Prevention and Mitigation of ASR in Median Barriers with Varying Degrees of Damage

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ABSTRACT

Alkali-silica reaction (ASR) is a deleterious expansive reaction which occurs in concrete. The goal of this research is to extend the service life of concrete transportation structures (median barriers and pavements) effected by ASR through surface treatment mitigation. The goal was achieved through instrumentation and treatments of a concrete median barrier to measure strain and relative humidity. Strain was measured with detachable mechanical strain gages and gage studs embedded into the concrete. Relative humidity was measured with a portable probe inserted into the concrete. Surface treatments were applied to the concrete and included silane, linseed oil, and elastomeric paint. Results show that silane is effective at reducing internal relative humidity below the recommended threshold of 80 percent in concrete which exhibits minimal cracking. In concrete with moderate or severe cracking elastomeric paint is more effective at controlling expansion.

INTRODUCTION

Alkali-silica reaction. Alkali-silica reaction (ASR) is an expansive deleterious reaction which may lead to cracking and premature deterioration in concrete. Reactive siliceous minerals, within the aggregate, will dissolve in the presence of highly alkaline cement pore solution. According to Diamond, the dissolved silica solution reacts with calcium hydroxide, present within the cement pore solution, and produces alkali-silica gel (Diamond, 1989). In the absence of sufficient calcium hydroxide, the dissolved silica will remains in solution and gel will not form (Davies and Oberholster, 1988; Diamond, 1989). Alkali-silica gel imbibes water from the surrounding cement pore solution due to an osmotic pressure differences between the alkali silica gel and pore solution (Diamond, 1989). The expansive pressure produced by the absorption of water is sufficient to overcome the tensile strength of the surrounding cement matrix, leading to micro-cracking. Alkali silica gel will migrate into the micro-cracks, and cracks will develop throughout the cement paste matrix. The three factors which directly influence the development of alkali-silica

gel and the development of expansive pressure are cement alkali content, reactive silica content and composition, and available moisture.

After alkali-silica gel forms, expansion due to water absorbed from the surrounding cement pore solution will continue as long as sufficient moisture is available (ACI, 1998). Stark found that lowering the internal relative humidity to 80 percent will slow or cease ASR expansion. Some additional factors are ambient temperature and humidity which will increase the expansion rate of alkali-silica gel (Stark, et al, 1993).

Efficacy of treatment on different damage levels. Surface vapor barriers such as silane and siloxane have been success in treating ASR. The treatment is applied topically and prevents the ingress of water into the concrete, while allowing vapor to escape from the concrete, reducing internal relative humidity. Silane has proven effective at reducing internal relative humidity and slowing or stopping expansion due to ASR (Bérubé et al, 2002a; Bérubé et al;, 2002b; Drimalas et al, 2012; Folliard et al, 2012). In addition to silane, alternative surface treatments such as elastomeric paints can be used to reduce internal relative humidity and seal small cracks (Thomas et al, 2012). In a 10 year study of sealers applied to median barriers with varying degrees of surface map cracking Berube concludes that silane was effective at stopping expansion for at least six years after treatment. In addition, siloxane was shown to be effective, although less so than silane. The efficacy and durability of a sealer depends on the degree of cracking present at the time of treatment (Bérubé et al, 2002a).

Objective. The goal of the research program is to determine an effective treatment, or combination of treatments, which will increase the service life of transportation structures which exhibit varying degrees of ASR related damage. Although silane has proven effective at slowing expansion in concrete with random map cracking it is unknown how effective silane is in treating severely damaged concrete (Bérubé et al, 2002a). The damage levels in several sections of the median barrier greatly exceed the recommended level for silane treatment reported in the literature. In addition, alternative treatments such as elastomeric paint and linseed oil may prove more effective and economical in severely damaged concrete.

Petrographic examination. Core samples were extracted from the median barrier and pavement in 2012 and sent to CTLGroup for petrographic examination. Alkali-silica reaction was determined as the culprit in the premature deterioration of the median barrier after a full petrographic examination was performed on two samples of the concrete. The Arkansas River sand used in the concrete was found to contain chalcedony minerals which were involved in the development of alkali-silica gel. In addition the crushed limestone coarse aggregate also contained chalcedony nodules which showed evidence of ASR. Micro cracking throughout the concrete radiated from alkali silica gel deposits within chalcedonic particles. Although this evidence suggest ASR was the cause of the significant cracking within the median barrier,

there was also significant evidence that the problem was exacerbated by repeated freeze thaw cycles

Median Barrier. Due to variability in the cement alkali content and environmental conditions at placement, the degree of damage varies significantly throughout the median barrier. The median barrier was cast in 1997 using a slip form paver. Although the exact mix characteristics are not available, the water to cement ratio estimated during petrographic examination was between 0.35 and 0.40. The estimated air content (non-air-entrained) was between 2.8 and 3.8 percent. Fly ash was present at an estimated by weight replacement of between 10 and 15 percent. Supplier information shows this to be a Class C fly ash with a calcium oxide content of 27.4 percent and 1.54 percent available alkalis. The coarse aggregate was crushed limestone which contains nodules of chert and chalcedony. The fine aggregate was natural river sand composed mainly of quartz with some feldspar, limestone, chert, and chalcedony. Supplier information shows that the crushed limestone was received from the West Fork Arkansas quarry, and the sand received from the Arkansas River in Van Buren Arkansas. Alkali silica reaction is clearly present within the wall with several sections exhibiting moderate to severe map cracking in addition to large (2 to 3 mm) horizontal cracks parallel to the reinforcement.

MATERIALS AND METHODS

Treatments. The following three surface treatments were evaluated in this project: silane (Enviroseal 40), linseed oil (Euclid), and elastomeric paint (Sikaguard 550w). Fifteen sections of median barrier wall were selected based on damage level, five each of minimal (Figure 1a), moderate (Figure 1b), and severe (Figure 1c) damage. For each damage level, one section was left untreated as a control, the second treated with silane, the third treated with linseed oil, the fourth treated with elastomeric paint, and the final section treated with silane and after six months, silane was reapplied to the section.

The manufacturer recommended application was followed for all three treatments. The materials cost and application rates are summarized in below in Table 1. Both silane and linseed oil were applied with a hand sprayer. Linseed oil is both less expensive and has a higher application rate than silane, however it is not a vapor barrier and will trap moisture within the concrete. Elastomeric paint is the most expensive treatment and must be applied with paint rollers. Therefore, the cost associated with treating the entire barrier wall is prohibitive. However, for treating sections which exhibit moderate to severe cracking it may prove more effective at sealing wide cracks.

Table 1. Material Costs and Application Rates.

	Silane	Elastomeric Paint	Linseed Oil
Brand	Enviroseal 40	Sikaguard 550w	Euclid
Cost (19 L)	$217.22	$248.02	$174.10
Application Rate (m^2/L)	3.7	2.5	7.4
Cost ($/$m^2$)	$3.12	$5.34	$1.25

Location and time of treatment. In March 2013 the surface treatments were applied to fifteen sections of the median barrier located on Interstate 540 in West Fork Arkansas. The 7 km median barrier and 19 km concrete pavement were cast in the summer of 1998. Both the pavement and median barrier have shown signs of premature deterioration due to ASR. Temperatures at the time of treatment were low (~3 degrees C) compared to the summer months (25 to 30 degrees C). However, none of the stain values were corrected for temperature due to effects of confinement.

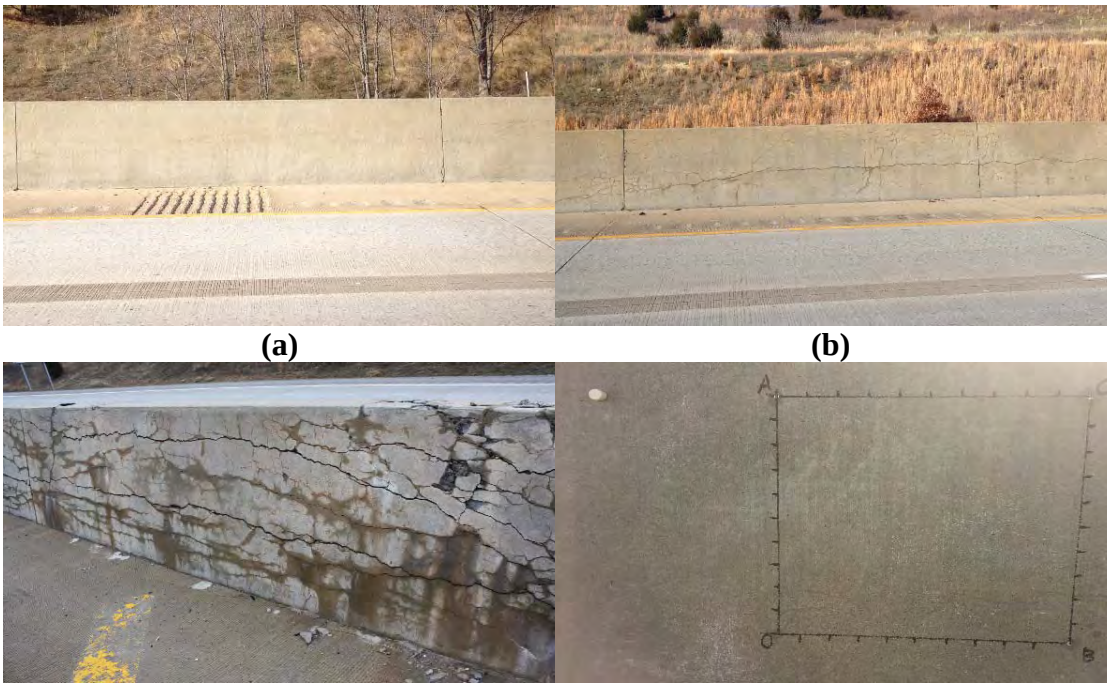

Figure 1. Typical sections showing minimal (a), moderate (b), and severe damage (c). Typical measurement grid showing reference gage studs and internal humidity port (d) (self credit for all photos).

Instrumentation and monitoring. In January 2013 the median barrier was instrumented with devices to monitor strain and internal relative humidity and temperature. Gage reference studs (75 mm by 8 mm) were installed into the surface of each median section. Four reference studs were drilled and affixed with epoxy into the face of the wall. Each stud was placed at the corner of a 500 mm square grid (Figure 1d). Two vertical measurements and two horizontal measurements were taken along each side of the grid. The strain, in each direction, was calculated as the

average of four measurements. Strain was measured via a detachable mechanical strain gage (DEMEC) with a precision of ±0.00025 percent.

In addition to strain measurements, a 12 mm diameter, 150 mm deep hole was drilled into the face of each median section. The hole was capped with a 50 mm section of plastic pipe. Internal relative humidity and temperature were measured at the same time as strain using a Vaisala HM40S probe. The hole was drilled to a depth equal to half the thickness of the wall, so that the measured values represent the internal humidity and temperature.

RESULTS AND DISCUSSION

Hardened concrete typically has an internal relative humidity which varies with changes in ambient humidity and temperature. As previously stated, research has shown that if the internal relative humidity remains below 80 percent, ASR expansion ceases. The primary means of reducing internal relative humidity is through the application of a surface vapor barrier, which blocks water from entering the concrete while allowing water vapor to escape.

Relative humidity and temperature. Prior to treatment there was very little difference in the internal relative humidity in the median wall due to the very high humidity typically present in concrete. The internal relative humidity in sections of minimal damage was two percent lower than the sections of severe damage. It is expected that humidity levels in the treated sections will decrease over time as compared to the control, and remain at a lower level for approximately six years [2].

Minimal damage. Three months after treatment, minimally damaged sections treated with silane appear to have a noticeable reduction in internal relative humidity as compared to the control and other treated sections (Figure 2b). This trend is not present in the sections with moderate or severe damage, which is expected since silane is not effective at bridging or sealing large cracks.

Moderate damage. Internal relative humidity and temperature remain very similar for all moderate sections with no apparent change due to treatment (Figure 3b). The sections treated with elastomeric paint reflect sunlight, and as such have a lower internal temperature (~2 to 3 degrees C) than sections treated with silane, linseed oil, or left untreated.

Severe damage. It is apparent that the severe section treated with elastomeric paint also exhibits slightly lower (97.6 as compared to 95.3 percent) internal relative humidity than the other sections (Figure 4b). Due to the crack bridging ability elastomeric paint, rain water was prevented from collecting in large cracks. Due to the short period (6 months) over which relative humidity and temperature were monitored, a noticeable decrease in humidity was not been observed in the treated moderate and severe sections.

Strain. Strain has been measured monthly, since January 2013, on all 15 median barrier sections. As stated earlier, each treatment was evaluated on all sections of all three damage levels. In addition, the strain from each damaged section was compared to a control with the same degree of damage. Vertical strain in all sections were considerably larger than corresponding horizontal strain (Figures 1a, 2a, 3a). Due to the short (6 month) duration over which strain was monitored it is difficult to conclude on the efficacy of each treatment on slowing expansion. However, some conclusions, which will be discussed in the following sections, can be made on the efficacy of treatments on sections depending on damage levels (e.g. mimimal, moderate, severe). A summary of monthly strain rates and the difference from control sections is provided in Table 2.

Table 2. Vertical Strain Rates and Differential Relative to the Control

	Expansion rate (Percent/month)				
	Control (C-v)	Silane (S-v)	linseed oil (L-v)	Elastomeric (E-v)	Silane 2 (S2-v)
Minimal	+0.006256	+0.006945	+0.004718	+0.005432	+0.006287
Differential[a]	--	+0.000689	-0.001538	-0.000823	+0.000031
Moderate	+0.008762	+0.007291	+0.008515	+0.005319	+0.009369
Differential[a]	--	-0.001471	-0.000247	-0.003443	+0.000607
Severe	+0.012104	+0.012254	+0.010295	+0.011473	+0.008314
Differential[a]	--	+0.000150	-0.001809	-0.000631	-0.003789

[a]Differential strain relative to the control section of the same damage level

Minimal damage. In the silane treated median section which exhibits minimal damage, the vertical strain has been greater than the control (Figure 2a). Meanwhile, the median sections treated with elastomeric paint and linseed oil have exhibited less vertical expansion than the control (Figure 2a). The variation in expansion between the treated sections and the control is too small (<0.009 percent) to consider one treatment more effective than the others at this point. However, the vertical expansion in the treated sections has slowed as compared to the control. Horizontal expansion in the minimally cracked median sections is less than the vertical expansion (Figure 2a). As there is more restraint in the horizontal direction the strain is reduced, and as the joints close confining stresses are caused by the surrounding median barrier sections.

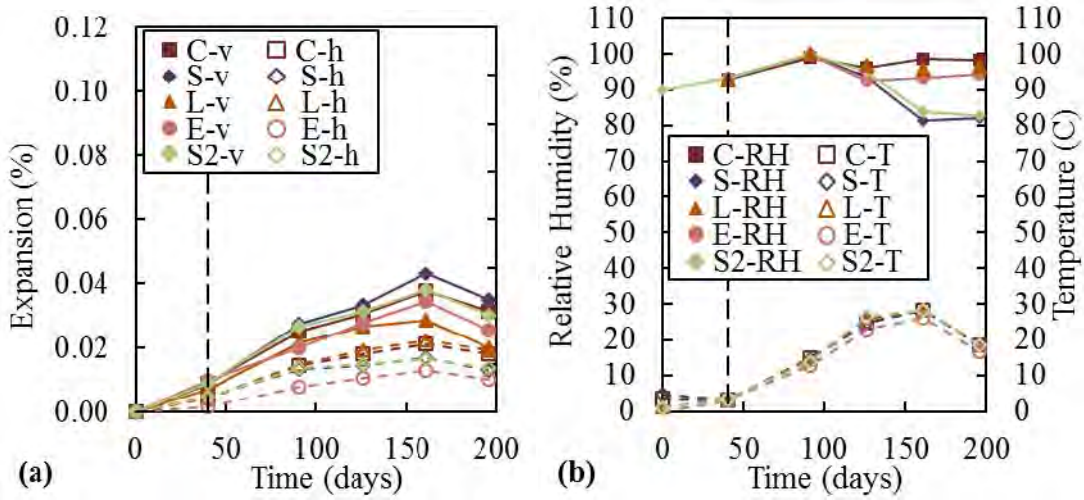

Figure 2. Strain with respect to time (a) and relative humidity and temperature with respect to time (b) data for minimally damaged median barrier sections.

Moderate damage. The median sections which exhibit moderate damage have shown greater vertical expansion (0.01219 percent) than the sections with minimal damage (Figure 3a). Five months after treatment, the control section has expanded more than the sections treated with linseed oil, elastomeric paint, and one of the sections treated with silane. However, the vertical expansion in the first sections treated with silane is greater, although slowing, as compared to the control (Figure 3a). The section treated with elastomeric paint has expanded less (-0.003443 percent per month) than the control section (Figure 3a). This is attributed to the ability of elastomeric paint to bridge large cracks and protect the concrete from rain water and ambient humidity. Horizontal strain in moderately damaged sections is significantly lower (0.04629 percent) in all of the sections. The section treated with elastomeric paint has contracted as compared to the control (Figure 3a). The limited strain in the horizontal direction is again due to restrain from reinforcement and confinement.

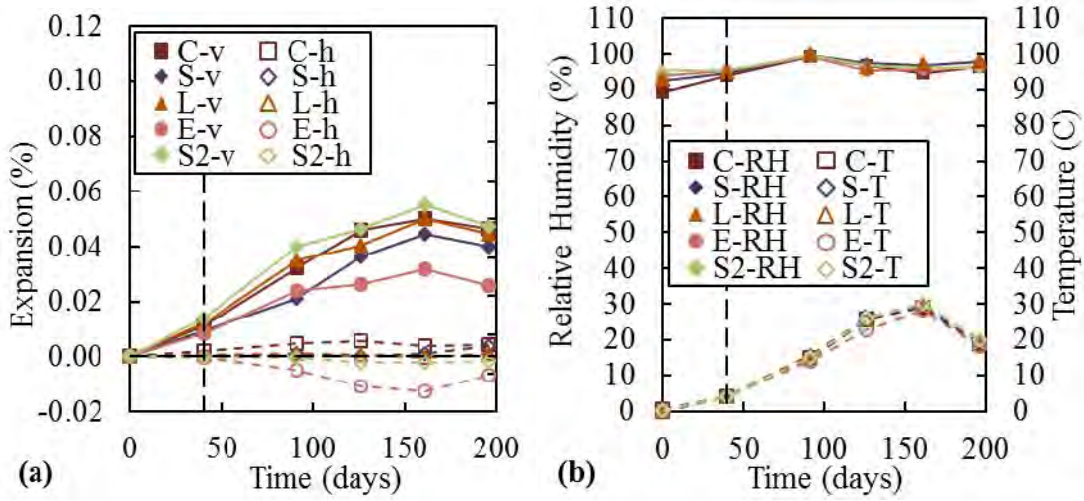

Figure 3. Strain with respect to time (a) and relative humidity and temperature with respect to time (b) data for moderately damaged median barrier sections.

Severe damage. Median sections with severe damage have expanded significantly more (0.03232 percent) in the vertical direction as compared to the minimally damaged sections (Figure 3a). Four months after treatment all sections are exhibiting less overall expansion than the control. Similar to the moderately damaged sections, one of the section treated with silane initially showed greater expansion than the control. However, the expansion in the silane treated section has slowed, and was overtaken by the control (Figure 4a). Similar to the median sections with minimal or moderate damage, the elastomeric paint is effective at reducing expansion even in sections with severe damage (Figure 4a). Horizontal strain in the severe sections is restricted by reinforcement and confining stresses. The horizontal strain is less (0.06648 percent) than vertical. All of the treated sections have shown a horizontal contraction since treatment, which is due to confining stresses from adjacent sections which reduce crack widths within the measurement grid.

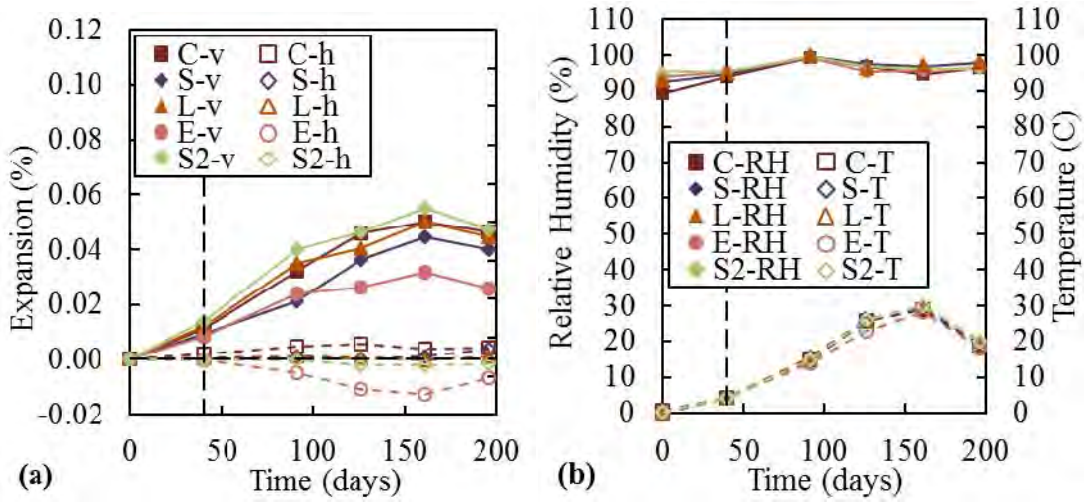

Figure 4. Strain with respect to time (a) and relative humidity and temperature with respect to time (b) data for severely damaged median barrier sections.

Treatments. In sections of all three damage levels most treatments have reduced expansion as compared to the control. The treatments appear to be less effective in the sections with minimal damage. However, as expansion continues the treated sections will be protected from rain and ambient humidity which will result in less expansion as compared to the control. Due to the large cracks which were developed in the moderately and severely damaged sections before treatment was applied, the treatments have resulted in a greater reduction in expansion in the relatively short (5 months) time since treatment.

Silane. It would appear that in median sections with minimal cracking, the silane is effective at reducing internal relative humidity and as such will prevent future expansion. The silane does not appear effective at sealing the larger cracks in the moderately and severely damaged sections and a reduction in relative humidity has not been measured. However, the silane does appear effective at slowing expansion even in sections with large cracks.

Linseed oil. Unfortunately, linseed oil is not a breathable barrier, and despite efforts to treat the median barrier when internal relative humidity was at its lowest, moisture was trapped in the concrete. This has resulted in a constant internal relative humidity measured in the sections treated with linseed oil. Fortunately, the linseed oil protects the concrete from rain water and in all three damage levels the vertical expansion is less than that of the control.

Elastomeric paint. Elastomeric paint has been the most effective treatment at controlling expansion in the moderately cracked sections, and is similarly effective in severely cracked sections. The crack bridging ability of the paint is effective at protecting the large cracks from rain water. However, due to the higher viscosity and greater difficulty of applying the paint, as compared to silane, it is less effective at providing a complete vapor barrier over the entire surface of the median barrier. As such, there has not been a significant reduction in relative humidity measured in any of the sections.

CONCLUSIONS

Alkali-silica reaction developed within the coarse portion of the fine aggregate. Microcracking was exacerbated by freeze thaw action which led to significant cracking in several miles of median wall. All three treatments evaluated in this study have shown to slow the expansion due to ASR as compared to untreated control sections. The treatments have shown a varying degree of success on median sections of increasing damage level. As expected the silane has proven successful at reducing internal relative humidity in sections with minimal damage. However, elastomeric paint has provided the greatest reduction in expansion for sections with moderate to severe damage. Very little information regarding mitigating ASR in severely damaged concrete exist in the literature. This research provides information on treatment methods which extend the useful life of concrete with damage which cannot be mitigated with traditional methods such as silane. ASR is a very slow process, and several years of monitoring are required to determine the most effective treatment method. Silane is the best treatment method for slowing or stopping ASR (in median barriers and similar structures). However, silane may be less effective if the concrete is not treated before expansion and other forms of deterioration leads to significant cracking.

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