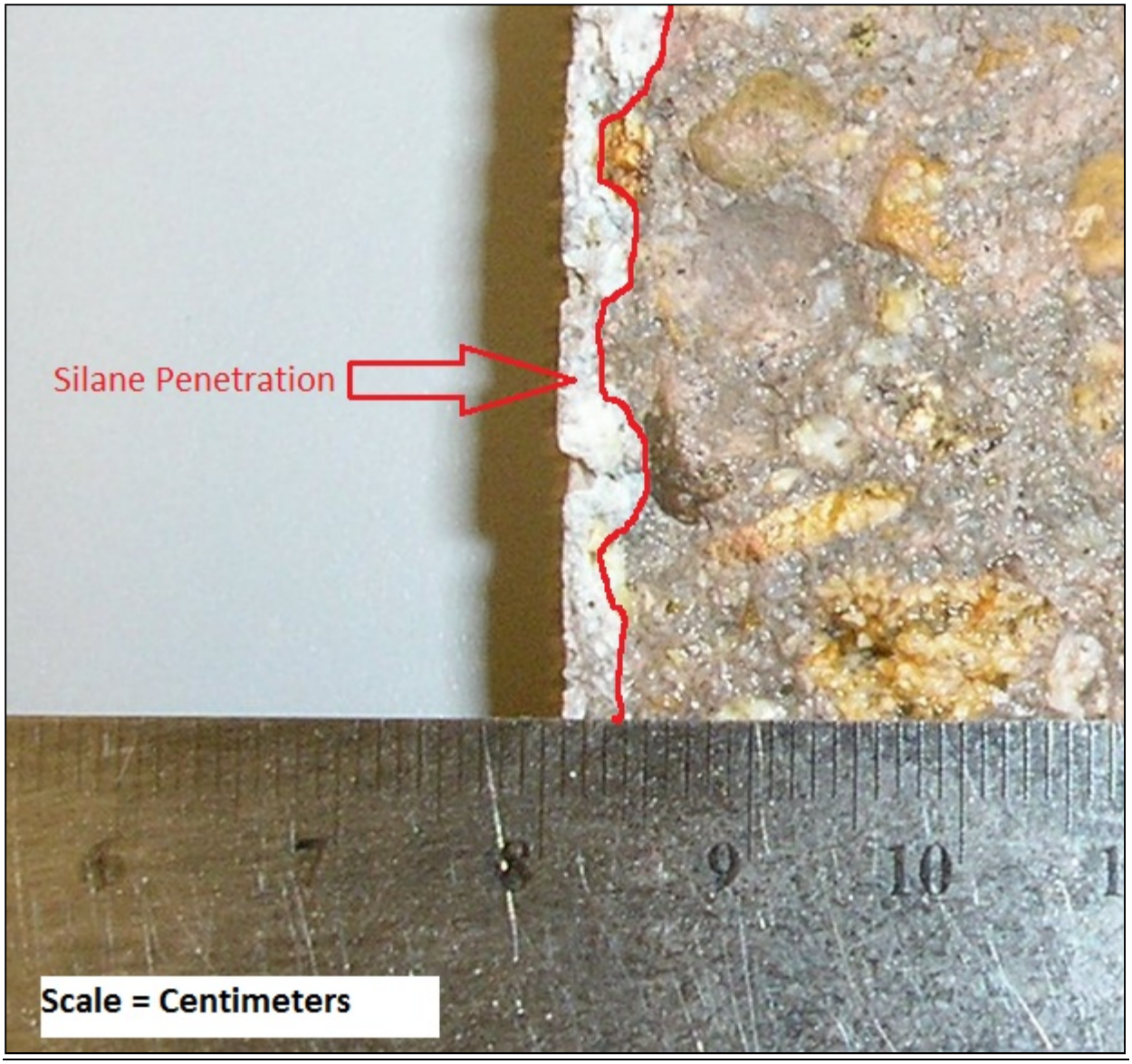


Figure 5.1 Silane Penetration in a Silane Sealed Sample

Figure 5.1 highlights the variability encountered while measuring penetration depth. Aggregates and void space can influence the depth of penetration measurement. ITD's specification for penetrating concrete sealers calls for a minimum penetration depth of 3.8 mm (ITD 2010). The average value encountered in this study from 144 measurement points, 3.66 mm, was less than the required specification. However, it is likely different results could be obtained if the test was repeated on other samples.

Several studies highlight the variability in penetration depth measurements for water repellent sealers (Johnson et al. 2009; Pincheira et al. 2005). Pincheira et al. 2005, observed that the sealants with the largest penetration depths had the lowest ratios of absorbed chloride content (Pincheira et al. 2005).

Freeze Thaw Cycling Test

Three trials were performed for a total of 11 data points for each treatment. The results are summarized in Table 5.10.

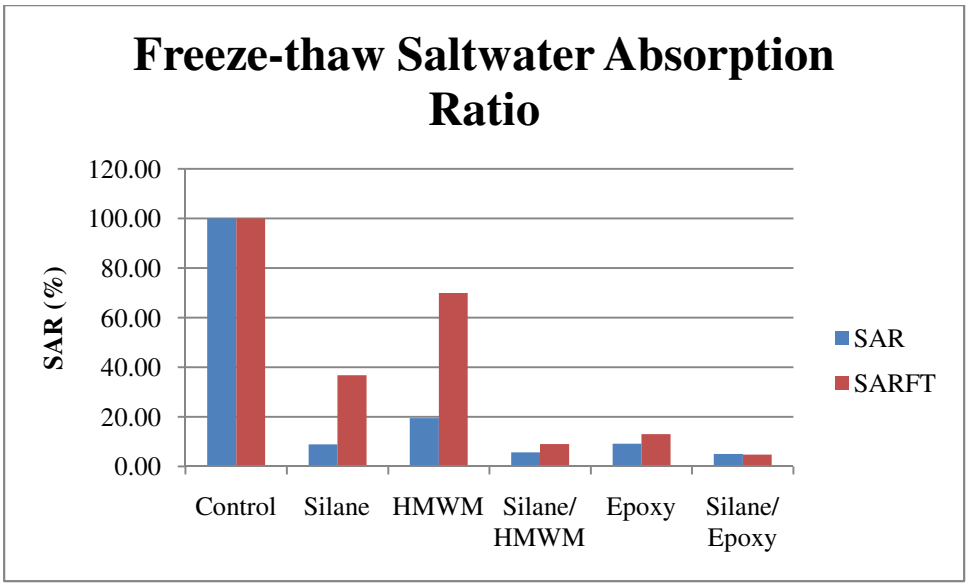
Table 5.10 Mean Freeze-Thaw Performance

	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
Deterioration Rating (1-5)	2.00	2.27	0.45	0.45	0.36	0.45
ΔW_{WT}	0.92	2.26	-1.01	-0.65	-0.54	-0.39
FTR	100.00	246.54	-110.86	-70.80	-59.35	-42.34
SAR	100.00	8.95	19.43	5.60	9.15	4.99
SAR_{FT}	100.00	36.71	69.85	8.97	12.97	4.73
SAR_{FT}/ SAR	1.00	4.10	3.60	1.60	1.42	0.95

The term, ΔW_{WT}, refers to the percent weight loss after freeze-thaw cycling. Negative values for ΔW_{WT} and the freeze thaw ratio (FTR) indicate weight gain rather than weight loss. Control and silane samples had a significant paste loss with the silane losing the most paste as demonstrated by the FTR of 187%. However, the SAR_{FT} for silane indicates a 73% reduction in saltwater absorption relative to control samples. The penetration depth of the silane was beyond the paste lost during freeze-thaw cycling and the sealer still functioned. Figure 5.2 shows a before and after freeze-thaw cycling for a silane sample.

Figure 5.2 Silane Before and After 300 Freeze-Thaw Cycles

The HMWM and epoxy treatments showed occasional coating delamination where small voids occurred on the samples from air pockets created during casting. This did not affect the performance of the epoxy samples. The HMWM had a significant increase in saltwater absorption as indicated in Graph 5.8.



Graph 5.8 Mean SAR and SAR_{FT}

Saltwater Absorption Ratio

The alkali resistance, saltwater absorption, and freeze-thaw resistance tests underwent an identical 7-day saltwater absorption test. The calculated SAR values had considerable variability throughout each trial of each test. Table 5.11 summarizes the statistics of the 7-day SAR values for 11 different 7-day saltwater absorption tests.

Table 5.11. SAR (%) of 7-day Saltwater Absorption Tests of 11 Different Trials

	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
Mean	24.83	42.65	11.33	14.99	7.77
Std Dev	23.33	21.63	8.66	7.09	4.19
Max	80.22	71.45	30.47	24.48	15.10
Min	7.47	13.77	3.36	7.64	2.39

This discrepancy is primarily a result of the amount of water absorbed by the control sample during each test. Table 5.12 displays weight gain statistics of 35 samples of each treatment that underwent a 7-day saltwater absorption test.

Table 5.12 Weight Gain (g) of 7-day Saltwater Absorption Tests of 35 Samples

	Control	Silane	HMWM	HMWM/ Silane	Epoxy	Epoxy/ Silane
Mean	22.96	3.91	7.88	1.96	2.87	1.49
Std Dev	9.49	1.60	3.11	0.81	0.83	0.71
Max	34.60	7.99	14.87	3.52	4.77	3.18
Min	8.78	2.03	3.63	0.65	1.68	0.66

Field

Only one core sample for each treatment at each location was analyzed for water absorption. Table 5.13 and Table 5.14 display the WAR and the weight gain respectively for the field samples at an age two months after application.

Table 5.13 Water Absorption Ratio (WAR) of Field Samples Taken 2 Months after Application

Location	Unsealed control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
Caldwell	64.83	77.61	79.26	83.09	73.85	89.03
POE	66.47	88.71	80.89	92.13	86.05	89.98
Eisenmann	-5.29	88.47	79.21	97.01	58.67	92.57
Connector	53.55	83.18	79.61	87.99	86.63	94.70

Table 5.14 Weight Gain (%) of Field Samples Taken 2 Months after Application

Location	Unsealed control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
Caldwell	4.68	2.98	2.76	2.25	3.48	1.46
POE	5.79	1.95	3.30	1.36	2.41	1.73
Eisenmann	24.66	2.70	4.87	0.70	9.68	1.74
Connector	7.54	2.73	3.31	1.95	2.17	0.86

As mentioned in Chapter 4, the WAR value differs from SAR values calculated in other tests. The WAR represents a percent reduction of the water absorption of the saw

cut ends of the field cores, while the SAR represents the ratio of the weight gain of sealed samples versus the weight gain of control samples. For example, at the Caldwell site, the silane sealer reduced the water absorbed by 77.61% compared to the amount absorbed by the saw cut end. For the unsealed (control) core samples, a significant reduction in water absorption was observed compared to the saw cut ends of the cores. It is likely the pores on the traffic exposed face of the cores were filled with debris and reduced the amount of water absorbed.

Future core samples will be tested and compared with these baseline values in the next phase of the study. The Eisenmann Bridge site had two values, unsealed control and epoxy, with potentially erroneous values. The unsealed control sample had a much larger weight gain than the saw cut end resulting in a negative WAR value. The epoxy also had a significant amount of weight gain resulting in a low WAR value. More initial core samples would have been beneficial to analyze these anomalies; however, only one sample was extracted for each treatment.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

In this study, five different surface applied concrete sealer treatments were evaluated in the laboratory for water vapor transmission, saltwater absorption, alkali resistance, UV exposure and cyclic saltwater ponding, penetration depth, and freeze-thaw cycling resistance. The performance of each treatment was measured relative to the performance of unsealed control samples with the exception of the depth of penetration test. In addition, the same treatments were applied at four different field sites near Boise, Idaho to instigate a long term field evaluation of surface applied concrete sealers in Idaho. The treatments consisted of: (i) an epoxy, (ii) a silane, (iii) a high molecular weight methacrylate (HMWM), (iv) a base coat of silane with a top coat of epoxy, and (v) a base coat of silane with a top coat of HMWM. Only one brand from each sealer class was tested, and the results of this study do not intend to represent the general performance of all products within each class of sealer.

In the laboratory tests, the best performance for saltwater absorption, alkali resistance, and freeze-thaw cycling was obtained by dual treatments consisting of a silane base coat followed by an epoxy or HMWM top coat. The silane/epoxy exhibited better performance than silane/HMWM. The same performance from dual treatment systems was observed on water absorption tests performed on the early age core samples extracted and tested from the four field sites. Dual treatments offer the benefits of a deck

sealing penetrating sealer (silane) and a crack sealer (epoxy and HMWM), at limiting water and chloride ingress into PCCPs. In single sealer treatments, the best performance was observed, in descending order by epoxy, silane and HMWM for saltwater absorption, alkali resistance, and freeze-thaw cycling. Only the silane sealer exhibited a consistently measurable depth of penetration and was the only sealer that exhibited greater than 35% vapor transmission ability relative to control samples.

Based on the results of the laboratory tests, the following recommendations can be made:

1. Dual treatment systems consisting of a silane base coat and an epoxy or HMWM top coat appear to provide the best protection to seal decks and existing cracks in PCCP.
2. If the concrete pavement or bridge deck cannot transmit water vapor through surfaces other than the sealed surface, then a silane or a sealer that allows at least 35% water vapor transmission relative to control samples is recommended.
3. In the next phase of the study, chloride concentration analysis at the conclusion of the 21-day saltwater absorption test would yield additional information about sealer performance.
4. Utilizing a test, in the next phase of the study, to mimic the affect of surface wear on sealer performance would also yield valuable information. WJE suggests using a sandblasting method using a known volume of sand to abrade the treated sample surface. An initial 7-day saltwater absorption test followed by a second 7-day immersion after sand blasting would yield sealer performance after simulated traffic wear.

Based upon the literature review, these additional recommendations can be made:

1. Early application of sealers in the life of PCCPs (age 3 to 6 months) has the best potential for increasing service life. Sealers, applied to PCCPs in a moderate state

of deterioration, can provide increased service life but, may not arrest deterioration mechanisms already in progress.

2. Surface preparation, following manufacturer suggestions, is recommended to achieve the best performance. If a sealer is applied to seal cracks, the cracks need to be free of debris for the best chance of success.
3. If a PCCP, exposed to traffic, has a low amount of cracks that are not of concern, then a silane sealer is recommended, since barrier coatings would likely wear off in a few years; a deep penetrating silane sealer would offer a longer service life before needing reapplication and would allow vapor transmission.
4. Adopting a standard method of test, such as the methods offered by WJE, would facilitate selection and product evaluation for transportation agencies in the future.

CHAPTER 7: IMPLEMENTATION PLAN

Sealer Selection

A concrete sealer that performs the best in laboratory tests may not perform as well in the field. Determining the best performing compounds in the laboratory should be followed by field trials on the PCCP to be sealed to confirm performance. Selecting the best surface applied concrete sealing product for application can be facilitated by the following process.

1. Identify classes of compounds for desired application
    a) Evaluate condition of PCCP: low, moderate or severe state of deterioration, as well as age, service environment, and water vapor transmission requirements;
    b) Determine if the goal is to seal cracks, generally seal the concrete deck, or both;
    c) Select gravity fill crack sealers, penetrating deck sealers, or both.
2. Perform universal tests in the laboratory using multiple brands of each class of sealer
    a) Water vapor transmission test: Does the sealer exhibit at least a 35% vapor transmission relative to control samples if water vapor transmission is a concern?
    b) Saltwater absorption test: Can the sealer limit water absorption by 75% relative to control samples?
    c) Sandblast samples and repeat saltwater absorption test: Can the sealer limit water absorption by 75% relative to control samples?
    d) Chloride content test: Can the sealer limit chloride ingress by 75% relative to control samples?

e) Alkali resistance test: Does the sealer's saltwater absorption increase after alkali exposure?
f) Depth of penetration: If a penetrating sealer, does the sealer have an average penetration depth >3.8 mm?
g) UV weathering and cyclic saltwater ponding: Does the sealer exhibit visual deterioration and does it reduce chloride content by 75% relative to control samples?
h) Freeze-thaw resistance: Does the sealer reduce saltwater absorption by 75% relative to control samples after 300 cycles of freezing and thawing?

3. Select best products tested in the laboratory and apply to test sections in the field where products are to be used
    a) Extract a minimum of three core samples for each sealer used
    b) Test for water absorption before and after abrasion using Alberta BT005 Method B: Can sealer limit water absorption relative to control by 82.5% before sandblasting and by 75% after sandblasting?
    c) Select best performing product for application

REFERENCES

AASHTO. 2005. AASHTO T260 Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials. In *AASHTO T 260-97*: American Association of State Highway Transportation Officials.

———. 2006. AASHTO T259 Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration. In *AASHTO T259*: American Association of State Highway Transportation Officials.

———. 2008. AASHTO T161 Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing. In *AASHTO T161*: American Association of State Highway and Transportation Officials
.

Alberta. 2000. BT001 Test Procedure For Measuring the Vapor Transmission, Waterproofing and Hiding Power of Concrete Sealers. In *Alberta BT001*: Alberta Transportation
.

———. 2000. BT005 Test Procedure for Measuring the Waterproofing Performance of Core Samples Taken From Sealed Concrete Surfaces. In *Alberta BT005*: Alberta Transportation.

ASTM. 2008. ASTM C666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing. In *ASTM C666*: American Society for Testing and Materials.

Attanayake, Upul, Xuemei Liang, Simon Ng, and Haluk Aktan. 2006. Penetrating Sealants for Concrete Bridge Decks---Selection Procedure. *Journal of Bridge Engineering* 11 (5):533-540.

Basheer, L., and D. J. Cleland. 2006. Freeze-thaw resistance of concretes treated with pore liners. *Construction and Building Materials* 20 (10):990-998.

Bush, Thomas D. Jr. 1998. Laboratory Test Procedures for Evaluating Concrete Treated with Sealers. *American Concrete Institute Materials Journal* 95 (4):436-444.

Cady, Philip D. 1994. *Sealers for Portland cement concrete highway facilities*. Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program.

ITD. 2010. Standard Specification for Highway Construction. Boise, Idaho: State of Idaho Transportation Department (ITD).

Johnson, Karl, Section Minnesota. Dept. of Transportation. Research Services, Engineering University of Minnesota. Dept. of Civil, and Board Minnesota Local Road Research. 2009. *Crack and concrete deck sealant performance*. St. Paul, Minn.; Springfield, Va.: Minnesota Department of Transportation, Research Services Section ; Available through the National Technical Information Service.

Krauss, P. D., Lawler, J., Steiner, K. 2009. Proposed Testing Protocols for Surface Applied Concrete Sealers. In *NCHRP Project 20-07 Task 235 TRB,*. Northbrook, Illinois: Wiss, Janney, Elstner Associates, Inc.

Krauss, P. D., J. Mallela, Brian D. Aho, Engineering United States. Federal Highway Administration. Office of, Research Highway Operations, Development, Janney Elstner Wiss, Associates, and Eres Division Applied Research Associates. 2006. *Highway concrete pavement technology development and testing, field evaluation of Strategic Highway Research Program (SHRP) C-202 test sites (alkali-silica reaction (ASR) volume 1*. McLean, Va.: Research, Development, and Technology, Turner-Fairbank Highway Research Center.

LaRosa Thompson, J., M. R. Sisbee, P. J. Gill, B. E. Scheetz, and Symposium. 1997. Characterization of Silicate Sealers on Concrete.

Medeiros, M. H. F., and P. Helene. 2009. Surface treatment of reinforced concrete in marine environment: Influence on chloride diffusion coefficient and capillary water absorption. *Construction and Building Materials* 23 (3):1476-1484.

Medeiros, M., and P. Helene. 2008. Efficacy of surface hydrophobic agents in reducing water and chloride ion penetration in concrete. *Materials and Structures* 41 (1):59-71.

Meggers, David A. 1998. *Crack Sealing and Repair of Older Serviceable Bridges Using Polymer Sealers*.

Miller, John S., Bellinger, William Y. 2003. Distress Identification Manual for the Long-Term Pavement Performance Program, edited by U. S. D. o. Transportation: Federal Highway Administration.

ODOT. 1982. Test for Depth of Penetration of Concrete by Penetrating Water Repellent Treatment Solutions. Oklahoma City, Oklahoma: Oklahoma Department of Transportation.

Pfeifer, D. W., M. J. Scali, Highway American Association of State, Officials Transportation, and Administration United States. Federal Highway. 1981. *Concrete sealers for protection of bridge structures*. Washington, D.C.: Transportation Research Board, National Research Council.

Pincheira, José A., Melissa A. Dorshorst, Transportation Wisconsin. Dept. of, Civil University of Wisconsin--Madison. Dept. of, Engineering Environmental, and Program Wisconsin Highway Research. 2005. *Evaluation of concrete deck and crack sealers*. [Madison, Wis.?]; Springfield, VA: Wisconsin Highway Research Program ; Available through the National Technical Information Service.

Rahim, Ashraf M., Daniel C. Jansen, Nagi A. Abo-Shadi, Services California. Dept. of Transportation. Division of Engineering, San Luis Obispo Dept of Civil California Polytechnic State University, and Engineering Environmental. 2006. *Concrete bridge deck crack sealing an overview of research*. San Luis Obispo, CA: California Polytechnic State University, Civil and Environmental Engineering.

Shi, X., L. Fay, M. M. Peterson, and Z. Yang. Freeze-thaw damage and chemical change of a portland cement concrete in the presence of diluted deicers. *Materials and Structures* 43 (7):933-946.

Soriano, Ariel 2003. Alternative Sealants for Bridge Decks: Final Report, edited by S. D. D. o. Transportation. Pierre, SD.

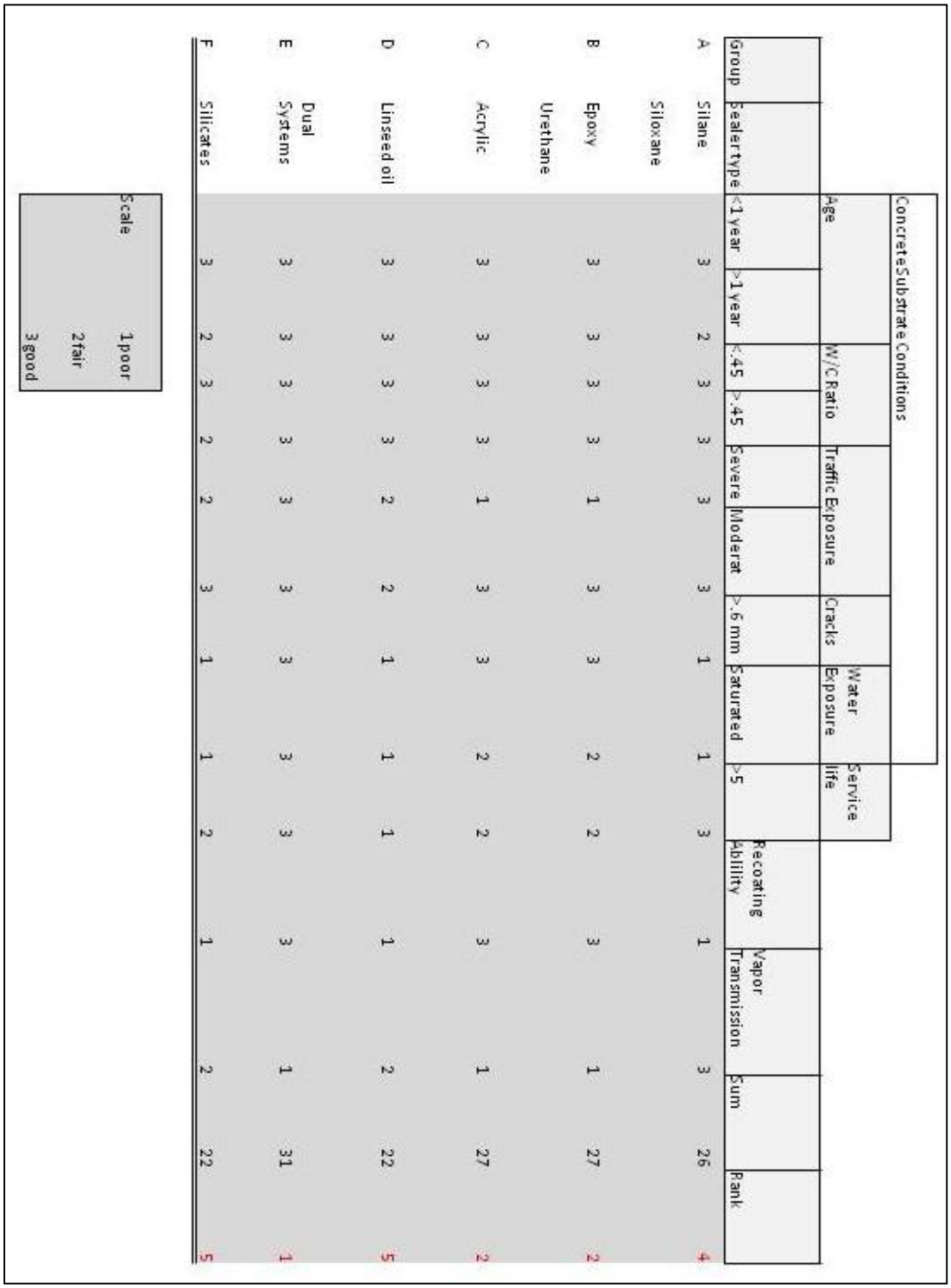
Wenzlick, John D. 2007. *Bridge deck concrete sealers*. Jefferson City, Mo.: Missouri Dept. of Transportation.

Weyers, Richard E. 2005. Concrete sealers: Use and selection. *International journal of materials and product technology* 23:177-186.

APPENDIX A

Sealer Selection Matrix

Table A.1 Sealer Selection Matrix



		Concrete Substrate Conditions											
		Age		W/C Ratio	Traffic Exposure		Cracks	Water Exposure	Service life	Recoating Ability	Vapor Transmission	Sum	Rank
Group	Sealertype	<1 year	>1 year	<.45	>.45	Severe	Moderat	>.6 mm	Saturated	>5			
A	Silane	3	2	3	3	3	3	1	1	3	1	3	26	4
	Siloxane													
B	Epoxy	3	3	3	3	1	3	3	2	2	3	1	27	2
	Urethane													
C	Acrylic	3	3	3	3	1	3	3	2	2	3	1	27	2
D	Linseed oil	3	3	3	3	2	2	1	1	1	1	2	22	5
E	Dual Systems	3	3	3	3	3	3	3	3	3	3	1	31	1
F	Silicates	3	2	3	2	2	3	1	1	2	1	2	22	5

Scale	
1	poor
2	fair
3	good

APPENDIX B

Laboratory Concrete

Raw Materials

Coarse Aggregates

Source:

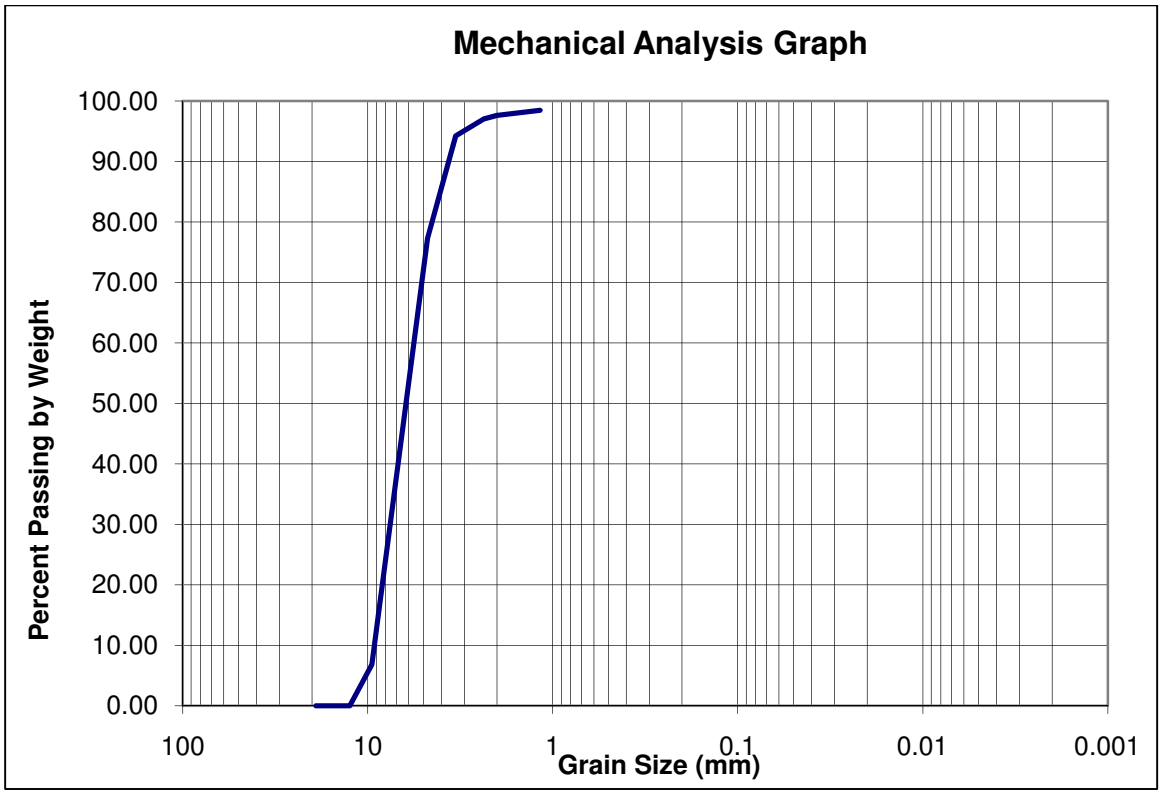
Idaho Concrete Company

2755 E State St
Eagle, ID
83616-6225

Gradation:

Table B1 Sieve Analysis Coarse Aggregates

Sieve No.	Sieve Opening (mm)	Mass of Soil Retained	% Retained	Cumulative % Retained	% Finer
3/4	19.1	0.00	0.00	0.00	100.00
1/2	12.5	0.00	0.00	0.00	100.00
3/8	9.51	272.42	6.82	6.82	93.18
4	4.75	2811.84	70.44	77.27	22.73
6	3.35	676.60	16.95	94.22	5.78
8	2.36	111.16	2.78	97.00	3.00
10	2	23.30	0.58	97.59	2.41
14	1.168	33.83	0.85	98.43	1.57
pan		62.55	1.57	100.00	0.00



Graph B.1 Coarse Aggregate

Fine Aggregates

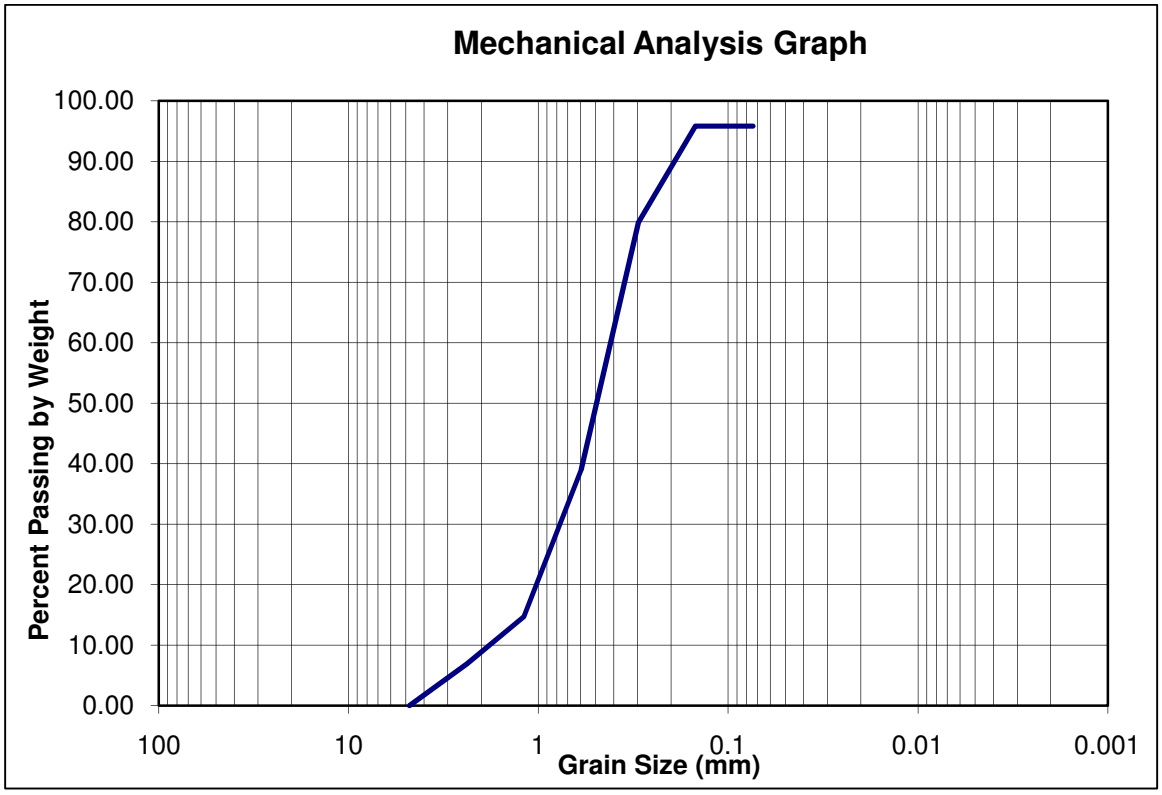
Source:

Idaho Concrete Company

2755 E State St
Eagle, ID,
83616-6225

Table B.2 Fine Aggregate Sieve Analysis

Sieve No.	Sieve Opening (mm)	Mass of Soil Retained	% Retained	Cumulative % Retained	% Finer
4	**4.76**	0.00	0.00	**0.00**	100.00
8	**2.38**	34.20	6.85	**6.85**	93.15
16	**1.19**	39.07	7.82	**14.67**	85.33
30	**0.595**	121.44	24.31	**38.97**	61.03
50	**0.297**	204.22	40.88	**79.85**	20.15
100	**0.149**	79.56	15.93	**95.78**	4.22
200	**0.074**	0.00	0.00	**95.78**	4.22
Pan		21.09	4.22	100.00	0.00



Graph B.2 Fine Aggregate

Cement

Source:

Ashgrove Type I/II

Mill Certificate:

Being processed

Admixtures

Air Entrainment

BASF Micro Air

BASF
The Chemical Company

Safety data sheet
MICRO AIR®

Revision date : 2009/05/20 Page: 1/6
Version: 1.0 (30337840/SDS_GEN_US/EN)

1. Substance/preparation and company identification

Company
BASF Construction Chemicals
100 Campus Drive
Florham Park, NJ 07932

24 Hour Emergency Response Information
CHEMTREC: 1-800-424-9300
BASF HOTLINE: 1-800-832-HELP

2. Composition/information on ingredients

CAS Number	Content (W/W)	Chemical name
61790-12-3	5.0 - 10.0 %	Tall oil, fatty acids
25322-68-3	1.0 - 5.0 %	Polyethylene glycol

Safety data sheet
MICRO AIR®

Odour:	No data available.	
Colour:	brown	
pH value:	10.7 - 12.3	(25 °C)
Boiling point:	105 °C	
Vapour pressure:		No data available.
Density:	1.01 g/cm3	
Vapour density:		Heavier than air.
Partitioning coefficient n-octanol/water (log Pow):		No data available.
Viscosity, dynamic:		No data available.
Solubility in water:		completely soluble

Mix Design

The mix design was based on Table 4.. A 40% fine aggregate to 60% coarse aggregate percentage was used. The mix design was based on a 5600 psi compressive strength and is displayed in the table below.

Table B.3 Sample Mix Design

Coarse Aggregate	Fine Aggregate	Cement	Water	Air Entrainment
(lbs/ft^3)	(lbs/ft^3)	(lbs/ft^3)	(lbs/ft^3)	(ml/ft^3)
65.7	44.2	24.4	10.25	7

Additional water was added to meet a slump average of 1".

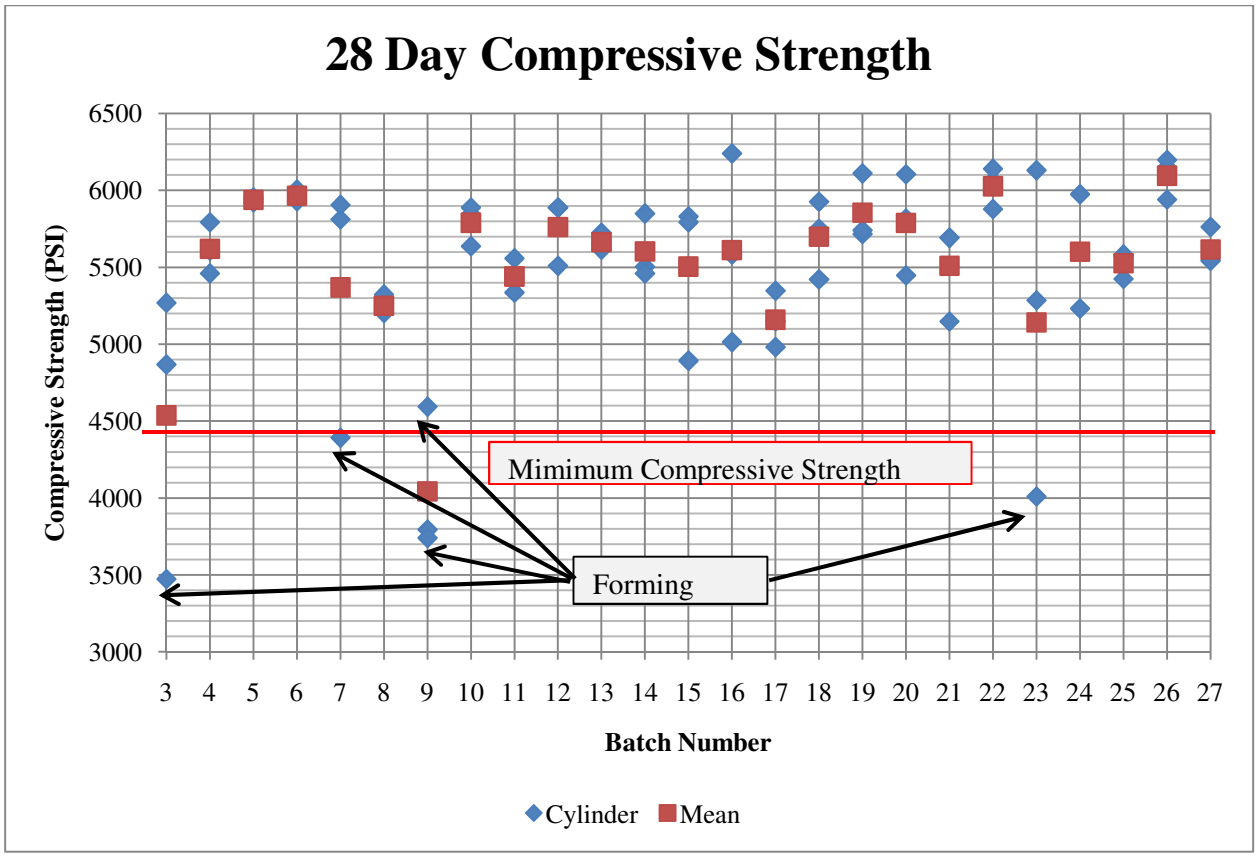
Concrete Properties

Slump, air content, average compressive strength is displayed in Table B.4 and compressive strength in Graph B.3.

Table B.4 Batch Properties

Batch	1	2	3	4	5	6	7	8	9
Slump (in)	1.5	NA	0.25	1	1	1	1	1	2
Air (%)	5	NA	7	5	5	6	5.5	5.5	6
Compressive (psi)		NA	4537	5620	5939	5965	5369	5249	4043
Batch	10	11	12	13	14	15	16	17	18
Slump (in)	1	1.75	1	2	1		1	2.5	1
Air (%)	6.5	7	6	7	5.5	7	5.5	6	5.5
Compressive (psi)	5790	5440	5761	5664	5604	5505	5612	5159	5699
Batch	19	20	21	22	23	24	25	26	27
Slump (in)	1	1.75	1.75	1.25	1.75	1.5	1.25	0.5	0.5
Air (%)	5.5	6	6	6	6	6	5.5	5	5.25
Compressive (psi)	5855	5789	5510	6027	5149	5601	5527	6095	5616

*Note= Batch 7,9,23 had forming issues, Batch 3 had too low slump, Batch 17 too high slump



Graph B.3 Batch 28 Day Compressive Strength

Moisture Capacity of Laboratory Samples

The moisture capacity of the concrete was calculated by weighing the sample at 100% moisture content (saturated, surface dry weight (W_{ssd}) and then drying the samples in a laboratory oven until there was a negligible change in weight in a 24 hour period. The calculations are displayed in Table B.5

Table B.5: Moisture Capacity of Laboratory Cast Samples

Sample Number	W_{ssd} (kg)	W_{od} (kg)	M_{ssd} %
1.3	2.44	2.29	6.5502183
6.5	2.4	2.27	5.7268722
7.15	2.29	2.16	6.0185185
8.24	2.38734	2.24709	6.2414056
9.24	2.32161	2.17628	6.6779091
10.24	2.34792	2.20011	6.7183004
11.24	2.34545	2.22495	5.415852

Sample Number	W_{ssd} (kg)	W_{od} (kg)	M_{ssd} %
15.24	2.35512	2.25392	4.4899553
16.24	2.4163	2.30966	4.6171298
23.24	2.37674	2.23979	6.1144125
24.24	2.22628	2.10024	6.0012189
25.24	2.33193	2.19922	6.0344122
26.24	2.39141	2.25623	5.9914105
27.24	2.34741	2.21687	5.8884824
	Mean	2.222605	5.8918641

APPENDIX C

Sealer Information

Silane: Kwik Bond Polymers Sil Seal

Manufacturer:
Kwik Bond Polymers

923 Teal Drive
Benicia, CA 94510

(866) 434-1772 (toll-free)
(707) 746-7981 (fax)
contact@kwikbondpolymers.com

Date Manufactured:

Lot Number

MSDS

HMWM: Kwik Bond Polymers KBP 204

Manufacturer:
Kwik Bond Polymers

923 Teal Drive
Benicia, CA 94510

(866) 434-1772 (toll-free)
(707) 746-7981 (fax)
contact@kwikbondpolymers.com

Date Manufactured:

09-06

Lot Number
09-06-502601

MSDS

Epoxy: Unitex Bridge Seal

Manufacturer:
Unitex

3103 Gardner

Kansas City, MO 64120

866-231-7700

Date Manufactured:
2008

Lot Number
UNIA2/Y2.0/100 08/USA/M4121/5

MSDS

	Part A	Part B	Mixed System
Weight per Gal/Liter:	8.7 lbs./4 kg	7.7 lbs./3.5 kg	8.2 lbs./3.7 kg
Viscosity	<50 cps	<50 cps	<50 cps
Specific Gravity	1.05	.93	.97

MSDS Material Safety Data Sheet
UNITEX

BRIDGE SEAL

MSDS Number: 11015 Revision Date: 10/9/2008

1 PRODUCT AND COMPANY IDENTIFICATION

Manufacturer

UNITEX
3101 Gardner Ave

Kansas City, MO 64120

Contact: Technical Services
Telephone Number: 816-231-7700
FAX Number: 816-483-3149
E-Mail: mail@unitex-chemicals.com
Web www.unitex-chemicals.com

Product Name:	BRIDGE SEAL
Revision Date:	10/9/2008
MSDS Number:	11015
Common Name:	polyamine
Product Code:	BRIDGE SEAL
Chemical Family:	polyamine
Product Use:	Penetrating Epoxy Healer Sealer

EMERGENCY TELEPHONE No.: 800-424-9300 CHEMTREC 24 hrs.

2 HAZARDS IDENTIFICATION

Route of Entry:	Eyes, Skin, Swallowing, Inhalation
Target Organs:	None Known
Inhalation:	May cause irritation to nose and throat.
Skin Contact:	May cause irritation and dermatitis.
Eye Contact:	May cause irritation, sensitization and may lead to eye damage.
Ingestion:	May cause irritation of the mouth, stomach and sensitization.

MSDS Material Safety Data Sheet
UNITEX

BRIDGE SEAL

MSDS Number: 11015 Revision Date: 10/9/2008

3 COMPOSITION/INFORMATION ON INGREDIENTS

Ingredients:

Cas #	Chemical Name	Perc.
COMPONENT A		
25068386	Modified Bisphenol A Epoxy Resin	70-80%
1330207	Aromatic 100	20-30%
COMPONENT B		
Trade Secret	Amine Blend containing one or more of the following:	20-40%
694837		
90722		
100516		
1330207	Aromatic 100	20-30%
84852153	Nonylphenol	30-50%

4 FIRST AID MEASURES

Inhalation: Using proper respiratory protection, immediately remove the affected victim from exposure. Administer artificial respiration if breathing is stopped. Keep at rest. Get immediate medical attention.

Skin Contact: Flush with large amounts of water; use soap if available. SOLVENTS SHOULD NOT BE USED because they carry the irritant into the skin. Remove grossly contaminated clothing, including shoes, and launder before reuse.

Eye Contact: Flush eyes with large amounts of water until irritation subsides. If necessary gently hold open eyelids during the flush. If irritation persists, get medical attention.

Ingestion: If swallowed, DO NOT INDUCE VOMITING. Should vomiting occur, be sure to keep victim's head below hips to avoid aspiration of vomitus into the lungs. Keep at rest. Get prompt medical attention.

5 FIRE FIGHTING MEASURES

Flash Point: 147 deg. F.
Flash Point Method: Cleveland Open Cup Method
Burning Rate: No data available
Autoignition Temperature: 932 deg. F. (Approximate)
LEL: 2.4% by volume (Approximate)
UEL: 14.2% by volume (Approximate)

Special Fire Fighting Procedures: None. Avoid breathing smoke. NFPA Class B- extinguisher (dry chemical or foam) for class 1C fires. Water spray may be ineffective on fire but can protect fire-fighters and cool closed containers. Use fog nozzels if water is used. Use supplied breathing masks. At higher temperature, pressure builds up in sealed containers. Electrical grounding is recommended when transferring material in containers 1 gallon or larger. NOTE: Flammable liquid can release vapors that form flammable mixtures at temperatures at or above the flashpoint. Toxic gases will form upon combustion. Empty containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, drill, grind, or expose such containers to heat, flame, sparks, static electricity, or other sources or ignition; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH. Empty containers should be returned to a drum reconditioner, or properly disposed of.

MSDS Material Safety Data Sheet
UNITEX

BRIDGE SEAL

MSDS Number: 11015 Revision Date: 10/9/2008

6 ACCIDENTAL RELEASE MEASURES

SMALL SPILL: Absorb with an inert material (sand, vermiculite, etc.). Sweep or scoop up and put into disposal containers. Flush area immediately with water (prevent water from entering waterways).

LARGE SPILLS:
Containment: For large spills, dike far ahead of liquid spill for later disposal. Do not release into sewers or waterways.
Cleanup: Absorb with an inert material (sand, vermiculite, etc.). Sweep or scoop up into disposal containers. Flush area immediately with water (prevent water from entering waterways).
Regulatory Requirements: Follow applicable OSHA regulations (29 CFR 1910.120).

Eliminate all sources of ignition. Warn occupants. If water spill, warn occupants in surrounding and downwind areas of fire hazard and request to stay clear. Remove from surface with suitable absorbents. If allowed by local authorities and environmental agencies, sinking and/or suitable dispersants may be used in non-confined waters. Consult an expert on disposal of recovered material and ensure conformity to local disposal regulations.

7 HANDLING AND STORAGE

Handling Precautions: For professional use only. Avoid eye/skin contact. Wash after using and before eating or smoking. Avoid breathing vapors. Use as directed. Avoid uncontrolled mixing with other mixtures (strong acids, bases and oxidizers). Respiratory protection is required when ventilation is inadequate. NIOSH/OSHA approved respirators should be provided and worn.

Storage Requirements: Store in a cool/dry location. Do not allow material to freeze, as product may be damaged. Store away from sparks and open flames. Material will accumulate static charges which may cause an electrical spark (ignition source). Use proper bonding and/or grounding procedures. Do not pressurize, cut, heat, or weld containers. Empty product containers may contain product residue. Do not reuse empty containers without commercial cleaning or reconditioning.

8 EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering Controls: The use of local exhaust ventilation is recommended to control process emissions near the source. Laboratory samples should be handled in a lab hood. Provide mechanical ventilation of confined spaces.

Protective Equipment: RESPIRATORY PROTECTION: Seek professional advice prior to respirator selection and use. Follow OSHA respirator regulations (29 CFR 1910.134) and, if necessary, wear OSHA/NIOSH approved respirator. Select respirator based on its suitability to provide adequate worker protection for given working conditions, level of airborne contamination, and presence of sufficient oxygen.

PROTECTIVE CLOTHING/EQUIPMENT: Wear chemically protective gloves, boots, aprons to prevent prolonged or repeated skin contact. Wear protective goggles and face shield, per OSHA eye and face protection regulations (29 CFR 1910.133).

CONTAMINATED EQUIPMENT: Remove contaminated clothes immediately. Launder before reuse.

OTHER PRECAUTIONS: Never eat, drink or smoke in work areas. Electrical grounding is recommended when transferring material in containers 1 gallon or more.

MSDS Material Safety Data Sheet
UNITEX

BRIDGE SEAL

MSDS Number: 11015 Revision Date: 10/9/2008

9 PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	A- Clear B-Dark Amber		
Physical State:	Liquid	**Boiling Point:**	282-286 Deg. F (Xylene)
Odor:	A/B= Distinct Solvent Odor	**Freezing/Melting Pt.:**	31 Deg. F.
pH:	Part A - 7, Part B - 12	**Solubility:**	0.02 @ 77 Deg. F.
Vapor Pressure:	N/E	**Spec Grav./Density:**	(H2O=1) A:0.9 B:0.9
Vapor Density:	(Air=1) >1		

VOC:	~240 g/l
Evap. Rate:	(Ether=1) >1
Viscosity:	Thin
Percent Volatile:	80% when A/B mixed

10 STABILITY AND REACTIVITY

Stability:	Stable
Conditions to avoid:	None
Materials to avoid (Incompatability):	Srong acids, bases, mercapatans and peroxides may initate polymerization.
Hazardous Decomposition products:	CO, CO2, NOX.
Hazardous Polymerization:	None when handled properly.

11 TOXICOLOGICAL INFORMATION

12 ECOLOGICAL INFORMATION

No specific ecological data are available for this product.

13 DISPOSAL CONSIDERATIONS

Dispose of in accordance with local, state and federal regulations.

14 TRANSPORT INFORMATION

DOT Class: Corrosive (8) #8

Shipping Name: COMPONENT "B" Amines Liquid Corrosive, N.O.S. (polyamine) UN2735, Class 8 Corrosive, PGIII

Placards required over 1000lbs.

MSDS Material Safety Data Sheet
UNITEX

BRIDGE SEAL

MSDS Number: 11015 Revision Date: 10/9/2006

15 REGULATORY INFORMATION

This MSDS has been prepared in accordance with federal OSHA Hazard Communication Standard 29 CFR 1910.1200.

HMIS Codes: Health(2) Flammbility(2) Reactivity(0) PPE(H)

This product has been classified according to the hazard criteria of the CPR and the MSDS contains all the information required by the CPR.

State of California Proposition 65. This product is known to the state of California to cause birth defects or other reproductive harm.

This product or all components of this product are listed on the U.S. TSCA inventory.

This product does not contain toxic chemicals at levels which require reporting under Superfund Amendments and Reauthorization Act of 1986 Title III (Emergency Planning and Community Right to Known Act).

16 OTHER INFORMATION

The information and recommendations in this document are based on the best information available to us at the time of preparation. We make no other warranty, expressed or implied, as to the correctness or completeness, or as to the results or reliance of this product

END OF MSDS DOCUMENT

APPENDIX D:

Laboratory Tests Data

Vapor Transmission

Table D.1 Vapor Transmission Trial 1

		Date						
		Week 1 11/25/2009 Mass	Week 2 12/2/2009 Mass	Week 3 12/9/2009 Mass	Difference Week2-3 Mass	VT	VT Mean	DRC
Sample ID	Treatment	(Kg)	(Kg)	(Kg)	(g)	(g/(m^2hr))	(g/(m^2hr))	(%)
1-5	HMWM	2.38711	2.38612	2.38486	1.26	0.120968	0.088	33.394
7-4	HMWM	2.34195	2.3416	2.34093	0.67	0.064324		
6-13	HMWM	2.33559	2.33475	2.3337	1.05	0.100806		
6-14	HMWM	2.31882	2.3181	2.31727	0.83	0.079685		
6-15	HMWM	2.32705	2.32664	2.32594	0.7	0.067204		
6-16	HMWM	2.31617	2.31543	2.31443	1	0.096006		
7-6	sil/HMWM	2.34648	2.34621	2.34566	0.55	0.052803	0.054	20.424
7-7	sil/HMWM	2.33692	2.33662	2.33602	0.6	0.057604		
6-21	sil/HMWM	2.31517	2.31492	2.31439	0.53	0.050883		
6-22	sil/HMWM	2.30108	2.30081	2.30027	0.54	0.051843		
6-23	sil/HMWM	2.32642	2.32594	2.32531	0.63	0.060484		
6-24	sil/HMWM	2.31784	2.31746	2.31694	0.52	0.049923		
1-1	control	2.38179	2.37878	2.37557	3.21	0.30818	0.264	100.000
7-1	control	2.34009	2.3377	2.33481	2.89	0.277458		
7-8	control	2.31232	2.30999	2.30735	2.64	0.253456		
6-1	control	2.36927	2.36695	2.36447	2.48	0.238095		
6-2	control	2.35923	2.35716	2.3544	2.76	0.264977		
6-3	control	2.35604	2.35392	2.3514	2.52	0.241935		
1-2	silane	2.38926	2.38617	2.3835	2.67	0.256336	0.205	77.818
7-2	silane	2.33865	2.33648	2.33436	2.12	0.203533		
6-4	silane	2.34697	2.34505	2.34281	2.24	0.215054		
6-6	silane	2.33744	2.33551	2.33362	1.89	0.181452		
6-7	silane	2.31137	2.30956	2.30777	1.79	0.171851		
6-8	silane	2.31276	2.31088	2.30875	2.13	0.204493		
1-4	Epoxy	2.38065	2.37948	2.37805	1.43	0.137289	0.105	39.636
7-3	Epoxy	2.34274	2.34163	2.34047	1.16	0.111367		
6-9	Epoxy	2.33196	2.33089	2.32985	1.04	0.099846		
6-10	Epoxy	2.33344	2.33234	2.33119	1.15	0.110407		
6-11	Epoxy	2.3347	2.33378	2.33285	0.93	0.089286		
6-12	Epoxy	2.34201	2.34112	2.34029	0.83	0.079685		
1-6	sil/epoxy	2.39801	2.39691	2.39575	1.16	0.111367	0.090	34.121
7-5	sil/epoxy	2.37453	2.37348	2.37246	1.02	0.097926		
6-17	sil/epoxy	2.33683	2.33602	2.33517	0.85	0.081605		
6-18	sil/epoxy	2.33537	2.33453	2.3337	0.83	0.079685		
6-19	sil/epoxy	2.30258	2.30172	2.30091	0.81	0.077765		
6-20	sil/epoxy	2.29413	2.29323	2.29227	0.96	0.092166		

Table D.2 Vapor Transmission Trial 2

Sample ID	Treatment	Date Week 1 2/20/2010 Mass (g)	Week 2 2/27/2009 Mass (g)	Week 3 3/6/2010 Mass (g)	Difference Week2-3 Mass (g)	VT (g/(m^2hr))	VT Mean (g/(m^2hr))	DRC (%)
8-7	HMWM	2297.31	2296.47	2295.36	1.11	0.11	0.11	27.43
8-8	HMWM	2305.24	2304.43	2303.30	1.13	0.11		
8-9	HMWM	2299.43	2298.53	2297.38	1.15	0.11		
9-4	HMWM	2314.62	2313.76	2312.63	1.13	0.11		
9-5	HMWM	2326.14	2325.15	2323.84	1.31	0.13		
9-6	HMWM	2331.70	2330.98	2330.00	0.98	0.09		
8-20	sil/HMWM	2345.00	2344.44	2343.63	0.81	0.08	0.09	21.51
8-21	sil/HMWM	2341.15	2340.48	2339.60	0.88	0.08		
8-22	sil/HMWM	2357.46	2356.78	2355.89	0.89	0.09		
8-23	sil/HMWM	2357.99	2357.33	2356.50	0.83	0.08		
9-15	sil/HMWM	2287.27	2286.60	2285.63	0.97	0.09		
9-16	sil/HMWM	2290.28	2289.56	2288.60	0.96	0.09		
8-4	control	2321.05	2317.07	2313.06	4.01	0.38	0.40	100.00
8-5	control	2300.26	2295.88	2291.63	4.25	0.41		
8-6	control	2305.23	2301.45	2297.61	3.84	0.37		
9-1	control	2319.57	2314.88	2310.71	4.17	0.40		
9-2	control	2280.15	2275.70	2271.29	4.41	0.42		
9-3	control	2281.50	2277.33	2273.18	4.15	0.40		
8-13	silane	2301.50	2298.32	2295.41	2.91	0.28	0.31	77.04
8-14	silane	2286.13	2282.69	2279.52	3.17	0.30		
8-15	silane	2267.11	2263.95	2261.08	2.87	0.28		
9-10	silane	2270.58	2266.85	2263.37	3.48	0.33		
9-11	silane	2272.73	2269.08	2265.70	3.38	0.32		
9-12	silane	2262.90	2259.32	2256.00	3.32	0.32		
8-10	Epoxy	2312.28	2311.49	2310.48	1.01	0.10	0.11	27.10
8-11	Epoxy	2296.69	2295.81	2294.70	1.11	0.11		
8-12	Epoxy	2270.76	2269.93	2268.89	1.04	0.10		
9-7	Epoxy	2280.06	2279.04	2277.74	1.30	0.12		
9-8	Epoxy	2276.81	2275.92	2274.78	1.14	0.11		
9-9	Epoxy	2279.83	2278.93	2277.80	1.13	0.11		
8-16	sil/epoxy	2299.01	2297.93	2296.78	1.15	0.11	0.11	27.14
8-17	sil/epoxy	2298.88	2297.82	2296.72	1.10	0.11		
8-18	sil/epoxy	2276.89	2275.98	2274.98	1.00	0.10		
8-19	sil/epoxy	2338.76	2337.75	2336.64	1.11	0.11		
9-13	sil/epoxy	2257.02	2255.88	2254.64	1.24	0.12		
9-14	sil/epoxy	2265.76	2264.65	2263.51	1.14	0.11		

Table D.3 Vapor Transmission Trial 3

Sample ID	Treatment	Date Week 1 40249.00 Mass (g)	Week 2 40256.00 Mass (g)	Week 3 40263.00 Mass (g)	Difference Week2-3 Mass (g)	VT (g/(m^2hr))	VT Mean (g/(m^2hr))	DRC (%)
9-17	HMWM	2262.08	2261.80	2260.87	0.93	0.09	0.09	25.72
10-1	HMWM	2248.35	2247.98	2247.14	0.84	0.08		
10-2	HMWM	2250.45	2250.26	2249.42	0.84	0.08		
10-3	HMWM	2275.64	2275.39	2274.41	0.98	0.09		
11-1	HMWM	2288.11	2287.87	2286.95	0.92	0.09		
11-2	HMWM	2269.73	2269.49	2268.55	0.94	0.09		
9-18	sil/HMWM	2262.45	2262.35	2261.49	0.86	0.08	0.09	25.44
10-4	sil/HMWM	2284.96	2284.90	2284.13	0.77	0.07		
10-5	sil/HMWM	2290.01	2289.96	2289.00	0.96	0.09		
10-6	sil/HMWM	2269.01	2268.80	2267.91	0.89	0.09		
11-3	sil/HMWM	2276.49	2276.28	2275.38	0.90	0.09		
11-4	sil/HMWM	2264.38	2264.13	2263.12	1.01	0.10		
9-19	control	2266.22	2265.26	2261.60	3.66	0.35	0.34	100.00
10-7	control	2206.83	2206.16	2202.71	3.45	0.33		
10-8	control	2254.96	2253.96	2250.35	3.61	0.35		
10-9	control	2236.90	2236.08	2232.49	3.59	0.34		
11-5	control	2250.59	2250.17	2246.68	3.49	0.34		
11-6	control	2237.83	2237.52	2234.13	3.39	0.33		
9-20	silane	2280.61	2277.95	2274.84	3.11	0.30	0.29	85.37
10-10	silane	2240.64	2237.72	2234.76	2.96	0.28		
10-11	silane	2245.15	2242.42	2239.55	2.87	0.28		
10-12	silane	2241.85	2239.16	2236.25	2.91	0.28		
11-7	silane	2300.64	2297.61	2294.46	3.15	0.30		
11-8	silane	2311.14	2308.28	2305.19	3.09	0.30		
9-21	Epoxy	2281.83	2281.43	2280.53	0.90	0.09	0.08	24.26
10-13	Epoxy	2271.05	2270.68	2269.78	0.90	0.09		
10-14	Epoxy	2290.52	2290.19	2289.35	0.84	0.08		
10-15	Epoxy	2253.31	2253.01	2252.07	0.94	0.09		
11-9	Epoxy	2309.02	2308.66	2307.87	0.79	0.08		
11-10	Epoxy	2339.22	2338.92	2338.15	0.77	0.07		
9-22	sil/epoxy	2292.68	2292.28	2291.41	0.87	0.08	0.08	23.78
10-16	sil/epoxy	2261.97	2261.68	2260.86	0.82	0.08		
10-17	sil/epoxy	2282.80	2282.40	2281.65	0.75	0.07		
10-18	sil/epoxy	2262.75	2262.38	2261.56	0.82	0.08		
10-19	sil/epoxy	2326.50	2326.19	2325.34	0.85	0.08		
11-11	sil/epoxy	2313.16	2312.79	2311.86	0.93	0.09		
9-23	PPC HS	2278.55	2278.65	2277.47	1.18	0.11	0.09	26.14
10-20	PPC HS	2320.00	2320.37	2319.59	0.78	0.07		
10-21	PPC HS	2317.71	2317.90	2317.03	0.87	0.08		
10-22	PPC HS	2277.42	2278.26	2277.46	0.80	0.08		

Sample ID	Treatment	Date Week 1 40249.00 Mass (g)	Week 2 40256.00 Mass (g)	Week 3 40263.00 Mass (g)	Difference Week2-3 Mass (g)	VT (g/(m^2hr))	VT Mean (g/(m^2hr))	DRC (%)
9-17	HMWM	2262.08	2261.80	2260.87	0.93	0.09	0.09	25.72
10-1	HMWM	2248.35	2247.98	2247.14	0.84	0.08		
10-2	HMWM	2250.45	2250.26	2249.42	0.84	0.08		
10-3	HMWM	2275.64	2275.39	2274.41	0.98	0.09		
11-1	HMWM	2288.11	2287.87	2286.95	0.92	0.09		
11-2	HMWM	2269.73	2269.49	2268.55	0.94	0.09		
9-18	sil/HMWM	2262.45	2262.35	2261.49	0.86	0.08	0.09	25.44
10-4	sil/HMWM	2284.96	2284.90	2284.13	0.77	0.07		
10-5	sil/HMWM	2290.01	2289.96	2289.00	0.96	0.09		
10-6	sil/HMWM	2269.01	2268.80	2267.91	0.89	0.09		
11-3	sil/HMWM	2276.49	2276.28	2275.38	0.90	0.09		
11-4	sil/HMWM	2264.38	2264.13	2263.12	1.01	0.10		
9-19	control	2266.22	2265.26	2261.60	3.66	0.35	0.34	100.00
10-7	control	2206.83	2206.16	2202.71	3.45	0.33		
10-8	control	2254.96	2253.96	2250.35	3.61	0.35		
10-9	control	2236.90	2236.08	2232.49	3.59	0.34		
11-5	control	2250.59	2250.17	2246.68	3.49	0.34		
11-6	control	2237.83	2237.52	2234.13	3.39	0.33		
9-20	silane	2280.61	2277.95	2274.84	3.11	0.30	0.29	85.37
10-10	silane	2240.64	2237.72	2234.76	2.96	0.28		
10-11	silane	2245.15	2242.42	2239.55	2.87	0.28		
10-12	silane	2241.85	2239.16	2236.25	2.91	0.28		
11-7	silane	2300.64	2297.61	2294.46	3.15	0.30		
11-8	silane	2311.14	2308.28	2305.19	3.09	0.30		
9-21	Epoxy	2281.83	2281.43	2280.53	0.90	0.09	0.08	24.26
10-13	Epoxy	2271.05	2270.68	2269.78	0.90	0.09		
10-14	Epoxy	2290.52	2290.19	2289.35	0.84	0.08		
10-15	Epoxy	2253.31	2253.01	2252.07	0.94	0.09		
11-9	Epoxy	2309.02	2308.66	2307.87	0.79	0.08		
11-10	Epoxy	2339.22	2338.92	2338.15	0.77	0.07		
9-22	sil/epoxy	2292.68	2292.28	2291.41	0.87	0.08	0.08	23.78
10-16	sil/epoxy	2261.97	2261.68	2260.86	0.82	0.08		
10-17	sil/epoxy	2282.80	2282.40	2281.65	0.75	0.07		
10-18	sil/epoxy	2262.75	2262.38	2261.56	0.82	0.08		
10-19	sil/epoxy	2326.50	2326.19	2325.34	0.85	0.08		
11-11	sil/epoxy	2313.16	2312.79	2311.86	0.93	0.09		
9-23	PPC HS	2278.55	2278.65	2277.47	1.18	0.11	0.09	26.14
10-23	PPC HS	2293.65	2294.76	2293.85	0.91	0.09		
11-12	PPC HS	2315.53	2315.80	2314.80	1.00	0.10		

Table D.4 Vapor Transmission Trial 4

		Date Week 1 40298.00 Mass	Week 2 40305.00 Mass	Week 3 40312.00 Mass	Difference Week2-3 Mass	VT	VT Mean	DRC
11-17	HMWM	2263.30	2262.84	2262.52	0.32	0.03	0.03	25.12
11-18	HMWM	2255.59	2255.07	2254.73	0.34	0.03		
15-6	HMWM	2334.45	2334.15	2333.90	0.25	0.02		
15-7	HMWM	2301.16	2300.80	2300.57	0.23	0.02		
15-8	HMWM	2296.28	2295.93	2295.68	0.25	0.02		
16-4	HMWM	2381.11	2380.65	2380.44	0.21	0.02		
11-19	sil/HMWM	2285.77	2285.23	2284.88	0.35	0.03	0.02	24.49
11-20	sil/HMWM	2277.27	2276.75	2276.48	0.27	0.03		
15-9	sil/HMWM	2311.35	2311.06	2310.90	0.16	0.02		
15-10	sil/HMWM	2313.59	2313.25	2312.99	0.26	0.02		
15-11	sil/HMWM	2304.02	2303.74	2303.47	0.27	0.03		
16-5	sil/HMWM	2334.97	2334.68	2334.43	0.25	0.02		
11-13	control	2254.87	2251.21	2250.08	1.13	0.11	0.10	100.00
11-14	control	2225.80	2221.90	2220.70	1.20	0.12		
15-1	control	2342.24	2339.50	2338.61	0.89	0.09		
15-2	control	2352.75	2349.70	2348.74	0.96	0.09		
16-1	control	2364.91	2362.08	2361.11	0.97	0.09		
16-2	control	2340.85	2337.30	2336.08	1.22	0.12		
11-15	silane	2232.42	2227.80	2226.68	1.12	0.11	0.09	86.19
11-16	silane	2249.27	2244.50	2243.38	1.12	0.11		
15-3	silane	2372.45	2368.80	2367.97	0.83	0.08		
15-4	silane	2362.62	2359.06	2358.26	0.80	0.08		
15-5	silane	2353.02	2349.20	2348.40	0.80	0.08		
16-3	silane	2368.59	2364.64	2363.82	0.82	0.08		
11-22	Epoxy	2276.52	2275.80	2275.40	0.40	0.04	0.03	27.16
15-16	Epoxy	2324.69	2324.29	2324.02	0.27	0.03		
15-17	Epoxy	2321.54	2321.03	2320.74	0.29	0.03		
15-18	Epoxy	2317.80	2317.44	2317.19	0.25	0.02		
15-19	Epoxy	2288.16	2287.80	2287.60	0.20	0.02		
16-7	Epoxy	2324.31	2323.85	2323.53	0.32	0.03		
11-21	sil/epoxy	2234.30	2233.27	2232.80	0.47	0.05	0.04	34.69
15-12	sil/epoxy	2285.72	2285.06	2284.70	0.36	0.03		
15-13	sil/epoxy	2302.65	2302.04	2301.72	0.32	0.03		
15-14	sil/epoxy	2327.80	2327.16	2326.84	0.32	0.03		
15-15	sil/epoxy	2323.85	2323.10	2322.74	0.36	0.03		
16-6	sil/epoxy	2329.40	2328.70	2328.32	0.38	0.04		
11-23	PPC HS	2267.81	2266.80	2266.31	0.49	0.05	0.03	32.34
15-20	PPC HS	2294.40	2294.14	2293.88	0.26	0.02		
15-21	PPC HS	2296.32	2295.80	2295.53	0.27	0.03		
15-22	PPC HS	2303.86	2303.40	2303.04	0.36	0.03		
15-23	PPC HS	2267.80	2303.10	2302.82	0.28	0.03		

Table D.5 Summary Vapor Transmission

Trial	Control (g/(m^2hr))	Silane (g/(m^2hr))	HMWM (g/(m^2hr))	Silane/ HMWM (g/(m^2hr))	Epoxy (g/(m^2hr))	Silane/ Epoxy (g/(m^2hr))
1	0.31	0.26	0.12	0.05	0.14	0.11
1	0.28	0.20	0.06	0.06	0.11	0.10
1	0.25	0.22	0.10	0.05	0.10	0.08
1	0.24	0.18	0.08	0.05	0.11	0.08
1	0.26	0.17	0.07	0.06	0.09	0.08
1	0.24	0.20	0.10	0.05	0.08	0.09
2	0.38	0.28	0.11	0.08	0.10	0.11
2	0.41	0.30	0.11	0.08	0.11	0.11
2	0.37	0.28	0.11	0.09	0.10	0.10
2	0.40	0.33	0.11	0.08	0.12	0.11
2	0.42	0.32	0.13	0.09	0.11	0.12
2	0.40	0.32	0.09	0.09	0.11	0.11
3	0.35	0.30	0.09	0.01	0.09	0.08
3	0.33	0.28	0.08	0.01	0.09	0.08
3	0.35	0.28	0.08	0.01	0.08	0.07
3	0.34	0.28	0.09	0.01	0.09	0.08
3	0.34	0.30	0.09	0.01	0.08	0.08
3	0.33	0.30	0.09	0.01	0.07	0.09
4	0.11	0.11	0.03	0.03	0.04	0.05
4	0.12	0.11	0.03	0.03	0.03	0.03
4	0.09	0.08	0.02	0.02	0.03	0.03
4	0.09	0.08	0.02	0.02	0.02	0.03
4	0.09	0.08	0.02	0.03	0.02	0.03
4	0.12	0.08	0.02	0.02	0.03	0.04
Mean	0.28	0.22	0.08	0.04	0.08	0.08
Maximum	0.42	0.33	0.13	0.09	0.14	0.12
Minimum	0.09	0.08	0.02	0.01	0.02	0.03
Std. D	0.11	0.09	0.03	0.03	0.03	0.03
DRC(%)	100.00	80.64	28.12	15.67	29.24	28.48

Table D.6 Drying Rate Coefficient

Trial	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
1	100	77.8	33.4	20.4	39.6	34.1
2	100	77	27.4	21.5	27.1	27.1
3	100	85	25.7	25.4	24.3	23.8
4	100	86	25.1	24.5	27.2	34.7

DRC

Saltwater Absorption

Table D.7 Saltwater Absorption Trial 1

Sample Number	Class	Oven Dried W_{od1} (g)	W_{ssd1} (g)	Cured weight W_{csa} (g)	Moisture Content M_c (%)	W_0 Initial 12/28/09 Mass(g)	W_7 7-day 1/04/10 Mass(g)	W_{14} 14-day 1/11/10 Mass(g)	W_{21} 21-day 1/18/10 Mass(g)	ΔW_7 (%)	ΔW_{14} (%)	ΔW_{21} (%)	SAR 7-day SAR (%)	SAR 14-day SAR (%)	SAR 21-day SAR (%)
1-1	control	2300.00	2440.00	0.00	3.08	2370.79	2384.51	2390.86	2394.26	0.58	0.85	0.99	100.00	100.00	100.00
7-1	control	2262.00	2400.00	0.00	3.03	2330.63	2354.18	2359.74	2361.07	1.01	1.25	1.31			
6-1	control	2290.00	2430.00	0.00	3.09	2360.66	2379.25	2384.34	2386.08	0.79	1.00	1.08			
Mean					3.07					0.79	1.03	1.12			
1-2	Silane	2300.00	2440.00	4.61	3.24	2379.11	2383.71	2385.84	2386.14	0.19	0.28	0.30	21.47	24.91	22.45
6-4	Silane	2271.00	2410.00	4.79	2.79	2339.11	2343.15	2344.93	2344.50	0.17	0.25	0.23			
6-6	Silane	2262.00	2400.00	4.48	2.82	2330.23	2333.59	2335.83	2335.62	0.14	0.24	0.23			
Mean					2.95					0.17	0.26	0.25			
7-4	HMWM	2253.00	2390.00	11.27	3.33	2339.27	2344.16	2348.35	2350.73	0.21	0.39	0.49	38.81	51.04	55.86
6-15	HMWM	2234.00	2370.00	12.20	3.49	2324.11	2329.68	2334.78	2337.13	0.24	0.46	0.56			
6-16	HMWM	2234.00	2370.00	12.73	2.92	2311.97	2322.92	2328.95	2331.25	0.47	0.73	0.83			
Mean					3.25					0.31	0.53	0.63			
7-7	Dual/HMWM	2253.00	2390.00	18.46	2.80	2334.52	2336.01	2337.58	2337.13	0.06	0.13	0.11	9.25	13.24	12.89
6-21	Dual/HMWM	2224.00	2360.00	16.80	3.25	2313.00	2314.98	2316.52	2317.17	0.09	0.15	0.18			
6-22	Dual/HMWM	2215.00	2350.00	17.94	2.97	2298.83	2300.45	2301.75	2302.11	0.07	0.13	0.14			
Mean					3.01					0.07	0.14	0.14			
7-3	Epoxy	2253.00	2390.00	12.70	3.20	2337.85	2342.62	2344.68	2345.45	0.20	0.29	0.33	21.56	22.51	22.66
6-11	Epoxy	2234.00	2370.00	12.90	3.75	2330.65	2334.72	2336.00	2336.25	0.17	0.23	0.24			
6-12	Epoxy	2253.00	2390.00	12.45	3.24	2338.34	2341.47	2342.45	2342.99	0.13	0.18	0.20			
Mean					3.40					0.17	0.23	0.25			
7-5	Dual/Epoxy	2290.00	2430.00	19.67	2.64	2370.11	2371.60	2372.30	2372.35	0.06	0.09	0.09	9.08	9.51	8.53
6-19	Dual/Epoxy	2215.00	2350.00	20.12	2.87	2298.76	2300.20	2300.57	2300.49	0.06	0.08	0.08			
6-20	Dual/Epoxy	2215.00	2350.00	19.40	2.52	2290.30	2292.37	2293.13	2293.00	0.09	0.12	0.12			
Mean					2.68					0.07	0.10	0.10			

Table D.8 Saltwater Absorption Trial 2

Trial 2		Oven Dried W_{od1}	W_{ssd1}	Cured weight W_{csa}	Moisture Content M_c	W_{i0} Initial	W_{i7} 7-day	W_{i14} 14-day	W_{i21} 21-day	ΔW_{i7}	ΔW_{i14}	ΔW_{i21}	SAR 7-day	SAR 14-day	SAR 21-day
Sample ID Number	Class	(g)	(g)	(g)	(%)	3/11/09 Mass(g)	3/18/10 Mass(g)	3/25/10 Mass(g)	4/01/10 Mass(g)	(%)	(%)	(%)	Saltwater absorbtion Ratio(%)	Saltwater absorbtion Ratio(%)	Saltwater absorbtion Ratio(%)
8-4	control	2233.78	2375.00	0.00	3.53	2312.69	2340.07	2348.94	2356.16	1.18	1.57	1.88	100.00	100.00	100.00
8-5	control	2214.70	2354.72	0.00	3.45	2291.18	2322.62	2329.58	2336.01	1.37	1.68	1.96			
9-1	control	2231.20	2372.23	0.00	3.55	2310.33	2336.98	2343.40	2349.70	1.15	1.43	1.70			
Mean					3.51					1.24	1.56	1.85			
8-13	Silane	2208.80	2348.44	4.61	3.69	2295.01	2297.56	2298.82	2300.71	0.11	0.17	0.25	10.38	12.33	14.38
8-14	Silane	2197.90	2336.81	4.79	3.47	2278.85	2281.79	2283.35	2284.36	0.13	0.20	0.24			
9-10	Silane	2192.00	2330.59	4.50	3.02	2262.72	2266.00	2267.54	2269.66	0.14	0.21	0.31			
Mean					3.39					0.13	0.19	0.27			
8-7	HMWM	2197.80	2336.78	11.27	3.84	2293.52	2301.80	2307.40	2310.31	0.36	0.61	0.73	37.30	47.24	47.86
8-8	HMWM	2206.50	2346.02	12.20	3.75	2301.43	2310.47	2317.10	2320.92	0.39	0.68	0.85			
9-4	HMWM	2235.40	2376.67	12.12	2.86	2311.54	2326.10	2332.86	2336.33	0.63	0.92	1.07			
Mean					3.49					0.46	0.74	0.88			
8-20	Silane/HMWM	2237.60	2379.05	22.58	3.67	2342.31	2343.88	2345.62	2345.97	0.07	0.14	0.16	5.61	9.69	9.84
8-21	Silane/HMWM	2232.04	2373.15	19.44	3.89	2338.28	2339.93	2341.92	2343.04	0.07	0.16	0.20			
9-15	Silane/HMWM	2192.10	2330.68	17.94	3.41	2284.77	2286.38	2288.33	2289.00	0.07	0.16	0.19			
Mean					3.66					0.07	0.15	0.18			
8-10	Epoxy	2211.40	2351.20	14.30	3.75	2308.69	2310.92	2312.40	2313.02	0.10	0.16	0.19	8.25	10.11	10.25
8-11	Epoxy	2197.30	2336.18	12.70	3.76	2292.72	2295.55	2296.75	2297.39	0.12	0.18	0.20			
9-7	Epoxy	2194.10	2332.86	12.45	3.19	2276.55	2278.51	2279.65	2280.57	0.09	0.14	0.18			
Mean					3.57					0.10	0.16	0.19			
8-16	Silane/Epoxy	2199.00	2338.03	23.59	3.33	2295.75	2296.79	2297.28	2297.25	0.05	0.07	0.07	4.11	4.53	4.17
8-17	Silane/Epoxy	2198.04	2337.00	19.67	3.52	2294.98	2295.94	2296.64	2296.69	0.04	0.07	0.07			
9-13	Silane/Epoxy	2169.40	2306.50	18.62	3.02	2253.53	2255.00	2255.17	2255.58	0.07	0.07	0.09			
Mean					3.29					0.05	0.07	0.08			

Table D.9 Saltwater Absorption Trial 3

Sample ID Number	Class	Oven Dried W_{od1} (g)	W_{ssd1} (g)	Cured weight W_{cta} (g)	Moisture Content M_c (%)	W_{i0} Initial 4/1/09 Mass(g)	W_{i7} 7-day 4/8/10 Mass(g)	W_{i14} 14-day 4/15/10 Mass(g)	W_{i21} 21-day 4/22/10 Mass(g)	ΔW_{i7} (%)	ΔW_{i14} (%)	ΔW_{i21} (%)	SAR 7-day Saltwater absorbtion Ratio(%)	SAR 14-day Saltwater absorbtion Ratio(%)	SAR 21-day Saltwater absorbtion Ratio(%)
10-8	control	2179.00	2316.82	0.00	3.24	2249.52	2259.05	2262.75	2264.65	0.42	0.59	0.67	100.00	100.00	100.00
10-9	control	2162.70	2299.40	0.00	3.20	2231.80	2242.34	2246.92	2249.90	0.47	0.68	0.81			
11-6	control	2170.80	2308.12	0.00	2.89	2233.50	2242.28	2245.68	2246.16	0.39	0.55	0.57			
Mean					3.11					0.43	0.60	0.68			
10-11	Silane	2165.80	2305.76	4.44	3.14	2238.35	2246.34	2246.64	2247.24	0.36	0.37	0.40	80.22	57.84	55.37
10-12	Silane	2160.53	2297.12	4.79	3.23	2235.10	2242.86	2242.86	2243.19	0.35	0.35	0.36			
11-8	Silane	2227.40	2368.26	4.63	3.23	2304.03	2311.63	2311.63	2312.70	0.33	0.33	0.38			
Mean					3.20					0.34	0.35	0.38			
10-2	HMWM	2162.80	2299.50	15.26	3.27	2248.73	2254.02	2259.12	2262.45	0.24	0.46	0.61	68.29	88.48	94.95
10-3	HMWM	2186.00	2324.23	11.16	3.50	2273.70	2282.60	2289.18	2291.66	0.39	0.68	0.79			
11-2	HMWM	2188.80	2327.14	12.32	3.04	2267.76	2273.51	2278.18	2280.16	0.25	0.46	0.55			
Mean					3.27					0.29	0.53	0.65			
10-5	Silane/HMWM	2194.80	2333.56	16.72	3.50	2288.25	2291.77	2294.71	2295.56	0.15	0.28	0.32	30.47	45.92	46.57
10-6	Silane/HMWM	2175.60	2313.13	14.99	3.52	2267.13	2270.01	2273.50	2274.67	0.13	0.28	0.33			
11-4	Silane/HMWM	2180.80	2318.61	14.74	3.05	2262.10	2264.63	2268.17	2268.95	0.11	0.27	0.30			
Mean					3.36					0.13	0.28	0.32			
10-14	Epoxy	2198.50	2337.53	11.76	3.56	2288.42	2290.93	2292.02	2292.52	0.11	0.16	0.18	23.92	25.75	24.18
10-15	Epoxy	2166.43	2303.40	12.02	3.36	2251.14	2253.58	2255.13	2255.05	0.11	0.18	0.17			
11-10	Epoxy	2246.90	2388.91	11.81	3.50	2337.26	2339.37	2340.34	2340.60	0.09	0.13	0.14			
Mean					3.47					0.10	0.16	0.17			
10-18	Silane/Epoxy	2169.70	2306.82	18.32	3.35	2260.69	2262.28	2262.52	2262.22	0.07	0.08	0.07	15.10	14.33	11.21
10-19	Silane/Epoxy	2229.20	2370.11	16.26	3.55	2324.54	2326.03	2326.69	2326.40	0.06	0.09	0.08			
11-11	Silane/Epoxy	2217.80	2357.99	18.59	3.36	2310.94	2312.33	2312.93	2312.84	0.06	0.09	0.08			
Mean					3.42					0.06	0.09	0.08			
10-22	PPC HS	2189.60	2332.46	11.04	3.46	2276.47	2289.10	2298.53	2304.80						
10-23	PPC HS	2210.80	2350.60	9.65	3.27	2292.71	2308.38	2319.81	2326.42						
11-12	PPC HS	2228.00	2368.82	10.80	3.36	2313.63	2326.53	2333.46	2339.82						
Mean					3.36										

Table D.10 Saltwater Absorption Trial 4 Magnesium Chloride

Trial 4		Oven Dried		Cured weight	Moisture Content									SAR	SAR	SAR
		W_{od1}	W_{sod1}	W_{csa}	M_c	W_o	W_7	W_{14}	W_{21}	ΔW_7	ΔW_{14}	ΔW_{21}	7-day Saltwater absorption	14-day Saltwater absorption	21-day Saltwater absorption
Sample ID						3/11/09	3/18/10	3/25/10	4/01/10						
Number	Class	(g)	(g)	(g)	(%)	Mass(g)	Mass(g)	Mass(g)	Mass(g)	(%)	(%)	(%)	Ratio(%)	Ratio(%)	Ratio(%)
8-4	control	2233.78	2375.00	0.00	3.53	2312.69	2340.07	2348.94	2356.16	1.18	1.57	1.88	100.00	100.00	100.00
8-5	control	2214.70	2354.72	0.00	3.45	2291.18	2322.62	2329.58	2336.01	1.37	1.68	1.96			
9-1	control	2231.20	2372.23	0.00	3.55	2310.33	2336.98	2343.40	2349.70	1.15	1.43	1.70			
Mean					3.51					1.24	1.56	1.85			
8-13	Silane	2208.80	2348.44	4.61	3.69	2295.01	2297.56	2298.82	2300.71	0.11	0.17	0.25	10.38	12.33	14.38
8-14	Silane	2197.90	2336.81	4.79	3.47	2278.85	2281.79	2283.35	2284.36	0.13	0.20	0.24			
9-10	Silane	2192.00	2330.59	4.50	3.02	2262.72	2266.00	2267.54	2269.66	0.14	0.21	0.31			
Mean					3.39					0.13	0.19	0.27			
8-7	HMWM	2197.80	2336.78	11.27	3.84	2293.52	2301.80	2307.40	2310.31	0.36	0.61	0.73	37.30	47.24	47.86
8-8	HMWM	2206.50	2346.02	12.20	3.75	2301.43	2310.47	2317.10	2320.92	0.39	0.68	0.85			
9-4	HMWM	2235.40	2376.67	12.12	2.86	2311.54	2326.10	2332.86	2336.33	0.63	0.92	1.07			
Mean					3.49					0.46	0.74	0.88			
	Silane/HMW														
8-20	M	2237.60	2379.05	22.58	3.67	2342.31	2343.88	2345.62	2345.97	0.07	0.14	0.16	5.61	9.69	9.84
	Silane/HMW														
8-21	M	2232.04	2373.15	19.44	3.89	2338.28	2339.93	2341.92	2343.04	0.07	0.16	0.20			
	Silane/HMW														
9-15	M	2192.10	2330.68	17.94	3.41	2284.77	2286.38	2288.33	2289.00	0.07	0.16	0.19			
Mean					3.66					0.07	0.15	0.18			
8-10	Epoxy	2211.40	2351.20	14.30	3.75	2308.69	2310.92	2312.40	2313.02	0.10	0.16	0.19	8.25	10.11	10.25
8-11	Epoxy	2197.30	2336.18	12.70	3.76	2292.72	2295.55	2296.75	2297.39	0.12	0.18	0.20			
9-7	Epoxy	2194.10	2332.86	12.45	3.19	2276.55	2278.51	2279.65	2280.57	0.09	0.14	0.18			
Mean					3.57					0.10	0.16	0.19			
8-16	Silane/Epoxy	2199.00	2338.03	23.59	3.33	2295.75	2296.79	2297.28	2297.25	0.05	0.07	0.07	4.11	4.53	4.17
8-17	Silane/Epoxy	2198.04	2337.00	19.67	3.52	2294.98	2295.94	2296.64	2296.69	0.04	0.07	0.07			
9-13	Silane/Epoxy	2169.40	2306.50	18.62	3.02	2253.53	2255.00	2255.17	2255.58	0.07	0.07	0.09			
Mean					3.29					0.05	0.07	0.08			

Table D.11 Saltwater Absorption Trial 5 Magnesium Chloride

Sample ID		Oven Dried		Cured weight	Moisture Content	6/21/10	6/28/10	7/5/10	7/12/10					SAR	SAR	SAR
		W_{od1}	W_{od2}	W_{cs}	M_c	W_0 Initial	W_7 7-day	W_{14} 14-day	W_{21} 21-day	ΔW_7	ΔW_{14}	ΔW_{21}	7-day	14-day	21-day
Number	Class	(g)	(g)	(g)	(%)	Mass(g)	Mass(g)	Mass(g)	Mass(g)	(%)	(%)	(%)	SAR (%)	SAR (%)	SAR (%)
16-9	control	2227.38	2357.20		3.32	2301.32	2305.67	2304.30	2302.26	0.19	0.13	0.04	100.00	100.00	100.00
16-10	control	2235.68	2365.99		3.65	2317.21	2320.71	2319.05	2317.04	0.15	0.08	-0.01			
16-11	control	2200.16	2328.40		3.27	2272.14	2277.73	2276.49	2273.94	0.25	0.19	0.08			
18-1	control	2223.54	2353.14		3.53	2302.12	2305.94	2304.25	2301.89	0.17	0.09	-0.01			
18-2	control	2208.62	2337.35		3.46	2285.10	2289.43	2287.68	2285.66	0.19	0.11	0.02			
18-3	control	2224.77	2354.44		3.66	2306.26	2310.97	2309.21	2307.08	0.20	0.13	0.04			
mean					3.48					0.19	0.12	0.03			
16-12	Silane	2257.57	2389.15	3.58	3.66	2343.78	2342.74	2340.55	2338.25	-0.04	-0.14	-0.24	-31.83	-117.16	-931.42
16-13	Silane	2236.57	2366.93	3.12	3.69	2322.24	2321.19	2319.00	2316.77	-0.05	-0.14	-0.24			
16-14	Silane	2211.45	2340.34	3.36	3.43	2290.63	2288.93	2287.59	2284.82	-0.07	-0.13	-0.25			
18-4	Silane	2230.41	2360.41	3.32	3.72	2316.79	2315.00	2313.62	2310.39	-0.08	-0.14	-0.28			
18-5	Silane	2237.64	2368.06	3.36	2.93	2306.59	2305.14	2303.00	2300.70	-0.06	-0.16	-0.26			
18-6	Silane	2215.91	2345.06	3.56	2.39	2272.44	2271.06	2268.87	2266.54	-0.06	-0.16	-0.26			
mean					3.30					-0.06	-0.14	-0.25			
16-20	HMWM	2258.89	2390.55	10.83	3.79	2355.39	2355.02	2353.79	2352.40	-0.02	-0.07	-0.13	-8.66	-57.80	-521.46
16-21	HMWM	2288.23	2421.60	12.42	3.72	2385.83	2385.61	2384.44	2382.94	-0.01	-0.06	-0.12			
18-14	HMWM	2232.32	2362.43	13.28	3.63	2326.58	2326.23	2325.21	2323.62	-0.02	-0.06	-0.13			
18-15	HMWM	2222.93	2352.49	12.49	3.44	2311.83	2311.23	2309.92	2307.94	-0.03	-0.08	-0.17			
18-16	HMWM	2221.69	2351.18	12.34	3.43	2310.26	2309.53	2307.94	2305.89	-0.03	-0.10	-0.19			
18-17	HMWM	2216.34	2345.52	13.80	3.42	2305.88	2305.84	2304.59	2303.20	0.00	-0.06	-0.12			
mean					3.57					-0.02	-0.07	-0.14			
16-15	Silane/HMWM	2226.69	2356.47	15.74	3.65	2323.70	2323.72	2323.12	2322.04	0.00	-0.02	-0.07	7.35	-14.03	-255.68
16-16	Silane/HMWM	2208.89	2337.63	17.09	3.58	2305.10	2305.55	2304.97	2303.91	0.02	-0.01	-0.05			
16-17	Silane/HMWM	2181.76	2308.92	18.33	3.49	2276.31	2277.18	2276.29	2275.00	0.04	0.00	-0.06			
18-7	Silane/HMWM	2192.23	2320.00	13.59	4.62	2307.13	2307.13	2306.38	2305.18	0.00	-0.03	-0.08			
18-8	Silane/HMWM	2217.06	2346.28	13.32	3.37	2305.09	2305.69	2304.78	2303.56	0.03	-0.01	-0.07			
18-9	Silane/HMWM	2224.64	2354.30	13.28	3.36	2312.74	2312.73	2312.15	2310.78	0.00	-0.03	-0.08			
mean					3.68					0.01	-0.02	-0.07			
16-22	Epoxy	2283.35	2416.43	12.79	3.61	2378.51	2378.74	2377.16	2375.86	0.01	-0.06	-0.11	-0.04	-52.04	-359.49
16-23	Epoxy	2267.36	2399.51	10.88	3.66	2361.30	2361.40	2360.28	2359.02	0.00	-0.04	-0.10			
18-18	Epoxy	2208.58	2337.31	12.01	3.23	2291.99	2291.85	2290.49	2289.48	-0.01	-0.07	-0.11			
18-19	Epoxy	2258.83	2390.49	13.74	3.05	2341.47	2341.04	2340.01	2338.87	-0.02	-0.06	-0.11			
18-20	Epoxy	2247.03	2378.00	14.36	3.17	2332.58	2332.48	2331.18	2330.95	0.00	-0.06	-0.07			
18-21	Epoxy	2271.60	2404.00	16.73	3.17	2360.40	2360.74	2358.18	2358.35	0.01	-0.09	-0.09			
mean					3.32					0.00	-0.06	-0.10			
16-18	Silane/Epoxy	2212.33	2341.28	14.42	3.60	2306.46	2306.06	2305.18	2304.38	-0.02	-0.06	-0.09	-8.26	-46.77	-351.04
16-19	Silane/Epoxy	2267.42	2399.58	13.56	3.67	2364.18	2364.13	2363.42	2362.66	0.00	-0.03	-0.06			
18-10	Silane/Epoxy	2226.90	2356.69	14.25	3.24	2313.36	2312.16	2311.30	2310.65	-0.05	-0.09	-0.12			
18-11	Silane/Epoxy	2238.36	2368.82	12.99	3.26	2324.38	2324.07	2322.96	2321.80	-0.01	-0.06	-0.11			
18-12	Silane/Epoxy	2214.05	2343.09	14.40	3.28	2301.14	2301.11	2300.01	2298.96	0.00	-0.05	-0.09			
18-13	Silane/Epoxy	2206.04	2334.62	14.53	3.34	2294.16	2293.96	2292.87	2292.00	-0.01	-0.06	-0.09			
mean					3.40					-0.02	-0.06	-0.10			

Table D.12 Saltwater Absorption Trial 6

Sample ID		Oven Dried		Cured Weight	Moisture Content													
		W_{od1}	W_{sat1}	W_{cca}	M_c	W_0	W_7	W_{14}	W_{21}	ΔW_7	ΔW_{14}	ΔW_{21}	SAR	SAR	SAR
						Initial	7-day	14-day	21-day				7-day	14-day	21-day
						8/9/10	8/16/10	8/23/10	8/30/10						
Number	Class	(g)	(g)	(g)	(%)	Mass(g)	Mass(g)	Mass(g)	Mass(g)	(%)	(%)	(%)	SAR(%)	SAR(%)	SAR(%)
18-22	control	2272.84	2406.75	0.00	3.46	2351.38	2385.27	2388.53	2389.50	1.44	1.58	1.62	100.00	100.00	100.00
22-1	control	2183.59	2312.24	0.00	3.32	2256.09	2291.72	2293.79	2294.02	1.58	1.67	1.68			
23-1	control	2212.14	2342.48	0.00	3.08	2280.31	2316.01	2318.68	2319.28	1.57	1.68	1.71			
Mean					3.29					1.53	1.64	1.67			
18-23	Silane	2274.62	2408.64	3.57	3.52	2358.32	2360.35	2361.99	2361.37	0.09	0.16	0.13	9.22	12.01	10.24
22-4	Silane	2221.24	2352.11	3.62	3.33	2298.78	2302.80	2304.07	2303.25	0.17	0.23	0.19			
23-3	Silane	2184.61	2313.32	3.44	2.88	2250.88	2254.52	2255.53	2255.14	0.16	0.21	0.19			
Mean					3.24					0.14	0.20	0.17			
22-13	HMWM	2190.15	2319.19	10.13	3.35	2273.69	2282.10	2290.20	2295.10	0.37	0.73	0.94	26.46	46.15	58.16
22-14	HMWM	2204.95	2334.86	9.56	3.27	2286.70	2295.15	2303.53	2308.63	0.37	0.74	0.96			
23-10	HMWM	2200.06	2329.68	11.02	3.12	2279.80	2290.61	2298.37	2302.92	0.47	0.81	1.01			
Mean					3.25					0.40	0.76	0.97			
	Silane/HMW M														
18-24	Silane/HMW M	2268.85	2402.53	13.47	3.42	2359.85	2362.20	2363.81	2364.26	0.10	0.17	0.19	6.97	10.29	11.56
22-7	Silane/HMW M	2197.63	2327.11	12.53	3.08	2277.94	2280.39	2281.91	2282.33	0.11	0.17	0.19			
23-5	Silane/HMW M	2221.77	2352.67	13.22	2.94	2300.22	2302.81	2304.03	2304.81	0.11	0.17	0.20			
Mean					3.15					0.11	0.17	0.19			
22-17	Epoxy	2206.53	2336.54	8.91	3.34	2289.05	2293.79	2295.25	2295.96	0.21	0.27	0.30	11.62	15.18	17.24
22-18	Epoxy	2192.68	2321.87	8.99	3.19	2271.61	2275.94	2277.20	2277.57	0.19	0.25	0.26			
23-12	Epoxy	2210.35	2340.58	9.84	3.11	2289.04	2292.14	2294.35	2295.90	0.14	0.23	0.30			
Mean					3.21					0.18	0.25	0.29			
22-10	Silane/Epoxy	2231.80	2363.29	14.33	2.83	2309.28	2310.89	2311.13	2310.90	0.07	0.08	0.07	4.31	5.48	4.49
22-11	Silane/Epoxy	2219.76	2350.54	13.67	2.90	2297.83	2299.45	2300.78	2299.68	0.07	0.13	0.08			
23-7	Silane/Epoxy	2198.34	2327.86	13.09	2.87	2274.58	2275.89	2275.99	2276.27	0.06	0.06	0.07			
Mean					2.87					0.07	0.09	0.07			
22-21	PPC HS	2271.03	2404.84	16.19	2.89	2352.82	2377.44	2381.86	2382.87	1.05	1.23	1.28	67.51	78.97	81.65
22-22	PPC HS	2268.03	2401.66	16.54	2.86	2349.45	2373.82	2379.46	2381.22	1.04	1.28	1.35			
23-14	PPC HS	2195.90	2325.28	15.94	2.70	2271.23	2294.22	2302.67	2304.44	1.01	1.38	1.46			
Mean					2.82					1.03	1.30	1.36			

Table D.13 Summary of Trial 1, 2, 3, and 6 Sodium Chloride Tests

ΔW_{i7}

Trial	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
1	0.58	0.19	0.21	0.06	0.20	0.06
1	1.01	0.17	0.24	0.09	0.17	0.06
1	0.79	0.14	0.47	0.07	0.13	0.09
2	1.18	0.11	0.36	0.07	0.10	0.05
2	1.37	0.13	0.39	0.07	0.12	0.04
2	1.15	0.14	0.63	0.07	0.09	0.07
3	0.42	0.36	0.24	0.15	0.11	0.07
3	0.47	0.35	0.39	0.13	0.11	0.06
3	0.39	0.33	0.25	0.11	0.09	0.06
6	1.44	0.09	0.37	0.10	0.21	0.07
6	1.58	0.17	0.37	0.11	0.19	0.07
6	1.57	0.16	0.47	0.11	0.14	0.06
Mean	1.00	0.20	0.37	0.10	0.14	0.06
Std D	0.45	0.09	0.12	0.03	0.04	0.01
SAR_{7day}	100.00	19.66	36.78	9.53	13.88	6.36

ΔW_{i14}

Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
0.85	0.28	0.39	0.13	0.29	0.09
1.25	0.25	0.46	0.15	0.23	0.08
1.00	0.24	0.73	0.13	0.18	0.12
1.57	0.17	0.61	0.14	0.16	0.07
1.68	0.20	0.68	0.16	0.18	0.07
1.43	0.21	0.92	0.16	0.14	0.07
0.59	0.37	0.46	0.28	0.16	0.08
0.68	0.35	0.68	0.28	0.18	0.09
0.55	0.33	0.46	0.27	0.13	0.09
1.58	0.16	0.73	0.17	0.27	0.08
1.67	0.23	0.74	0.17	0.25	0.13
1.68	0.21	0.81	0.17	0.23	0.06
1.21	0.25	0.64	0.18	0.20	0.09
0.45	0.07	0.17	0.06	0.05	0.02
100.00	20.58	52.82	15.17	16.43	7.14

Mean
Std D
SAR_{14day}

	ΔW_{i21}					
	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
	0.99	0.30	0.49	0.11	0.33	0.09
	1.31	0.23	0.56	0.18	0.24	0.08
	1.08	0.23	0.83	0.14	0.20	0.12
	1.88	0.25	0.73	0.16	0.19	0.07
	1.96	0.24	0.85	0.20	0.20	0.07
	1.70	0.31	1.07	0.19	0.18	0.09
	0.67	0.40	0.61	0.32	0.18	0.07
	0.81	0.36	0.79	0.33	0.17	0.08
	0.57	0.38	0.55	0.30	0.14	0.08
	1.62	0.13	0.94	0.19	0.30	0.07
	1.68	0.19	0.96	0.19	0.26	0.08
	1.71	0.19	1.01	0.20	0.30	0.07
Mean	1.33	0.27	0.78	0.21	0.22	0.08
Std D	0.49	0.08	0.20	0.07	0.06	0.01
SAR_{21day}	100.00	20.05	58.82	15.74	16.85	6.09

Magnesium Chloride Summary

	ΔW_{i7}					
Trial	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
4	0.00	-0.02	0.00	-0.01	-0.01	0.02
4	0.03	-0.02	-0.01	-0.01	0.00	0.00
4	0.01	-0.02	-0.01	-0.01	0.02	-0.01
4	0.00	-0.01	-0.02	0.00	0.00	0.00
4	-0.01	-0.02	-0.01	-0.01	0.00	0.00
4	-0.04	-0.02	-0.01	0.01	0.00	0.00
5	0.19	-0.04	-0.02	0.00	0.01	-0.02
5	0.15	-0.05	-0.01	0.02	0.00	0.00
5	0.25	-0.07	-0.02	0.04	-0.01	-0.05
5	0.17	-0.08	-0.03	0.00	-0.02	-0.01
5	0.19	-0.06	-0.03	0.03	0.00	0.00
5	0.20	-0.06	0.00	0.00	0.01	-0.01
Mean	0.09	-0.04	-0.01	0.00	0.00	-0.01
Std D	0.11	0.02	0.01	0.02	0.01	0.02
SAR_{7day}	100.00	-42.86	-14.78	4.59	0.21	-7.24

	ΔW_{i14}					
	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
	-0.14	-0.14	-0.07	-0.06	-0.06	-0.03
	-0.09	-0.14	-0.07	-0.05	-0.03	-0.04
	-0.11	-0.11	-0.05	-0.04	-0.02	-0.04
	-0.13	-0.10	-0.07	-0.05	-0.04	-0.04
	-0.14	-0.12	-0.07	-0.04	-0.03	-0.04
	-0.15	-0.14	-0.07	-0.04	-0.05	-0.04
	0.13	-0.14	-0.07	-0.02	-0.06	-0.06
	0.08	-0.14	-0.06	-0.01	-0.04	-0.03
	0.19	-0.13	-0.06	0.00	-0.07	-0.09
	0.09	-0.14	-0.08	-0.03	-0.06	-0.06
	0.11	-0.16	-0.10	-0.01	-0.06	-0.05
	0.13	-0.16	-0.06	-0.03	-0.09	-0.06
Mean	0.00	-0.13	-0.07	-0.03	-0.05	-0.05
Std D	0.13	0.02	0.01	0.02	0.02	0.02
SAR_{7day}	100.00	6163.70	3143.21	1484.86	2338.81	2196.59

	ΔW_{i21}					
	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
	-0.25	-0.26	-0.13	-0.11	-0.11	-0.09
	-0.22	-0.24	-0.13	-0.09	-0.07	-0.07
	-0.19	-0.18	-0.10	-0.08	-0.07	-0.08
	-0.19	-0.15	-0.12	-0.07	-0.07	-0.07
	-0.25	-0.18	-0.12	-0.08	-0.07	-0.08
	-0.26	-0.23	-0.12	-0.08	-0.09	-0.08
	0.04	-0.24	-0.13	-0.07	-0.11	-0.09
	-0.01	-0.24	-0.12	-0.05	-0.10	-0.06
	0.08	-0.25	-0.13	-0.06	-0.11	-0.12
	-0.01	-0.28	-0.17	-0.08	-0.11	-0.11
	0.02	-0.26	-0.19	-0.07	-0.07	-0.09
	0.04	-0.26	-0.12	-0.08	-0.09	-0.09
Mean	-0.10	-0.23	-0.13	-0.08	-0.09	-0.09
Std D	0.14	0.04	0.02	0.01	0.02	0.02

SAR_{7day}	100.00	229.26	130.03	76.00	87.58	87.41

Alkali Resistance

Table D.14 Alkali Resistance Trial 1

		12/28/2009	1/4/2010				1/25/2010	2/1/2010					
		Initial Saltwater		weight		Mean	Final Saltwater		weight		Mean		
Sample	Sealer Class	W_0 Mass(g)	W_{fr} Mass(g)	change Mass(g)	ΔW_{fr} (%)	ΔW_{fr-m} (%)	SAR_{water}	W_0 Mass(g)	W_{fr} Mass(g)	change Mass(g)	$\Delta W_{fralkali}$ (%)	$\Delta W_{fralkali-m}$ (%)	SAR_{alkali}	Ratio SAR_{alkali}/ $SAR_{initial}$
1-5	HMVtM	2382.25	2391.20	8.95	0.38			2383.49	2393.40	9.91	0.42			
6-13	HMVtM	2331.14	2343.49	12.35	0.53	0.42	63.70	2339.00	2347.26	8.26	0.35	0.34	60.32	0.95
6-14	HMVtM	2315.12	2322.99	7.87	0.34			2319.15	2324.97	5.82	0.25			
7-6	HMVtM silane	2344.23	2345.85	1.62	0.07			2336.17	2336.45	0.28	0.01			
6-23	HMVtM silane	2323.55	2325.03	1.48	0.06	0.08	12.18	2304.81	2305.57	0.76	0.03	0.02	3.20	0.26
6-24	HMVtM silane	2315.35	2317.79	2.44	0.11			2302.17	2302.38	0.21	0.01			
7-8	control	2303.17	2322.48	19.31	0.84			2302.00	2323.29	21.29	0.92			
6-2	control	2350.87	2364.04	13.17	0.56	0.65	100.00	2353.01	2361.62	8.61	0.37	0.56	100.00	1.00
6-3	control	2347.40	2360.46	13.06	0.56			2345.41	2354.79	9.38	0.40			
7-2	Silane	2330.92	2335.26	4.34	0.19			2318.47	2319.15	0.68	0.03			
6-7	Silane	2304.50	2308.25	3.75	0.16	0.17	26.59	2294.24	2295.57	1.33	0.06	0.05	8.85	0.33
6-8	Silane	2304.93	2308.87	3.94	0.17			2294.79	2296.22	1.43	0.06			
1-4	Epoxy	2375.36	2378.72	3.36	0.14			2372.51	2373.95	1.44	0.06			
6-9	Epoxy	2327.37	2331.09	3.72	0.16	0.16	24.48	2325.60	2328.31	2.71	0.12	0.13	23.48	0.96
6-10	Epoxy	2328.75	2332.88	4.13	0.18			2325.63	2330.74	5.11	0.22			
1-6	Epoxy silane	2393.28	2394.77	1.49	0.06			2386.84	2386.38	-0.46	-0.02			
6-17	Epoxy silane	2333.39	2335.34	1.95	0.08	0.06	9.96	2326.18	2326.07	-0.11	0.00	-0.01	-1.57	-0.16
6-18	Epoxy silane	2331.69	2332.83	1.14	0.05			2324.69	2324.63	-0.06	0.00			

Table D.15 Alkali Resistance Trial 2

		3/11/2010 3/18/2010						4/9/2010 4/16/2010						
		Initial Saltwater		weight		Mean		Final Saltwater		weight		Mean		
	Sealer	W_{ip}	W_{ip}	change	ΔW_{ip}	ΔW_{ip-m}		W_{ip}	W_{ip}	change	$\Delta W_{ipalkali}$	$\Delta W_{ipalkali-m}$		Ratio
Sample	Class	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	$SAR_{Initial}$	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	SAR_{alkali}	$SAR_{alkali}/SAR'_{Initial}$
8-9	HMWM	2295.41	2304.94	9.53	0.415176			2315.7	2325.48	9.78	0.422334			
9-5	HMWM	2322.68	2337.55	14.87	0.640209	0.546726	71.45482	2340.47	2355.39	14.92	0.637479	0.52306	63.40573	0.887354
9-6	HMWM	2329.03	2342.65	13.62	0.584793			2346.05	2358	11.95	0.509367			
8-22	HMWM silane	2354.52	2355.97	1.45	0.061584			2355.6	2358.4	2.8	0.118866			
8-23	HMWM silane	2355.15	2356.53	1.38	0.058595	0.070513	9.215713	2355.93	2358.82	2.89	0.122669	0.117636	14.25992	1.547349
9-16	HMWM silane	2287.67	2289.76	2.09	0.091359			2289.6	2292.15	2.55	0.111373			
8-6	control	2297.33	2320.1	22.77	0.991151			2321.05	2341.89	20.84	0.897869			
9-2	control	2270.9	2286.42	15.52	0.683429	0.765135	100	2292.73	2311.5	18.77	0.818675	0.824941	100	1
9-3	control	2272.78	2286.89	14.11	0.620826			2292.03	2309.41	17.38	0.75828			
8-15	Silane	2260.31	2263.42	3.11	0.137592			2262.29	2266.36	4.07	0.179906			
9-11	Silane	2264.97	2267.86	2.89	0.127596	0.139092	18.17872	2267.09	2271.5	4.41	0.194522	0.186831	22.64774	1.245838
9-12	Silane	2255.27	2258.7	3.43	0.152088			2257.3	2261.5	4.2	0.186063			
8-12	Epoxy	2267.15	2269.38	2.23	0.098361			2273.93	2274.5	0.57	0.025067			
9-8	Epoxy	2273.29	2274.97	1.68	0.073902	0.086562	11.3133	2279.4	2279.89	0.49	0.021497	0.047068	5.705658	0.504332
9-9	Epoxy	2276.29	2278.28	1.99	0.087423			2282.3	2284.46	2.16	0.094641			
8-18	Epoxy silane	2273.71	2274.75	1.04	0.04574			2274.78	2275.59	0.81	0.035608			
8-19	Epoxy silane	2334.95	2336.12	1.17	0.050108	0.048748	6.371152	2336.3	2336.89	0.59	0.025254	0.033689	4.083812	0.640985
9-14	Epoxy silane	2262.11	2263.25	1.14	0.050395			2263.36	2264.27	0.91	0.040206			

Table D.16 Alkali Resistance Trial 3

		4/1/2010	4/8/2010					5/6/2010	5/13/2010					
		Initial Saltwater		weight		Mean		Final Saltwater		weight		Mean		
	Sealer	W_{i0}	W_{i7}	change	ΔW_{i7}	$\Delta W_{i7\text{-}m}$		W_{i0}	W_{i7}	change	$\Delta W_{i7alkali}$	$\Delta W_{i7alkali\text{-}m}$		Ratio
Sample	Class	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	$SAR_{initial}$	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	SAR_{alkali}	$SAR_{alkali}/SAR_{initial}$
9-17	HMWM	2260.03	2265.01	4.98	0.22			2262.96	2283.13	20.17	0.89			
10-1	HMWM	2246.38	2254.71	8.33	0.37	0.26	47.58	2250.89	2275.73	24.84	1.10	0.90	119.01	2.50
11-1	HMWM	2286.13	2290.61	4.48	0.20			2289.84	2306.05	16.21	0.71			
9-18	HMWM silane	2260.78	2263.53	2.75	0.12			2258.97	2264.11	5.14	0.23			
10-4	HMWM silane	2283.55	2285.58	2.03	0.09	0.11	19.16	2282.03	2285.93	3.90	0.17	0.22	28.42	1.48
11-3	HMWM silane	2274.65	2277.07	2.42	0.11			2271.12	2276.73	5.61	0.25			
9-19	control	2260.75	2271.21	10.46	0.46			2260.29	2276.16	15.87	0.70			
10-7	control	2202.06	2215.86	13.80	0.63	0.55	100.00	2203.82	2222.19	18.37	0.83	0.76	100.00	1.00
11-5	control	2245.90	2258.59	12.69	0.57			2246.66	2263.18	16.52	0.74			
9-20	Silane	2273.60	2278.43	4.83	0.21			2270.39	2278.14	7.75	0.34			
10-10	Silane	2233.97	2239.52	5.55	0.25	0.22	40.27	2231.23	2240.26	9.03	0.40	0.35	46.62	1.16
11-7	Silane	2293.46	2298.17	4.71	0.21			2290.33	2297.49	7.16	0.31			
9-21	Epoxy	2279.51	2281.59	2.08	0.09			2281.27	2283.80	2.53	0.11			
10-13	Epoxy	2268.81	2271.50	2.69	0.12	0.10	18.39	2270.75	2273.66	2.91	0.13	0.12	15.79	0.86
11-9	Epoxy	2306.99	2309.17	2.18	0.09			2309.22	2311.98	2.76	0.12			
9-22	Epoxy silane	2290.51	2291.76	1.25	0.05			2289.89	2290.99	1.10	0.05			
10-16	Epoxy silane	2260.08	2261.64	1.56	0.07	0.06	11.13	2259.45	2261.49	2.04	0.09	0.06	8.31	0.75
10-17	Epoxy silane	2280.81	2282.19	1.38	0.06			2280.19	2281.34	1.15	0.05			
9-23	PPC HS	2276.23	2284.90	8.67	0.38			2277.27	2313.51	36.24	1.59			
10-20	PPC HS	2318.68	2326.25	7.57	0.33	0.36	65.65	2320.78	2354.15	33.37	1.44	1.51	198.94	3.03
10-21	PPC HS	2316.04	2324.81	8.77	0.38			2317.50	2352.00	34.50	1.49			

Table D.17 Alkali Resistance Trial 6

			4/1/2009	4/8/2010				5/6/2010	5/13/2010						
			Initial Saltwater		weight	Mean		Final Saltwater		weight		Mean			
	Sealer		W_i	W_f	change	ΔW_{ave}	SAR_{ave}	W_f	W_f	change	$\Delta W_{calculated}$	$\Delta W_{calculated}$	$SAR_{calculated}$	Ratio	$\frac{SAR_{ave}}{SAR_{calculated}}$
Sample	Class	Mass (g)	Mass (g)	Mass (g)	(%)	(%)		Mass (g)	Mass (g)	(%)	(%)	(%)			
22-15	HMWM	2276.23	2284.03	7.8	0.342672			2274.95	2305.74	30.78	1.352891				
22-16	HMWM	2287.5	2295.32	7.82	0.341853	0.353372	22.76302	2286.23	2318.4	30.12	1.317424	1.314226	69.29215	3.044067	
23-11	HMWM	2300.4	2309.04	8.64	0.375587			2303.77	2333.08	29.31	1.272282				
22-8	HMWM silane	2286.09	2288.13	2.04	0.089235			2287.5	2290.01	2.51	0.109727				
22-9	HMWM silane	2291.91	2294.4	2.49	0.108643	0.099384	6.401975	2293.37	2296.74	3.37	0.146945	0.129004	6.801707	1.062439	
23-6	HMWM silane	2283.75	2286.04	2.29	0.100274			2286.32	2289.3	2.98	0.13034				
22-2	control	2300.25	2334.62	34.37	1.494185			2296.03	2339.28	43.2	1.881463				
22-3	control	2290.21	2325.6	35.39	1.545273	1.552396	100	2286.71	2329.7	42.99	1.879994	1.880644	100	1	
23-2	control	2282.43	2289.03	36.6	1.61773			2259.82	2303.4	43.58	1.928472				
22-5	Silane	2288.66	2303	3.34	0.145233			2288.55	2303.62	3.97	0.172642				
22-6	Silane	2283.86	2287.44	3.58	0.156752	0.157327	10.13449	2284.18	2288.39	4.21	0.184311	0.184426	9.723782	0.959475	
23-4	Silane	2276.59	2280.46	3.87	0.169991			2276.85	2281.33	4.47	0.196323				
22-19	Epoxy	2360.25	2364.42	4.17	0.176678			2360.23	2366.77	6.54	0.277092				
22-20	Epoxy	2336.33	2340.29	3.96	0.169497	0.218566	14.07924	2335.31	2342.16	6.85	0.293323	0.376565	10.95919	1.417633	
23-13	Epoxy	2271.23	2278.26	7.03	0.309524			2273.33	2286.18	12.85	0.56525				
22-12	Epoxy silane	2283.8	2287.82	4.02	0.176022			2286.65	2287.94	1.28	0.056977				
23-8	Epoxy silane	2301.62	2303.46	1.84	0.079944	0.116114	7.476686	2302.33	2303.22	0.84	0.036484	0.046471	2.566607	0.341873	
23-9	Epoxy silane	2284.12	2286.23	2.11	0.092377			2285.11	2286.32	1.21	0.052951				
22-23	PPC HS	2352.6	2376.57	23.97	1.018873			2345.55	2383.92	38.37	1.635884				
22-24	PPC HS	2367.25	2391	23.75	1.003274	1.019729	65.66742	2362.05	2398.39	36.33	1.538064	1.537112	81.04378	1.233779	
23-15	PPC HS	2285.35	2309.05	23.7	1.03704			2298.84	2321.74	22.9	1.437409				

Table D.18 Alkali Resistance Summary

ΔW_{i7}
Initial 7 day
Saltwater

Trial	Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
1	0.838	0.186	0.376	0.069	0.141	0.062
1	0.560	0.163	0.530	0.064	0.160	0.084
1	0.556	0.171	0.340	0.105	0.177	0.049
2	0.991	0.138	0.415	0.062	0.098	0.046
2	0.683	0.128	0.640	0.059	0.074	0.050
2	0.621	0.152	0.585	0.091	0.087	0.050
3	0.463	0.212	0.220	0.122	0.091	0.055
3	0.627	0.248	0.371	0.089	0.119	0.069
3	0.565	0.205	0.196	0.106	0.094	0.061
6	1.494	0.145	0.145	0.089	0.177	0.176
6	1.545	0.157	0.157	0.109	0.169	0.080
6	1.618	0.170	0.170	0.100	0.310	0.092
Mean	0.88	0.17	0.35	0.09	0.14	0.07
Std	0.43	0.03	0.17	0.02	0.07	0.04
$SAR_{initial}$	100.00	19.65	39.24	10.08	16.08	8.27

$\Delta W_{i7alkali}$
Final 7 Day Salt Water

Control	Silane	HMWM	Silane/ HMWM	Epoxy	Silane/ Epoxy
0.925	0.029	0.416	0.012	0.061	-0.019
0.366	0.058	0.353	0.033	0.117	-0.005
0.400	0.062	0.251	0.009	0.220	-0.003
0.898	0.180	0.422	0.119	0.025	0.036
0.819	0.195	0.637	0.123	0.021	0.025
0.758	0.186	0.509	0.111	0.095	0.040
0.702	0.341	0.891	0.228	0.111	0.048
0.834	0.405	1.104	0.171	0.128	0.090
0.735	0.313	0.708	0.247	0.120	0.050
1.881	0.172642	1.353	0.110	0.277	0.056
1.880	0.184311	1.317	0.147	0.293	0.036
1.928	0.196323	1.272	0.130	0.565	0.053
1.01	0.19	0.77	0.12	0.17	0.03
0.56	0.11	0.40	0.08	0.15	0.03
100.00	19.15	76.15	11.87	16.76	3.37
1.00	0.97	1.94	1.18	1.04	0.41

Mean
Std
SAR_{alkali}
$SAR_{alkali}/SAR_{initial}$

Depth of Penetration

Table D.19 Depth of Penetration Summary

Location	Sample 9-18 Silane (mm)	9-20 Silane (mm)	10-4 HMWM/ Silane (mm)	10-10 Silane (mm)	10-16 Epoxy/ Silane (mm)	10-17 Epoxy/ Silane (mm)	
1	2.5	2.5	3.5	3	2.5	4.5	
2	2.5	2.5	3	3	3	2.5	
3	2.5	3.5	3	2	4.5	3	
4	2.5	2.5	3.5	3	4.5	3	
5	3	3.5	4	2.5	2	2	
6	5	2.5	2.4	3	2.5	2.5	
7	5	3.5	3.5	2.5	5	4	
8	6.5	3	3.5	3	4	4	
9	7.5	3	3.5	3	4.5	3.5	
10	3.5	3.5	4	3	5.5	5	
11	9	3.5	3.5	3.5	6.5	5	
12	5.5	2.5	3.5	4	4.5	5	
13	4	3	3.5	4	3	4	
14	3	3.5	3.5	3	3	3.5	
15	4	4.5	2.5	3	3	4.5	
16	3.5	5	3.5	3	2.5	3.5	
17	3.5	3.5	4	3.5	2.5	3.5	
18	4.5	3	3	3.5	5	3	
19	4.5	3	2.5	3	3.5	6	
20	3.5	3.5	2	2.5	3.5	5	
21	4.5	3.5	2	3.5	3	5.5	
22	3.5	4	2.5	5	5	4.5	
23	5	4.5	2.5	3	5.5	5	
24	5	5	2.5	3.5	4	5.5	All Locations
Mean	4.3	3.4	3.1	3.2	3.9	4.1	3.7
Max	9.0	5.0	4.0	5.0	6.5	6.0	9.0
Min	2.5	2.5	2.0	2.0	2.0	2.0	2.0
Std. Dev	1.6	0.7	0.6	0.6	1.2	1.1	1.1

UV Weathering and Saltwater Resistance

Trial 2

Table D.20 UV Chloride Concentrations

Chloride (kg/m^3)			Assume Unit Weight equals	2323.000	(kg/m^3)		
Depth	Control 12-1	Control 13-1	Control 14-1	Control Mean	Silane 12-2	Silane 13-2	Silane 14-2	Silane Mean
1/4-1/2"	14.815	9.150	13.907	12.624	0.091	0.285	0.007	0.128
5/8-7/8"	7.106	5.734	7.577	6.806	0.035	0.035	0.203	0.091
1-1 1/4"	0.452	0.286	0.174	0.304	0.007	0.035	0.035	0.026
1 3/8-1 5/8"	0.008	-0.048	-0.048	0.000	0.035	0.007	-0.076	0.000

Chloride (kg/m^3)								
Depth	Silane/ HMWM 12-3	Silane/ HMWM 13-3	Silane/ HMWM 14-3	Silane/ HMWM Mean	Silane/ Epoxy 12-4	Silane/ Epoxy 13-4	Silane/ Epoxy 14-4	Silane/ Epoxy Mean
1/4-1/2"	0.146	0.147	-0.048	0.082	0.091	0.119	0.007	0.072
5/8-7/8"	0.147	0.091	-0.048	0.063	0.063	0.007	0.035	0.035
1-1 1/4"	0.035	0.091	-0.020	0.035	0.008	0.007	0.008	0.008
1 3/8-1 5/8"	-0.021	0.007	-0.021	0.000	0.035	0.063	-0.048	0.017

Chloride (kg/m^3)								
Depth	Epoxy 12-5	Epoxy 13-5	Epoxy 14-5	Epoxy Mean	HMWM 12-6	HMWM 13-6	HMWM 14-6	HMWM Mean
1/4-1/2"	0.007	0.202	0.286	0.165	0.091	0.119	-0.022	0.063
5/8-7/8"	-0.020	0.118	0.007	0.035	0.091	0.063	-0.049	0.035
1-1 1/4"	-0.020	0.063	-0.020	0.007	0.007	0.091	-0.076	0.007
1 3/8-1 5/8"	-0.048	0.063	-0.020	0.000	0.035	0.035	-0.049	0.007

Freeze-thaw Resistance

Table D.21 Freeze Thaw Trial 1

Freeze Thaw	1/27/2010													6/16/2010							
Trial #1	Initial Saltwater	weight		SAR	Freeze Thaw				Deterioration Rating		FTR	Target weight	Final Saltwater		weight		SAR$_{FT}$		
	Sealer	W_0	W_1	change	ΔW_1	7-day	100 cycle	200 cycle	300 cycle	ΔW_{FT}	(1-5)		W_0	W_1	change	ΔW_1	7-day	SAR$_{FT}$/ SAR	
Sample	Class	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	Mass (g)	Mass (g)	Mass (g)	(%)			Mass (g)	Mass (g)	Mass (g)	(%)	(%)	ratio	
7-9	silane	2278.92	2281.75	2.83	0.12	7.53	2285.89		2279.35	0.11	2.00	14.37	2276.52	2261.46	2266.09	4.63	0.20	17.24	2.29
7-10	silane	2318.47	2320.85	2.38	0.10		2326.29		2319.12	0.07	2.00		2316.74	2301.35	2307.42	6.07	0.26		
8-1	silane	2320.12	2322.64	2.52	0.11		2326.28		2317.43	0.22	2.00		2314.91	2297.74	2304.50	6.76	0.29		
													0.00						
	Dual/ silane		Mean	2.58	0.11					0.13	2.00					5.82	0.25		
7-11	Dual/ hmwm	2319.87	2320.52	0.65	0.03	3.39	2320.34		2333.42	-0.56	0.00	-48.03	2332.77	2322.40	2324.72	2.32	0.10	7.36	2.17
7-12	Dual/ hmwm	2322.09	2323.22	1.13	0.05		2322.60		2335.94	-0.55	1.00		2334.81	2324.29	2326.71	2.42	0.10		
8-2	Dual/ hmwm	2322.69	2324.42	1.73	0.07		2324.26		2330.17	-0.25	0.00		2328.44	2319.10	2321.92	2.82	0.12		
													0.00						
	Dual/ hmwm		Mean	1.17	0.05					-0.45	0.33					2.52	0.11		
7-13	Dual/ epoxy	2266.62	2267.60	0.98	0.04	2.91	2266.90		2271.28	-0.16	0.00	-21.69	2270.30	2270.09	2271.34	1.25	0.06	3.10	1.07
7-14	Dual/ epoxy	2276.18	2277.34	1.16	0.05		2277.40		2282.36	-0.22	0.00		2281.20	2280.68	2281.94	1.26	0.06		
8-3	Dual/ epoxy	2331.87	2332.70	0.83	0.04		2332.41		2338.00	-0.23	1.00		2337.17	2336.49	2337.12	0.63	0.03		
													0.00						
	Dual/ epoxy		Mean	0.99	0.04					-0.20	0.33					1.05	0.05		
7-16	control	2277.65	2310.39	32.74	1.44	100.00	2297.82		2291.72	0.81	2.00	100.00	2258.98	2258.13	2291.97	33.84	1.50	100.00	1.00
7-17	control	2258.40	2292.10	33.70	1.49		2273.50		2267.82	1.06	2.00		2234.12	2235.00	2267.01	32.01	1.43		
7-18	control	2267.49	2302.09	34.60	1.53		2284.57		2280.34	0.94	2.00		2245.74	2246.62	2280.17	33.55	1.49		
													0.00						
	control		Mean	33.68	1.49					0.94	2.00					33.13	1.47		
7-19	Epoxy	2296.01	2298.61	2.60	0.11	7.64	2302.80		2313.30	-0.64	0.00	-70.76	2310.70	2305.51	2309.65	4.14	0.18	11.58	1.52
7-20	Epoxy	2284.46	2286.93	2.47	0.11		2290.98		2303.82	-0.74	1.00		2301.35	2296.12	2298.96	2.84	0.12		
7-21	Epoxy	2268.95	2271.65	2.70	0.12		2276.01		2285.56	-0.61	0.00		2282.86	2278.21	2282.97	4.76	0.21		
													0.00						
	Epoxy		Mean	2.59	0.11					-0.66	0.33					3.91	0.17		
7-22	HMWM	2298.43	2302.30	3.87	0.17	13.77	2309.26		2324.12	-0.95	1.00	-96.64	2320.25	2301.53	2326.39	24.86	1.08	75.16	5.46
7-23	HMWM	2295.29	2301.86	6.57	0.29		2310.35		2320.66	-0.82	0.00		2314.09	2296.11	2322.00	25.89	1.13		
7-24	HMWM	2282.08	2285.71	3.63	0.16		2292.61		2307.50	-0.95	1.00		2303.87	2285.06	2310.60	25.54	1.12		
													0.00						
	HMWM		Mean	4.69	0.20					-0.91	0.67					25.43	1.11		

Table D.22 Freeze Thaw Trial 2

Freeze Thaw Trial #2		6/14/2010 Initial Saltwater weight				SAR	Freeze Thaw						Deterioration Rating	Target weight	8/16/2010 Final Saltwater weight				SAR$_{FT}$	
	Sealer	W_{i0}	W_{i7}	change	ΔW_{i7}	7-day	100 cycle	200 cycle	300 cycle	ΔW_{WT}	FTR				W_{i0}	W_{i7}	change	ΔW_{i7}	7-day	SAR$_{FT}$/ SAR
Sample	Class	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	Mass (g)	Mass (g)	Mass (g)	(%)			(1-5)		Mass (g)	Mass (g)	Mass (g)	(%)	(%)	ratio
17-1	silane	2293.85	2297.29	3.44	0.15	11.37	2300.34	2289.19	2246.43	2.21	359.57		2.00	2242.99	2218.02	2228.09	10.07	0.45	34.15	3.00
17-2	silane	2317.01	2320.74	3.73	0.16		2326.82	2310.09	2266.90	2.32			2.00	2263.17	2237.68	2248.93	11.25	0.50		
17-3	silane	2307.38	2311.29	3.91	0.17		2315.66	2299.22	2247.16	2.77			2.00	2243.25	2217.83	2229.65	11.82	0.53		
17-4	silane	2311.90	2316.50	4.60	0.20		2318.38	2302.92	2249.09	2.91			2.00	2244.49	2219.00	2232.56	13.56	0.61		
			Mean	3.92	0.17					2.55							11.68	0.53		
17-5	Dual/ hmwm	2318.77	2322.06	3.29	0.14	9.31	2330.78	2343.31	2347.15	-1.08	-146.94		0.00	2343.86	2319.65	2324.20	4.55	0.20	12.23	1.31
17-6	Dual/ hmwm	2313.44	2316.43	2.99	0.13		2320.31	2330.18	2335.23	-0.81			1.00	2332.24	2312.03	2315.67	3.64	0.16		
17-7	Dual/ hmwm	2254.90	2258.27	3.37	0.15		2269.67	2282.42	2286.33	-1.24			0.00	2282.96	2257.03	2261.52	4.49	0.20		
17-8	Dual/ hmwm	2262.55	2265.62	3.07	0.14		2273.04	2283.46	2289.21	-1.04			1.00	2286.14	2263.44	2267.96	4.52	0.20		
			Mean	3.18	0.14					-1.04							4.30	0.19		
17-9	Dual/ epoxy	2279.06	2282.24	3.18	0.14	8.92	2285.58	2289.40	2295.76	-0.59	-77.36		0.00	2292.58	2283.11	2285.65	2.54	0.11	7.46	0.84
17-10	Dual/ epoxy	2261.36	2264.46	3.10	0.14		2268.23	2272.31	2271.25	-0.30			2.00	2268.15	2260.23	2262.59	2.36	0.10		
17-11	Dual/ epoxy	2236.06	2238.92	2.86	0.13		2242.99	2246.94	2253.27	-0.64			0.00	2250.41	2240.15	2242.60	2.45	0.11		
17-12	Dual/ epoxy	2254.92	2257.81	2.89	0.13		2262.43	2267.08	2272.83	-0.67			0.00	2269.94	2259.14	2262.16	3.02	0.13		
			Mean	3.01	0.13					-0.55							2.59	0.11		
17-21	control	2264.24	2297.58	33.34	1.47	100.00	2301.89	2289.48	2283.52	0.61	100.00		2.00	2250.18	2246.51	2280.22	33.71	1.50	100.00	1.00
17-22	control	2262.06	2296.55	34.49	1.52		2298.76	2286.27	2279.78	0.73			2.00	2245.29	2241.48	2276.60	35.12	1.57		
17-23	control	2260.48	2294.35	33.87	1.50		2295.76	2288.16	2281.50	0.56			2.00	2247.63	2243.50	2278.62	35.12	1.57		
17-24	control	2262.13	2295.60	33.47	1.48		2296.44	2284.51	2274.03	0.94			2.00	2240.56	2237.55	2271.52	33.97	1.52		
			Mean	33.79	1.49					0.71							34.48	1.54		
17-17	Epoxy	2268.12	2271.88	3.76	0.17	11.56	2275.53	2282.40	2285.06	-0.58	-83.88		0.00	2281.30	2273.50	2275.71	2.21	0.10	6.25	0.54
17-18	Epoxy	2266.50	2270.39	3.89	0.17		2274.36	2280.31	2282.50	-0.53			0.00	2278.61	2272.11	2274.40	2.29	0.10		
17-19	Epoxy	2267.13	2271.29	4.16	0.18		2274.70	2281.70	2284.59	-0.59			1.00	2280.43	2274.21	2276.15	1.94	0.09		
17-20	Epoxy	2261.84	2265.68	3.84	0.17		2271.63	2279.10	2281.19	-0.68			0.00	2277.35	2270.16	2272.46	2.30	0.10		
			Mean	3.91	0.17					-0.60							2.19	0.10		
17-13	HMWM	2265.75	2275.13	9.38	0.41	24.47	2289.97	2298.16	2300.59	-1.12	-160.65		0.00	2291.21	2271.49	2291.27	19.78	0.87	55.46	2.27
17-14	HMWM	2266.21	2274.67	8.46	0.37		2288.50	2298.35	2300.44	-1.13			1.00	2291.98	2271.43	2291.48	20.05	0.88		
17-15	HMWM	2270.50	2278.09	7.59	0.33		2291.02	2301.12	2303.89	-1.13			0.00	2296.30	2275.28	2294.55	19.27	0.85		
17-16	HMWM	2279.40	2287.16	7.76	0.34		2301.27	2311.60	2314.17	-1.18			0.00	2306.41	2286.07	2304.61	18.54	0.81		
			Mean	8.30	0.37					-1.14							19.41	0.85		

Table D.23 Freeze Thaw Trial 3

		3/20/2010												f						
		Initial Saturated weight				SAR	Freeze Thaw							Final Saturated weight				SAR_{7d}		
	Sealer	W_i	W_i	change	ΔW_i	7-day	100 cycle	200 cycle	300 cycle	ΔW_{FT}	FTR	Target weight		W_f	W_f	change	ΔW_f	7-day	SAR	/SAR
Sample	Class	Mass (g)	Mass (g)	Mass (g)	(%)	(%)	Mass (g)	Mass (g)	Mass (g)	(%)				Mass (g)	Mass (g)	Mass (g)	(%)	(%)	ratio	
23-18	silane	2291.22	2299.59	2.39	0.05	7.47	2295.22	2281.19	2220.15	2.75	921.79	2225.10		2209.43	2218.23	14.79	0.67	66.14	7.57	
23-19	silane	2345.60	2346.24	2.44	0.10		2345.62	2301.57	2262.77	3.63		2267.23		2234.62	2252.23	17.75	0.79			
24-3	silane	2265.46	2268.54	2.39	0.09		2265.80	2230.34	2191.32	3.43		2196.23		2165.22	2179.12	13.84	0.64			
24-4	silane	2265.37	2269.20	2.33	0.13		2265.63	2223.36	2170.41	4.35		2167.58		2142.23	2160.23	17.94	0.84			
Mean				2.39	0.10					3.65						16.03	0.74			
23-20	Duralumum	2361.90	2362.80	0.90	0.04	3.36	2364.64	2363.73	2372.63	-0.42	-36.27	2361.90		2361.62	2364.13	2.55	0.11	6.51	1.34	
24-5	Duralumum	2273.69	2280.47	1.55	0.07		2281.64	2284.33	2285.52	-0.22		2275.69		2275.52	2277.33	1.85	0.08			
24-8	Duralumum	2298.08	2298.98	0.88	0.04		2300.62	2303.76	2308.61	-0.42		2298.08		2298.48	2299.63	1.03	0.05			
24-7	Duralumum	2232.73	2233.62	0.89	0.04		2235.60	2240.56	2246.63	-0.64		2232.73		2231.73	2234.12	2.33	0.10			
Mean				1.06	0.05					-0.43						1.95	0.09			
23-21	Dual epoxy	2343.24	2345.80	0.56	0.02	2.37	2345.67	2351.20	2356.35	-0.33	-32.94	2345.24		2347.81	2348.64	0.83	0.03	2.89	1.22	
24-8	Dual epoxy	2335.23	2336.54	0.71	0.03		2336.11	2340.40	2348.83	-0.34		2335.23		2336.31	2337.70	1.39	0.06			
24-9	Dual epoxy	2360.20	2361.10	0.76	0.03		2360.74	2365.40	2369.24	-0.35		2360.20		2361.25	2362.08	0.83	0.04			
24-10	Dual epoxy	2244.54	2245.29	0.35	0.04		2246.75	2253.36	2254.53	-0.41		2244.54		2246.86	2247.59	0.73	0.03			
Mean				0.70	0.03					-0.33						0.89	0.04			
23-16	control	2287.20	2318.16	30.76	1.35	100.00	2304.78	2302.38	2296.15	0.95	100.00	2265.20		2264.00	2293.63	29.63	1.30	100.00	1.30	
23-17	control	2273.65	2304.47	30.82	1.36		2295.29	2293.74	2288.75	0.63		2257.67		2256.95	2285.92	28.97	1.28			
24-1	control	2275.20	2305.79	30.46	1.34		2295.65	2292.30	2276.07	1.29		2245.58		2246.05	2273.81	28.75	1.28			
24-2	control	2253.16	2285.54	32.38	1.44		2285.64	2269.53	2251.52	1.49		2216.13		2218.83	2249.33	30.45	1.37			
Mean				31.15	1.37					1.10						29.43	1.31			
23-22	Epoxy	2332.93	2335.53	2.12	0.09	7.76	2336.20	2342.34	2349.42	-0.62	-56.99	2332.93		2333.91	2340.14	6.15	0.26	22.22	2.54	
24-14	Epoxy	2335.27	2336.46	2.39	0.10		2342.50	2347.10	2353.75	-0.65		2335.27		2338.75	2344.09	5.34	0.23			
24-15	Epoxy	2323.26	2325.73	2.48	0.11		2334.63	2338.34	2346.13	-0.62		2325.26		2329.45	2335.63	6.05	0.26			
24-16	Epoxy	2183.60	2181.65	2.75	0.13		2197.64	2202.10	2208.22	-0.75		2183.60		2191.33	2200.15	8.82	0.40			
Mean				2.44	0.11					-0.65						6.59	0.29			
23-22	H/WM	2364.28	2368.10	3.74	0.16	18.62	2365.87	2374.22	2380.63	-0.95	-37.86	2364.28		2348.61	2373.85	24.34	1.04	82.24	4.44	
24-11	H/WM	2268.64	2284.54	5.41	0.24		2275.89	2283.30	2288.01	-0.83		2266.64		2267.74	2290.25	22.61	1.00			
24-12	H/WM	2213.12	2219.64	6.52	0.31		2234.14	2293.24	2241.82	-0.99		2213.12		2210.73	2236.71	25.93	1.18			
24-13	H/WM	2283.10	2287.10	7.00	0.31		2285.20	2285.20	2289.35	-0.98		2286.10		2268.81	2293.70	24.89	1.10			
Mean				5.74	0.25					-0.97						24.43	1.08			

APPENDIX E:

Field Sites/Results

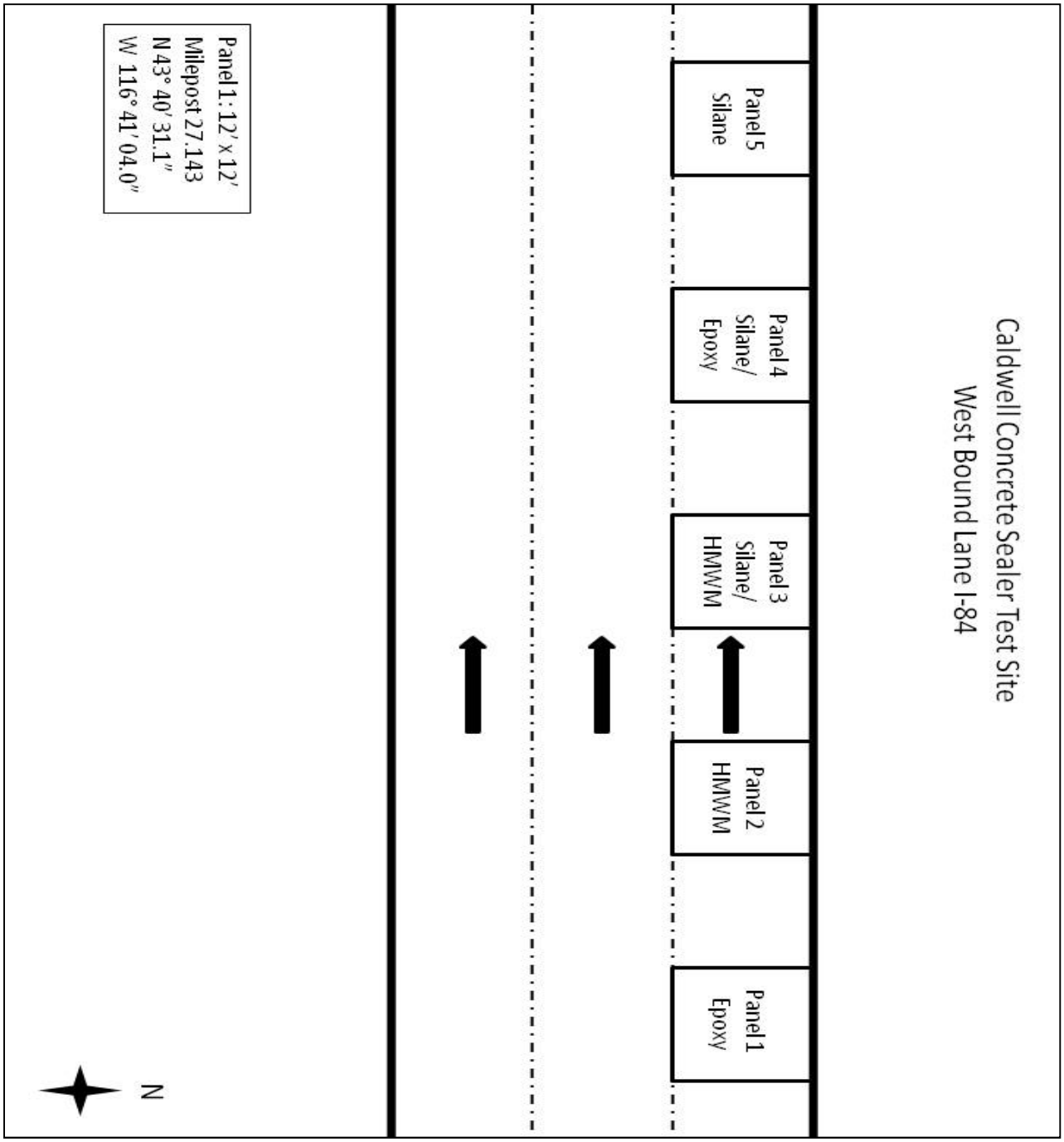


Figure E.1 Caldwell Field Site

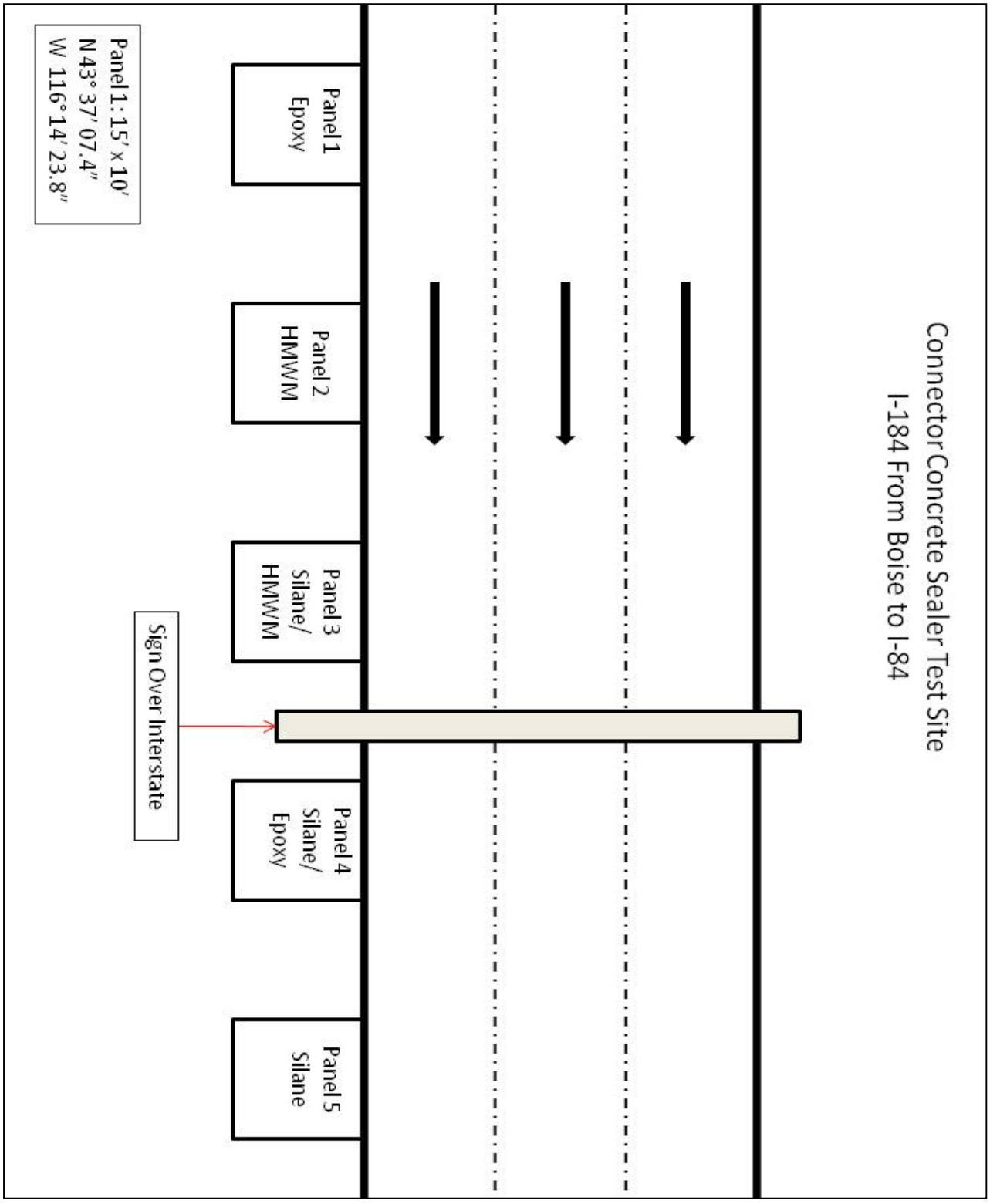


Figure E.2 Interstate 184 Connector

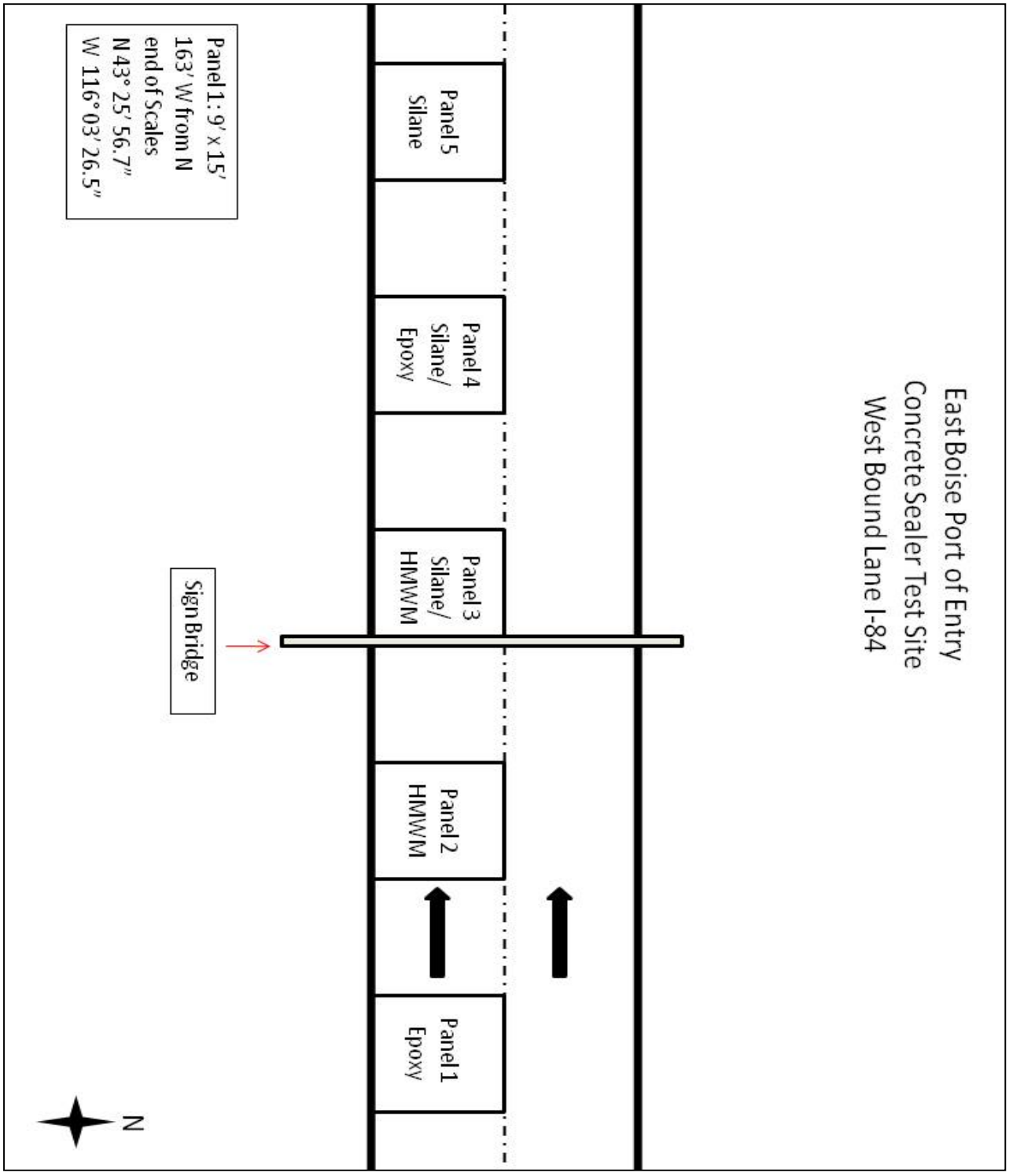


Figure E.3 East Boise Port of Entry Field Site

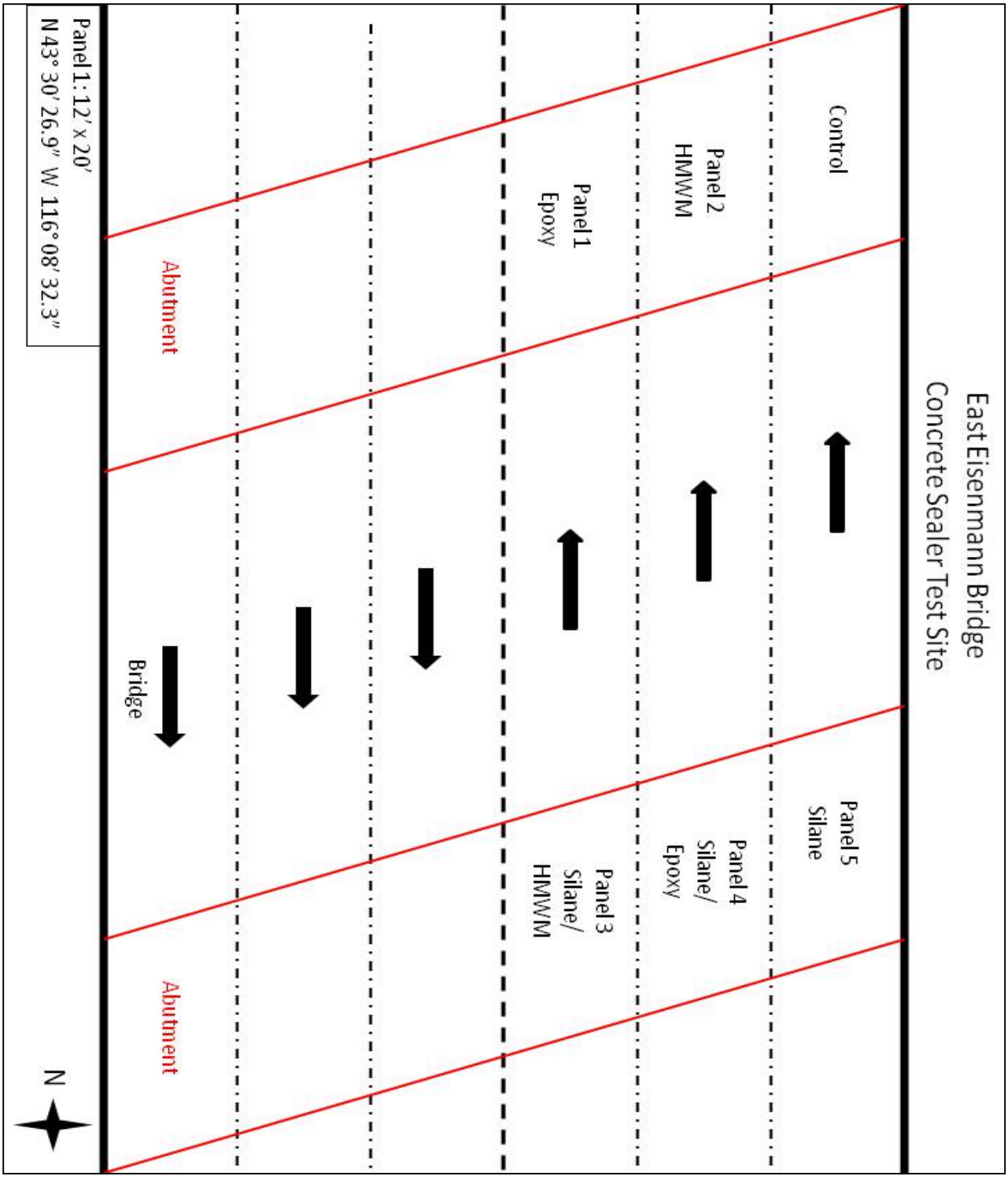


Figure E.4 East Eisenmann Bridge Field Site

Initial Core Water Absorption Results

All sites were cored approximately 2 months after application in November, 2009. Only one core was made for each sample.

Table E.1 Field Site Initial Water Absorption

ITD/BSU Concrete Sealer

24-hr Water absorption			2/9/2010		2/10/2010		2/11/2010				Averaged
Field Cores 11/24/2009			Sealed end				Unsealed end				ΔW_{61}
			Start: 3PM	End: 3PM	ΔW_{61}		Start: 3PM	End: 3PM	ΔW_{61}		
Location:	Panel #	Type	Mass (g)	Mass (g)		Mass (g)	Mass (g)	Mass (g)		SAR	SAR
Caldwell		1 Epoxy	1045.56	1049.04		3.48	1048.31	1061.92	13.61	74.43	73.85
Caldwell		2 HMWM	1048.09	1060.85		2.76	1050.59	1064.61	14.02	80.31	79.26
Caldwell		3 Dual HMWM	1035.55	1037.80		2.25	1037.40	1050.50	13.10	82.82	83.09
Caldwell		4 Dual Epoxy	984.38	985.84		1.46	985.61	996.92	11.31	87.09	89.03
Caldwell		5 Silane	1002.66	1005.64		2.98	1005.00	1020.66	15.66	80.97	77.61
Caldwell	control	unsealed	1047.06	1051.74		4.68	1051.19	1063.34	12.15	61.48	64.83
							Mean		13.31		
POE		1 Epoxy	904.61	907.02		2.41	906.82	921.11	14.29	83.14	86.05
POE		2 HMWM	918.55	921.85		3.30	920.93	936.32	15.39	78.56	80.89
POE		3 Dual HMWM	1020.77	1022.13		1.36	1021.88	1040.50	18.62	92.70	92.13
POE		4 Dual Epoxy	993.61	995.34		1.73	995.19	1012.76	17.57	90.15	89.98
POE		5 Silane	1045.67	1047.62		1.95	1047.18	1067.01	19.83	90.17	88.71
POE	control	unsealed	970.77	976.56		5.79	975.99	993.91	17.92	67.69	66.47
							Mean		17.27		
Eisenmann		1 Epoxy	926.42	936.10		9.68	933.85	951.01	17.16	43.59	58.67
Eisenmann		2 HMWM	970.79	975.66		4.87	975.20	999.83	24.63	80.23	79.21
Eisenmann		3 Dual HMWM	931.74	932.44		0.70	932.30	958.80	26.50	97.36	97.01
Eisenmann		4 Dual Epoxy	827.12	828.86		1.74	828.66	852.57	23.91	92.72	92.57
Eisenmann		5 Silane	955.94	958.64		2.70	957.99	990.04	32.05	91.58	88.47
Eisenmann	control	unsealed	885.92	910.58		24.66	905.68	921.96	16.28	-51.47	-5.29
							Mean		23.42		
Connector		1 Epoxy	1078.37	1080.54		2.17	1080.40	1093.61	13.21	83.57	86.63
Connector		2 HMWM	1079.19	1082.50		3.31	1082.21	1098.43	16.22	79.59	79.61
Connector		3 Dual HMWM	993.25	995.20		1.95	994.92	1011.98	17.06	88.57	87.99
Connector		4 Dual Epoxy	1000.05	1000.91		0.86	1000.63	1014.24	13.61	93.68	94.70
Connector		5 Silane	1037.56	1040.29		2.73	1039.81	1061.60	21.79	87.47	83.18
Connector	control	unsealed	1038.66	1046.20		7.54	1045.30	1060.80	15.50	51.35	53.55
							Mean		16.23		