COATINGS AND SEALERS FOR MITIGATION OF ALKALI-SILICA REACTION AND/OR DELAYED ETTRINGITE FORMATION

Racheal D. Lute[1*], Kevin J. Folliard[1], Thano Drimalas[1], Charles Karissa Rust[2]

[1]The University of Texas, Austin, TX, USA

[2] University of North Texas, Denton, TX, USA

Abstract

The use of concrete sealers to mitigate alkali-silica reaction (ASR) and delayed ettringite formation (DEF) has become increasingly popular. The research presented here was aimed at evaluating coatings and sealers that are intended to lower the internal relative humidity of concrete and thus reduce the future potential for ASR- and/or DEF-induced expansion and cracking. For this research various coatings were evaluated via outdoor exposure site testing, concrete prism testing, and relative humidity monitoring. Large exposure blocks were treated with various coatings at selected levels of expansion, and expansion measurements for each block were obtained frequently in order to determine the effectiveness of the coatings in terms of their ability to reduce expansion due to ASR and DEF. Parallel concrete prism testing was conducted to determine how well ASTM C1293 could predict the effectiveness of coatings, particularly silanes. Relative humidity measurements were also obtained to evaluate the ability of each sealer to reduce relative humidity in concrete. Results from these tests confirmed that some sealers can reduce ASR and/or DEF related expansion by reducing the internal relative humidity of concrete.

Keywords: alkali-silica reaction (ASR); delayed ettringite formation (DEF); silane; mitigation; relative humidity

1 INTRODUCTION

Over the past few decades, the state of Texas has been plagued by premature concrete deterioration of various transportation structures, especially bridges. The two main causes for this distress have been linked to alkali-silica reaction (ASR) and delayed ettringite formation (DEF). Significant research has focused on addressing these two distress mechanisms [1], and specifications have been implemented that will greatly reduce or completely eliminate ASR and DEF in newly constructed transportation structures. However, there are many structures built before these specifications were in place, and many of these structures are currently showing signs of distress or are expected to in the coming years. In an attempt to find a suitable and cost effective means to mitigate this type of premature deterioration, the Texas Department of Transportation (TxDOT) funded a research project aimed at evaluating coatings and sealers that are intended to lower the internal relative humidity of concrete and thus reduce the future potential for ASR- and/or DEF-induced expansion and cracking.

This paper provides long-term outdoor exposure block data for mixtures in which ASR and/or DEF was triggered and then followed with silane treatment. Exposure blocks were cast and allowed to expand to different expansion limits, at which silanes were then applied topically to slow-down the reactions by reducing the relative humidity within the exposure blocks.

1.1 Relative Humidity

The term relative humidity (RH) is one that is used quite commonly by engineers and non-engineers alike. It can be a somewhat confusing term, though. Many assume that RH is just the amount of water vapor that is in the air. This, however, is only half true. The mass of water vapor present in a unit mass of dry air is known as absolute or specific humidity. As water vapor is added to dry air the specific humidity increases. Dry air can take on water vapor to a point of saturation. If moisture is added after the air has reached its saturation point it will condense. In turn, relative humidity is the ratio of the amount of moisture in the air relative to the maximum amount of moisture the air can hold at that same temperature [2]. Relative humidity is dependent on air temperature.

---

[*] Correspondence to rachealdawn@gmail.com

Therefore, the relative humidity of air varies at different temperatures even when the specific humidity remains the same.

As stated earlier, expansion in concrete due to ASR is directly related to the amount of moisture available to the system. Environments with high humidity are able to perpetuate such deleterious reactions. Preventing the ingress of airborne moisture is critical to preventing and mitigating ASR expansion. Silane sealers are ideal for this function. Silanes can penetrate into concrete and form a hydrophobic barrier in the substrate. This barrier hinders moisture intrusion while allowing vapor transmission out of the concrete. Silanes work best when subjected to multiple wetting and drying cycles [3] [4][]. Over time, these sealers can effectively reduce the moisture content of concrete.

In the atmosphere, RH tends to decrease with increasing temperatures. The opposite relation between RH and temperature exists within partially saturated concrete [4]. An increase in temperature causes the movement and expansion of water in concrete. RH measurements of concrete are often taken in an attempt to estimate the moisture content of the concrete. Relative humidity is not a direct measure of the moisture content or degree of saturation of concrete. It is instead a measure of the concentration of water vapor in the concrete.

The relative humidity threshold values necessary to halt expansion due to ASR and DEF have been reported to be < 80% and <90%, respectively [5] [4]. In-depth studies on these threshold values have been conducted under this research project. Detailed information and conclusions from these studies can be found in Rust [4]. It was of interest to investigate the effects of silane sealers on internal relative humidity of concrete.

1.2 Silane

Silane is the generic term for a silicone-based penetrating coating. More specifically the term silane refers to alkyltrialkoxysilane. Silanes are typically clear, low-viscosity liquids. The active solids content of most silanes ranges from 20 – 100% (± 2%), and they are dissolved in a carrier of either solvent or water. The most common surface treatment used in the field is a silane with 40% active solids content in a solvent carrier. However, water based and higher active solids content products are becoming increasingly popular because of lower volatile organic compounds (VOCs). Silanes react with alkalies in concrete and chemically bond water-repellent hydrocarbon molecules to the concrete surface (substrate) thereby reducing the surface tension of concrete. When the surface tension of the substrate is less than that of water, it will be water-repellent [7]. When exposed to wetting and drying cycles silanes act as a "pump," slowly drawing water vapor out of the concrete. Over time this results in a decrease in the relative humidity of the concrete. Reducing the relative humidity of concrete below the threshold value to sustain ASR and DEF will halt expansion.

As previously described, a major objective in mitigating ASR and/or DEF in field structures is to minimize the amount of water available to the system. The effectiveness of surface treatments, especially silanes, at mitigating ASR and DEF is the main focus of this study.

2 MATERIALS AND METHODS

2.1 Concrete Materials

2.1.1 Aggregates

The combination of fine and coarse aggregate used remained constant for all mixtures including exposure block and ASTM C1293 mixtures. The fine aggregate was a natural, highly-reactive (with regard to ASR) siliceous sand containing quartz (64.0 %) chert (17.1 %), and feldspar (11.5 %). The sieve analysis results showed that this aggregate conforms to the requirements of fine aggregate for concrete based on ASTM C33 [8]. In previous research, this aggregate has shown to be highly alkali-silica reactive in ASTM C1260 [9] and ASTM C1293 [10]. In turn, this aggregate was selected to trigger ASR as quickly as possible.

The coarse aggregate used was a non-reactive dolomitic limestone. The coarse aggregate was sieved using a SIMCO Fractionator sieve machine into three equal parts of the three gradation sizes: 12.5mm, 9.5mm, 4.75mm for all mixtures. The absorption capacity of the coarse aggregate was determined to be 3.12%. Due to this high value, the aggregate was soaked for a minimum of 24 hours and then left to drain for another 24 hours before batching. This was done to ensure that the aggregate was as close to saturated-surface dry as possible at the time of mixing. This prevents the aggregate from imbibing significant amounts of mixing water during curing.

2.1.2 Cements

An ASTM C 150 [11] Type III cement was used for all exposure block mixtures. During the two year span of this research, two different batches of Type III cement, PC IIIA and PC IIIB, were obtained. Samples of these cements were sent to a testing laboratory where the chemical compositions of each were determined via ASTM C 114 [12]. The values from these analyses are shown in Table 1. Mixture proportions were determined according to ASTM C1293. The cement content of the mixtures was 420 kg/m^3 and the water to cement ratio (w/c) was 0.42 by mass. The alkali content of the cement was boosted to 1.25% Na_2O_{eq} by the addition of NaOH to the mixing water.

2.1.3 Coating Materials (Silanes)

Various coating systems were applied to the exposure blocks. The decision as to what coating scenarios to use on the exposure blocks was based primarily on the current practices within the State of Texas. Currently TxDOT paints, for aesthetics, all exterior girders, bridges, and columns with white latex paint. When treating a column with silane, TxDOT first sandblasts the column to remove the existing paint. After the removal of the paint the silane is applied. For aesthetic purposes a coating of latex paint is applied over the silane. Due to this process, it was of interest to evaluate the effectiveness of different types of silane and silane in combination with paint.

There are many different types of silane sealers. Silanes are classified based on the solids content and carrier type. The solids content of silanes can range anywhere from 20-100%, and the carrier base is either solvent or water. In the field, the most commonly used silane sealer is one with 40% solids content in solvent carrier. There are varying schools of thought as to which type is the best choice. Some claim that those with higher solids contents are more effective due to higher concentration. On the other hand, others state that a significant amount of solvent is necessary to facilitate greater depth of penetration which is often cited as a measure of effectiveness [13]. In order to address these claims the following coating scenarios were evaluated:

- 40% solvent based silane applied at 7 days
- 40% solvent based silane applied at 0.1% expansion
- 100% solvent based silane applied at 0.1% expansion

At the start of this research, it was not known what effects latex paint would have on the effectiveness of silane. Ideally, the most effective solution would be to apply silane directly over the latex painted columns. This would eliminate labor costs due to sandblasting and repainting. To address this issue, various scenarios were evaluated that included the application of latex paint. The latex paint used in this study was selected from a list of pre-approved paints specified by TxDOT [14]. The blocks cast to evaluate the combination of silane with latex paint are the following:

- 40% solvent based silane application followed by latex paint application at 0.1% expansion.
- Initial latex paint application, followed by 40% solvent-based silane application at 0.1% expansion.
- Initial latex paint application. At 0.1% expansion, removal of paint via sandblasting, then 40% solvent based silane application.
- Initial latex paint application with no further silane coating.

2.2 Methods for assessment and analysis

Exposure Block Testing

Various accelerated laboratory tests have been developed over the years to evaluate the potential for ASR and DEF in mortar or concrete. Although some of these tests are considered to be quite effective in assessing the susceptibility of materials and mixture proportions to these deleterious reactions, each of the tests relies upon unrealistic conditions (e.g., high temperature, highly alkaline soak solution, etc.) to accelerate the process(es). As such, it is often difficult (or impossible) to correlate the results from accelerated laboratory tests with real world performance in field structures. One way to bridge this gap is through the casting and testing of outdoor exposure blocks, where concrete blocks are exposed to actual climatic conditions. The long-term behavior of these blocks can then be correlated to accelerated laboratory tests. This approach was selected for this project to assess the ability of coatings and sealers to reduce expansion and cracking due to ASR and/or DEF.

Multiple large scale concrete exposure blocks were cast, treated with different types of coatings, and placed on the outdoor exposure site at The University of Texas in Austin, TX. The significance of an outdoor exposure site is that it allows the storage of large-scale specimens in realistic field conditions for extended periods of time. This will produce years worth of data that can be used to better predict the performance of aggregates and various mitigation techniques.

Description of Exposure Blocks

After mixing, the concrete was cast in a wooden exposure block mold with interior measurements of 0.7m X 0.4m X 0.4m. The material was placed in two lifts. Consolidation was achieved with a portable vibrating rod after each lift. Each block is instrumented with 12 cast-in-place stainless steel bolts that are later used to monitor expansion. These 9.5 mm diameter bolts are screwed into brass bushings and inserted into brass sockets that are inlaid in each side of the block mold. This set-up allows all but the very tip of the bolts to be cast into the exposure block. Before casting, a 1-mm deep "Demec" hole is machined into each of the bolts using a drill press with a 1-mm diameter drill bit. Eight expansion measurements are collected from these "Demec" points.

Curing Regime for Exposure Blocks

All ASR exposure blocks were wet cured in a 23ºC room for 7 days. After the finishing process, a piece of damp burlap was placed over the blocks. This was rewetted as needed while the blocks were still in the mold. At 3 days the blocks were demolded. The blocks were then covered on all sides by a damp felt wrap. This wrap was remoistened as needed for the rest of the 7 day curing period.

It is known that DEF occurs in concrete that has reached temperatures nominally above 70ºC during curing. In order to initiate DEF in exposure blocks, a high temperature curing regime was followed. All mixing materials, as well as the formwork, were preheated for 24 hours in a 60ºC oven. All DEF blocks were cast in a walk-in oven that was held at a constant temperature of 60ºC. After the final finish, the blocks were covered with damp burlap then wrapped in a thermal blanket. After approximately 18 hours (12 hours of continuous temperature above 70ºC) the block was removed from the oven and allowed to cool at ambient conditions. Each block was instrumented with thermocouple wires at three different depths within the concrete. The time-temperature data obtained from the thermocouple wires were used to confirm that temperatures within the concrete were great enough to instigate DEF. All exposure blocks cast using this procedure reached an internal curing temperature of 88ºC or greater. At 3 days the blocks were demolded, covered in damp felt wrap, and moist cured at ambient temperature for the remainder of the 7 day curing period.

ASTM C1293 Testing

ASTM C1293 [10] is a standard test method for determination of length change due to alkali-silica reactivity. It is used to determine the susceptibility of an aggregate to expand deleteriously due to ASR and is also commonly used to evaluate preventive measures, such as lithium compounds and supplementary cementing materials (SCMs). For this test method, four concrete prisms are placed in a bucket above water and stored at 38ºC for one year (for aggregates) or two years (for preventive measures).

Silanes react with hydroxyl molecules in the concrete substrate to form a hydrophobic barrier that prevents water from entering the concrete while still allowing water vapor to escape. Typically, silane coatings work best in environments where there are cyclic wetting and drying periods. This cyclic wetting and drying facilitates a reduction of internal relative humidity in concrete. ASR is normally only found in concrete with an internal relative humidity of >80% [5]. Reducing the relative humidity below this threshold value should effectively halt expansion due to ASR. For this research it was of interest to see how well ASTM C1293 could predict the effectiveness of coatings, particularly silanes. It was predicted that the constant high humidity environment of the test would render the coatings ineffective [15].

Two sets of ASTM C 1293 prisms were cast from each of the exposure block mixtures. One set served as a control; the other was treated with the same coating scenario as its parent block. The dimensions of the prisms are 75mm X 75mm X 285mm. Gauge studs were cast in each end of the prisms to give an effective length of 250mm [16]. The prisms were cured in a temperature-controlled fog room for 24 hours (± 2 hours) and then demolded. Upon removal from the mold initial length measurements of each prism were taken. The prisms were then placed in 3.78 L buckets complying with ASTM C1293 [10]. The prisms were stored in a 38ºC oven until further measurements were taken.

Relative Humidity Measurements

Vaisala HM44 relative humidity probes were chosen as the method of determination of relative humidity (RH) within the exposure blocks. These probes are specifically marketed for determining RH in concrete. For this method, a hole is drilled into the face of existing concrete. Then, a plastic sleeve is pushed into this hole and plugged with a rubber stopper. After a three day equilibration period, RH measurements can be obtained by removing the stopper and placing a Vaisala probe inside the sleeve.

Each block was instrumented with three Vaisala measurement sleeves. To install each sleeve a 16 mm diameter hole was drilled into the concrete using a hand held hammer drill. After drilling the hole, debris was removed using a compressed air can and the plastic sleeve was tapped into the hole using a rubber mallet. The sleeves were inserted at drill depths of 25mm, 50mm, and 75mm. All measurement sleeves were placed on the north face of each block. A rubber stopper is kept in the sleeve when measurements are not being taken.

To obtain RH values of concrete the Vaisala probes are inserted into the plastic sleeve embedded into the concrete. A plastic cap is placed on the end of the sleeve. This cap encloses the Vaisala probe shielding it from any environmental disturbances that may affect the results. The probe is left in the sleeve for a minimum of 1.5 hours. During this time the probe equilibrates to the environment in the sleeve. Measurements are obtained by connecting the probe to a digital reader, also manufactured by Vaisala. This reader outputs the RH and temperature inside the hole.

3 RESULTS

3.1 Exposure Block Expansion

3.1.1 ASR Blocks

The exposure blocks cast for this study were monitored periodically for over 2 years. Table 2 provides the final measured expansion measurements for each of the mixtures, and Figure 1 illustrates the expansion values for these blocks during this time. Heavy map cracking is visible on all ASR and DEF blocks. The control (A-1) reached an expansion of 1.07% after 796 days. From the results of previous research [1], it is predicted that this value is roughly half that of its ultimate expected expansion. A-11, the block that was initially coated with latex paint and then coated with 40% silane at approximately 0.1 % expansion, has experienced the least amount of expansion to date. The last measured expansion value for this block was 0.64%. Expansion values for the rest of the coated blocks subjected to ambient curing were between 0.70% and 1.03%. The superior performance of this block (A-11) is quite surprising as conventional thinking before this project suggested that silanes would be ineffective when applied over a painted surface (without first removing the paint). The practical importance of this result is significant in that, if one could avoid having to remove paint before applying silane, the cost of application could be significantly reduced and the environmental issues surrounding paint removal could be avoided.

From information found in literature, it was thought that the block treated with 100% silane would perform significantly better than those treated with 40% [13]. However, the 100% silane treatment (A-8) has performed similarly to the 40% silane treatment (A-4), in terms of arresting expansion. The blocks coated with 40% silane at 0.1% expansion (A-3, A-4, A-11, and A-12) have behaved similarly and have performed significantly better than the block coated with 40% silane at 7 days (A-10). The most recent expansion values for the blocks coated at 0.1% expansion are between 0.64% and 0.82% whereas the block treated at 7 days reached an expansion level of 1.03%. This suggests that silanes are more effective when applied to mature concrete. The blocks treated with coating scenarios involving silane and a form of paint (A-3, A-9, A-11, and A-12) showed similar behavior as well. The expansion values for these blocks are all in the 0.64 – 0.82% range. Interestingly, the block that was only treated with latex paint at 7 days (A-9) reached the same expansion level of 0.82% as the block treated with 40% silane and latex paint at 0.1% expansion (A-3). This suggests that the application of latex paint shortly after casting can have some benefits in terms of reducing expansion due to ASR.

As already mentioned, the most interesting coating scenario proved to be the one in which 40% solvent based silane was applied directly over latex paint (A-11). This exposure block has shown the least amount of expansion to date. More research should be conducted to evaluate the effects of applying silane directly over latex paint. Should this prove to be an effective means of mitigating ASR, it would also result in a more economic solution to the problem. The ability to treat ASR affected columns with silane without needing to remove any latex paint beforehand would drastically cut down on labor and material costs.

3.1.2 DEF Blocks

As expected, the DEF blocks have expanded much more rapidly and provide higher expansions than the ASR blocks. The expansion values for the DEF blocks are illustrated in Figure 2. DEF has been known to cause expansions in concrete upwards of 3.0% [17]. The control block (D-1) reached 2.70% expansion in little less than two years and is continuing to expand. Contrary to the results from the ASR blocks, the block treated with 100% silane (D-3) has performed better than the block treated with 40% silane (D-2). Both coated blocks have experienced significantly reduced expansions compared to the control.

Previous research (5) has shown that DEF has a higher RH threshold of <90% which could suggest that silanes would work better for mixtures susceptible to DEF. Ongoing monitoring will determine the effectiveness of silanes with DEF.

3.2 ASTM C 1293 Results

The ASTM C1293 prisms were monitored for over 1 year. The results of the ASTM C1293 testing were as expected since the samples were subjected to a constantly humid environment which did not allow the silane coatings to halt expansion due to ASR. The only exception to this conclusion was the set, A-10, that was coated with 40% solvent based silane at 7 days. The expansion values for this set were consistently 0.1% lower than the control set. Figure 3 shows the expansion graph for the ASTM C1293 testing for mix A-8. The coated set for mix A-8 was coated with 100% solvent based silane at approximately 0.2% expansion. There is no significant difference between the control set and the coated set. The expansion values for both sets track each other closely for the entire time of monitoring, and the last expansion values obtained for both sets are virtually identical. This trend is typical for all prism sets coated at 0.1% - 0.2% expansion.

3.3 Relative Humidity Monitoring

Six of the original ASR exposure blocks discussed earlier were instrumented so that internal relative humidity measurements could be obtained. Relative humidity measurements of the blocks were obtained after significant levels of expansion were noted in all exposure blocks. Measurements were taken when the outside temperature and RH were approximately 23°C and 40%, respectively. Probe readings were recorded after a 1.5 hour equilibration period. RH readings for depths of 25mm, 50mm, and 75mm into the concrete as well as the expansion of each block are listed in Table 3. These results proved to be extremely interesting. The blocks that have shown the least amount of expansion on the exposure site also have the lowest RH values. Again, the most interesting results were obtained from block A-11. In this scenario 40% solvent based silane was applied directly over latex paint at 0.1% expansion. Not only does this block show the least amount of expansion, but it also had the lowest RH values. This proves that relative humidity and internal moisture are correlated with expansion due to ASR. More RH measurements should be obtained on all exposure blocks in order to better correlate RH to level of expansion.

4 DISCUSSION

The purpose of this research was to evaluate coatings and sealers that are typically used to mitigate ASR and/or DEF. Various sealers and coatings were evaluated through the execution of numerous laboratory tests including: outdoor exposure block testing, ASTM C 1293 testing, and relative humidity monitoring.

All exposure block testing was conducted in Austin, TX. For this testing, numerous concrete blocks were treated with various coatings at certain expansion levels. The expansion level of each block was monitored before and after treatment to evaluate the effectiveness of the coatings. The blocks were produced with an extremely reactive sand in order to achieve high levels of expansion due to alkali-silica reaction and delayed ettringite formation. The exposure blocks that responded best to treatment were A-11 and A-12. Both of these blocks were coated with latex paint 7 days after casting. At approximately 0.1% expansion both blocks were treated with 40% solvent based silane. For block A-11 the silane was applied directly over the latex paint. The latex paint on block A-12 was removed by sandblasting before the silane treatment was applied. Not only have these two blocks performed better than the others, they also showed that there is little to no difference in performance between silane applied over latex or silane applied to a sandblasted surface. This could prove to be a very significant finding that has the potential to save highway departments both time and money with the elimination of the need to remove existing paint by sandblasting.

Parallel ASTM C 1293 testing was conducted in conjunction with the exposure block testing. This test was conducted in order to determine the effectiveness of coatings in constant humid environments and to determine the ability of ASTM C 1293 to accurately predict the performance of such coatings. As expected, the coatings were virtually ineffective in this environment because a constantly moist environment does not allow silanes (or similar products) to reduce internal humidity (without wetting and drying cycles).

Additionally, internal relative humidity (RH) measurements were collected from six of the outdoor exposure blocks. These measurements were obtained with the use of Vaisala HM44 relative humidity probes. RH measurements were obtained at depths of 25mm, 50mm, and75 mm for each block. As expected, RH values increased with depth. An indicator of an effective penetrating sealer is its ability to reduce the internal relative humidity of concrete over time. Interestingly, the blocks that showed the lowest RH values (A-11, A-12) were also the blocks with the lowest overall expansion values. This further supports the theory that reducing the internal RH of concrete can significantly reduce expansion due to ASR and/or DEF.

5 CONCLUSIONS

- 40% solvent bases silane sealers have the potential to significantly reduce ASR related expansion by reducing the internal relative humidity within affected concrete
- Silanes are more effective when applied to mature concrete (i.e. at 0.1% expansion) versus after a seven day wet cure
- Silanes are still effective at reducing expansion due to ASR when applied over latex paint
- ASTM C1293 is not an effective test method for predicting the performance of coatings due to the high humidity environment specified within the test method
- The exposure blocks with the lowest overall expansion values also showed the lowest relative humidity values

6 REFERENCES

[1] Folliard, K. et al "Preventing ASR/DEF in New Concrete: Final Report," Report No. FHWA/TX-06/0-4085-5, June 2006.

[2] Cengel, Y.A. and Turner, R.H., Fundamentals of Thermal-Fluid Sciences, 2nd Edition ed., McGraw Hill, 2005.

[3] R. Lute, "Evaluation of Coatings and Sealers for Mitigation of Alkali-Silica Reaction and/or Delayed Ettringite Formation (Thesis)," The University of Texas at Austin, Austin, TX, 2008.

[4] C. Rust, "Role of Relative Humidity in Concrete Expansion due to Alkali-Silica Reaction and Delayed Ettringite Formation: Relative Humidity Thresholds, Measurement Methods, and Coatings to Mitigate Expansion (Thesis)," The University of Texas at Austin, Austin, TX, 2009.

[5] Grasley, Z.C. et al "Relative Humidity in Concrete," *Concrete International,* vol. 28, no. 10, pp. p. 51-57, 2006.

[6] Fournier, B. et al "Alkali-Aggregate Reaction in Concrete: A Review of Basic Concepts and Engineering Implications," *Canadian Journal of Civil Engineering,* vol. 27, pp. p. 167-191, 2000.

[7] McGettigan, E. "Silicon-Bases Weatherproofing Materials," *Concrete International,* pp. p. 52-56, 1992, 14(6).

[8] ASTM C 33: Standard Specification for Concrete Aggregates, West Conshokocken, PA: ASTM International, 2003.

[9] ASTM C 1260: Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method), West Conshokocken, PA: ASTM International, 2005.

[10] ASTM C 1293: Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction, West Conshokocken, PA: ASTM International, 2001.

[11] ASTM C 150: Standard Specification for Portland Cement, West Conshokocken, PA: ASTM International, 2005.

[12] ASTM C 114: Standard Test Methods for Chemical Analysis of Hydraulic Cement, West Conshokocken, PA: ASTM International, 2005.

[13] Carter, P.D. "Evaluation of Dampproofing Performance and Effective Penetration Depth of Silane Sealers in Concrete," *ACI Materials Journal Special Publication,* vol. 151, pp. p. 95 - 118, 1994.

[14] TxDOT, "DMS-8110, Coatings for Concrete," Texas Department of Transportation, 2004.

[15] Berube, M. et al "Effectiveness of Sealers in Counteracting Alkali-Silica Reaction in Plain and Air-

Entrained Laboratory Concretes Exposed to Wetting and Drying, Freezing and Thawing, and Saltwater," *Canadian Journal of Civil Engineering,* vol. 29, pp. p. 289-300, 2002.

[16] Folliard, K. et al "Preventing ASR/DEF in New Concrete: Final Report," TxDOT 0-4085-5, 2005.

[17] Drimalas, T. "Laboratory Testing and Investigations of Delayed Ettringite Formation (Thesis)," The University of Texas at Austin, Austin, TX, 2004.

Table 1: Cement Properties.

Oxides	***Weight %***	
	PC IIIA	***PC IIIB***
SiO_2	19.94	19.49
$A_{l2}O_3$	5.28	5.02
Fe_2O_3	3.24	3.32
CaO	60.05	61.36
MgO	3.14	3.32
SO_3	4.27	3.66
Total Alkalis as Na_2O_{eq}	0.82	0.85

Table 2: Coating Scenarios and Expansion Results for Exposure Blocks.

Block	**Type of Curing**	**Initial Coating**	**Time of Initial Coating**	**Secondary Coating**	**Time of Secondary Coating**	**Age at Coating (days)**	**Expansion at Coating (%)**	**Age at Last Reading (days)**	**Latest Expansion (%)**
A-1	ASR	none	---	---	---	---	---	796	1.07%
A-3	ASR	40SBS* + Latex	0.1% expansion	---	---	169	0.13%	796	0.81%
A-4	ASR	40SBS	0.1% expansion	---	---	169	0.10%	796	0.82%
A-8	ASR	100SBS‡	0.1% expansion	---	---	162	0.09%	789	0.72%
A-9	ASR	Latex Paint	7 days	---	---	7	---	783	0.82%
A-10	ASR	40SBS	7 days	---	---	7	---	783	1.03%
A-11	ASR	Latex Paint	7 days	40SBS	0.1% expansion	194	0.08%	783	0.64%
A-12	ASR	Latex Paint	7 days	40SBS	0.1% expansion (after sandblasting)	226	0.18%	783	0.70%
D-1	DEF	none	---	---	---	---	---	639	2.70%
D-2	DEF	40SBS	0.1% expansion	---	---	69	0.12%	639	1.77%
D-3	DEF	100SBS	0.1% expansion	---	---	47	0.11%	639	1.23%

* 40% Solvent Based Silane

‡ 100% Solvent Based Silane

Table 3: Internal Relative humidity Measurements of Exposure Blocks and Corresponding Expansion Levels.

Block		**Internal Relative Humidity (%)**			**Expansion (%)**
		Depth (in)			
		1	**2**	**3**	
Control	**A-1**	84.3	92.7	90.5	0.73
40% Silane @ 0.1% exp	**A-4**	80.7	80.9	83.3	0.62
Latex Initially	**A-9**	77.8	88.7	91.5	0.53
40% Silane Initially	**A-10**	85	90.4	90.4	0.63
Latex, 40% silane @ 0.1% exp	**A-11**	54.7	72.6	77.4	0.44
Latex, Sandblast + 40% silane @ 0.1% exp	**A-12**	57.2	72.4	77.9	0.49

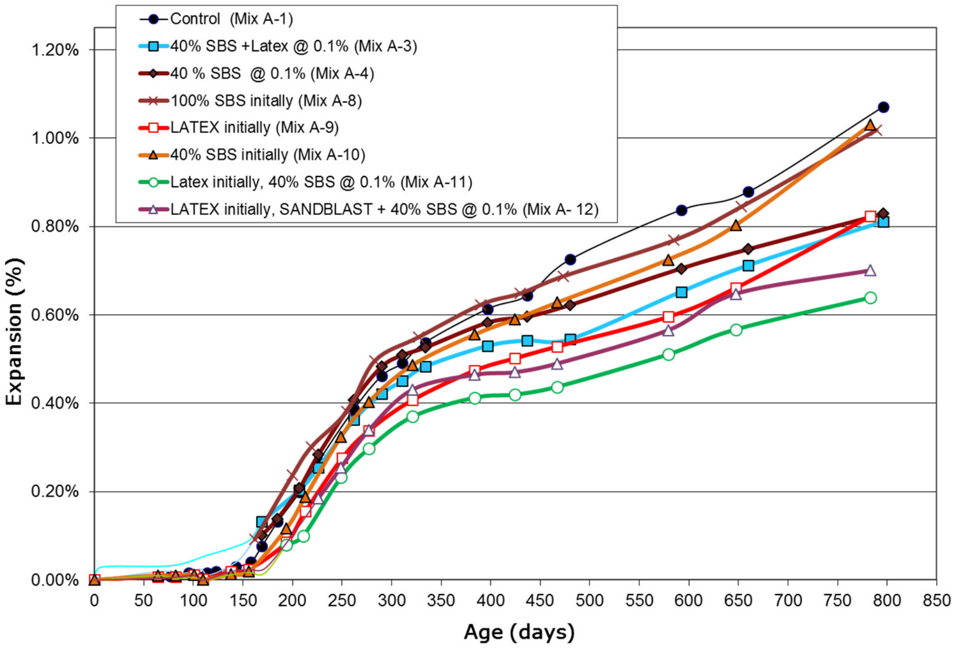

FIGURE 1: Expansion Results for ASR Exposure Blocks.

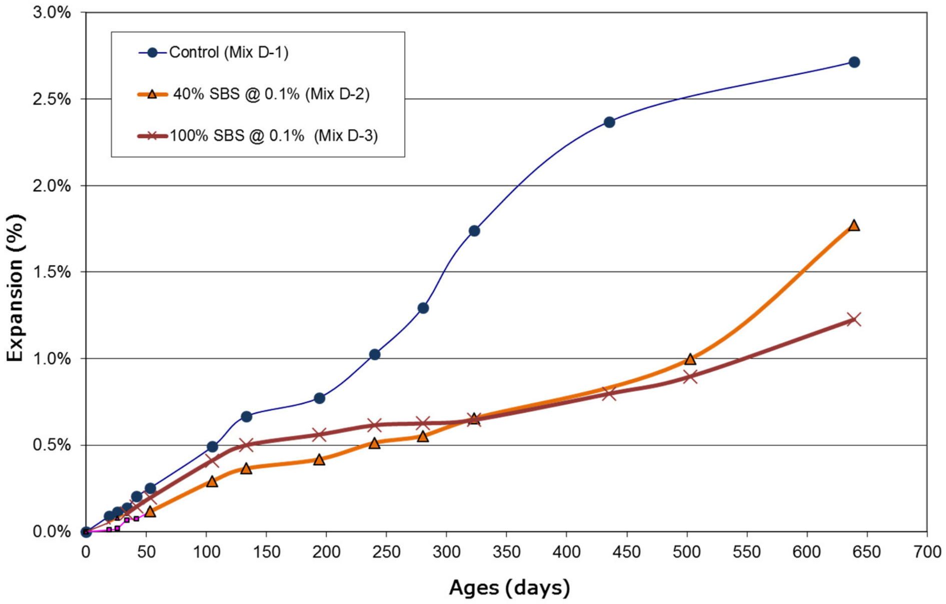

FIGURE 2: Expansion Results for DEF Exposure Blocks.

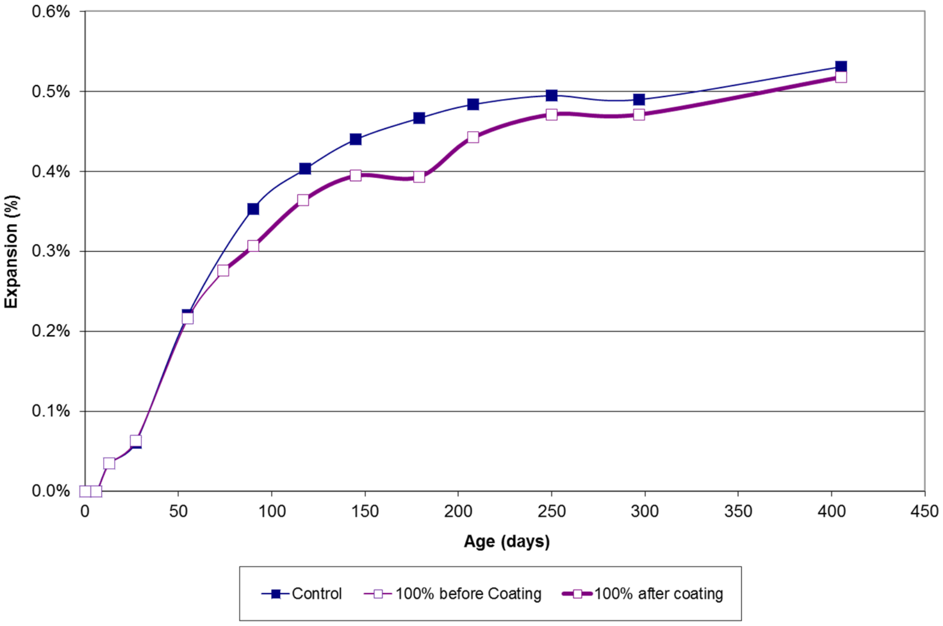

FIGURE 3: Expansion Results for ASTM C1293 Testing for Mix A-8.