EVALUATION OF MITIGATION MEASURES APPLIED TO ASR-AFFECTED CONCRETE ELEMENTS: PRELIMINARY FINDINGS FROM AUSTIN, TX EXPOSURE SITE

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ABSTRACT

This paper summarizes the key findings to date on an outdoor exposure site devoted to studying mitigation measures aimed at reducing the future expansion of concrete elements already affected by alkali-silica reaction (ASR). The primary focus of this project was on the transportation infrastructure, and small-scale specimens based on pavement, bridge deck, and bridge column elements were cast using concrete containing two different reactive aggregates. After ASR was initiated in the various specimens and expansion reached approximately 0.1 percent, a wide range of mitigation measures were applied to the various elements, including sealers, coatings, polymer overlays, hot-mix asphalt overlay, portland cement concrete overlays, fiber-reinforced polymer (FRP) wraps, and lithium nitrate (applied topically, electrochemically, and by vacuum). This paper presents results from only the pavement slab and bridge deck sections and focuses primarily on coatings and sealers; the findings from the columns will be reported elsewhere. The most effective treatments to date have been coatings and sealers (e.g., silanes) that reduce the relative humidity in concrete. The application of lithium nitrate solution to ASR-affected, hardened concrete was found to be ineffective in reducing future expansion.

Keywords: Alkali-silica reaction, silane, mitigation and repair, sealant material, lithium nitrate electrochemical treatments.

1. INTRODUCTION

Alkali-silica reaction (ASR) has plagued transportation infrastructure worldwide. In recent years, the Federal Highway Administration (FHWA) in the USA has funded considerable research on ASR, ranging from studies on underlying mechanisms, preventive measures, accelerated test methods, and mitigation measures for concrete elements already affected by ASR. Giannini [1] summarized the key findings from a series of field trials evaluating mitigation measures applied to transportation infrastructure, including highway barriers, pavements, and bridge columns. One major finding from the field trials was that it is difficult to accurately and effectively treat and monitor field structures, due to a lack of information about the history of the structure and the inherent limitations of monitoring real-world structures (e.g., limited access to structures, need for traffic control, etc.). This key finding led to the decision to develop a new exposure site, solely focusing on the treatment of concrete structures affected by ASR.

Under FHWA funding, a new outdoor exposure site was developed in 2008 at the Concrete Durability Center at the University of Texas at Austin. Details of the design, construction, and early findings from this site were previously reported by Bentivegna [2] and Resendez [3]. This paper briefly summarizes this outdoor

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exposure site-based project and focuses mainly on the application of sealants, coatings, and lithium nitrate solution to small-scale elements based on bridge deck and pavement sections.

2. OUTDOOR EXPOSURE SITE

In 2008, an outdoor exposure site was designed and constructed at the Concrete Durability Center at the University of Texas at Austin (USA). Specific details of this site can be found in Bentivegna [2]; only a brief synopsis is provided herein. The site selected was originally a vacant, grass field. The site was excavated, underground instrumentation was installed (for strain gauges and thermocouples), and a crushed rock base was backfilled and graded into the excavated section. The remainder of this section describes the materials and mixture proportions used to cast the concrete elements, specific details of the elements cast, and the instrumentation and monitoring schemes employed for the site.

2.1 Materials and Mixture Proportions

For this study, the materials and mixture proportions shown in Table 1 were used. The mixture proportions used for all test specimens were based on those specified in ASTM C 1293 (Concrete Prism Test). Because of the large volume of concrete needed for the outdoor exposure site specimens, a local, ready-mix concrete plant was used. A reactive fine aggregate from Texas (Jobe) and reactive coarse aggregate from New Mexico (Placitas) were shipped to the plant and stored until the time of casting. The reactive fine aggregate was used in combination with a local coarse aggregate for half the test specimens; the other half of the specimens were cast using the reactive coarse aggregate in combination with a local fine aggregate. The results of ASTM C 1260 (Accelerated Mortar Bar Test) and ASTM C 1293 for the above aggregates are shown in Table 2 and 3, respectively. As can be seen from Tables 2 and 3, the resultant mixtures were found to exhibit significant expansions in both tests, with expansions well above typical expansion limits. A high-alkali cement (Na_2O_e=0.80 percent) was shipped to the ready-mix plant, and NaOH was added to the mix water to attain a Na_2O_e of 1.25 percent, as per the requirements in ASTM C 1293.

2.2 Specimen Details

Three types of test specimens were selected in order to represent realistic elements used in transportation infrastructure: 1) unreinforced concrete pavement slabs, 2) reinforced bridge deck slabs, and 3) circular bridge columns.

2.2.1 Unreinforced concrete pavement slabs

Sixty-four slabs were cast in total – 32 slabs were constructed using the reactive fine aggregate (in combination with the local coarse aggregate) and 32 slabs were constructed using the reactive coarse aggregate (in combination with the local fine aggregate). In addition, two non-reactive slabs were also cast as controls, and the mix design for the control slabs included a dose of lithium nitrate at 200% of the manufacturer's recommended dose in order to prevent ASR (9.2 L of 30% lithium nitrate solution per cubic meter of concrete). The dimensions of all the slabs were 0.91 m x 0.91 m, with a thickness of 0.29 m. An epoxy-based paint sealant was applied on the sides of the slabs to prevent water infiltration; thereafter, all treatments on the slabs were applied to the top surface that was not painted with the epoxy paint.

2.2.2 Reinforced bridge deck slabs

A total of 60 bridge deck elements were constructed on the site, with 29 decks constructed using the reactive fine aggregate (in combination with the local coarse aggregate), 29 constructed with the reactive coarse aggregate (in combination with the local fine aggregate), and two non-reactive slabs using the similar preventative mix design using lithium nitrate as the pavement slabs. The dimensions of the bridge decks were 0.91 m x 0.91 m, with a thickness of 0.24 m. The slabs were designed with two mats of reinforcement (No. 16 Grade 420 MPa) spaced at 152.4 mm in the transverse direction and 254 mm in the longitudinal direction. The test specimens were supported on top of large wooden timbers to simulate how bridge decks are "open" to the elements on their underside.

2.2.3 Circular bridge columns

A total of 36 spirally reinforced concrete columns were constructed to simulate column structures commonly found in bridge elements. The dimensions of the columns were 0.61 m in diameter and 1.22 m in height. Two types of reinforcement, longitudinal and spiral, were used in the construction; the longitudinal reinforcement consists of seven No. 22 Grade 420 MPa and the spiral reinforcement consist of No. 10 Grade 420 MPa set at a 152 mm offset. Similar to the constructed slabs, half of the columns were constructed with the reactive fine aggregate and the other half were constructed with the reactive coarse aggregate used in the study (Jobe and Placitas). In addition, two columns were constructed without reinforcement to evaluate the effect of reinforcement on cracking and expansion. Figure 1 shows a photograph of the outdoor exposure site after all specimens were cast.

2.3 Instrumentation and monitoring

Significant emphasis was placed on the instrumentation and monitoring of the various test specimens. A comprehensive summary of the instrumentation/monitoring is beyond the scope of this paper, but readers are directed to Bentivegna [2] and Resendez [3] for more specific details. A brief overview of the instrumentation/monitoring is provided below.

The methods used for monitoring the progression of expansion and cracking of the various elements includes:

- Map cracking
- Expansion
    - Mechanical strain gage (DEMEC) measurements (on top surface of decks and slabs, and along sides, allowing for measurement of expansion as function of distance from top, treated surface)
    - Electrical strain gage measurements (mounted on reinforcing steel in selected specimens)
    - Electrical strain gage measurements (embedment gauges, placed within the concrete in selected specimens
    - Circumferential measurements on columns (using pi tapes)
- Relative humidity (using Vaisala probes, installed in selected specimens at varying distances from top, treated or exposed surface)
- Non-destructive testing (including resonant frequency, pulse velocity, and non-linear acoustic methods

Because of length restrictions applied to this paper, only a small subset of the results of monitoring program will be reported herein, primarily focusing on expansion results for pavement slab and bridge deck elements.

2.4 Treatment methods and details

After casting the test specimens, the specimens were monitored as per the previous section. Once the specimens reached an average expansion of 0.1 percent, a wide range of mitigation or treatment methods were applied, as summarized in Table 4 and described in detail elsewhere [2, 3]. In general, the treatment methods can be grouped as follows:

- Application of coating and sealers to reduce the internal relative humidity,
- Application of lithium nitrate by topical application, vacuum impregnation and electrochemical means,
- Application of external confinement (FRP wraps), and
- Application of overlays/barrier systems.

As stated previously, it is beyond the scope of this paper to present the findings from all of the above treatment methods; the focus will be primarily on the first two bullet points above (coatings, sealers, and lithium nitrate) and primarily for the deck and slab elements.

3 RESULTS AND DISCUSSION

This section presents a summary of the key findings to date, with focus primarily on coatings, sealers, and lithium nitrate applied to pavement slab and bridge deck elements. Most of the data presented herein are limited to expansion data measured with DEMEC gauges; future publications will include other data collected, included the results of strain gauge measurements, non-destructive testing, and relative humidity measurements.

When considering the various surface treatments applied to the slab and deck elements, the most effective treatments were coatings/sealers that aim to reduce the relative humidity in concrete. Figure 2 shows the effects of silane (40% and 100% silane contents) on the expansion of the top, treated surface of bridge decks containing reactive fine aggregate (Jobe), and Figure 3 shows similar data for bridge decks containing reactive coarse aggregate (Placitas). From these two figures, it can be seen that silanes were able to reduce but not eliminate expansion (note that the silanes were applied after the decks had reached an expansion of approximately 0.1 percent). It can also be seen that silanes are more effective in the Placitas decks as the rate of expansion is slower for Placitas, thereby allowing the silanes to reduce the internal relative before the bulk of the expansion would otherwise occur. These results are consistent with previous research at the University of Texas and the University of New Brunswick – silanes and other compounds that work by reducing internal humidity tend to be most effective with slower reactive aggregates as the rate of lowering internal relative humidity exceeds the rate of ASR reactivity. The same trend can also be observed in Figures 4 and 5, in which the expansions 25 mm from the top of the treated surface are shown. Similar trends were observed for the unreinforced pavement slabs and columns, but due to length restrictions, the data will not be presented herein.

Significant emphasis was placed on evaluating the application of lithium nitrate to the various specimen types. The results, however, were not encouraging as the topical application of lithium nitrate had little or no effect on subsequent expansion. These results are consistent with past research at the University of Texas and the University of New Brunswick, as well as past field trials funded by FHWA [4]; the ineffectiveness of lithium nitrate treatments applied to ASR-affected concrete has been linked to the lack of penetration into the treated substrate. Figures 6 and 7 clearly show that the lithium treatments had no beneficial effect in terms of reducing ASR-induced expansion, even when the lithium nitrate was applied weekly (36 times for Jobe decks; 20 times for Placitas decks).

4 CONCLUSIONS

This paper presented preliminary findings on a long-term exposure site study aimed at evaluating methods of reducing expansion in ASR-affected concrete. The primary focus of this paper was on the application of sealants, coatings, and lithium nitrate. The findings to date show that silanes (both 40- and 100-percent silane) were quite effective in reducing ASR-induced expansion through their ability to reduce internal relative humidity. On the other hand, the application of lithium nitrate solution to the surface of ASR-affected concrete showed no ability to reduce further expansion, which is consistent with prior laboratory and field work performed by the authors of this paper.

5 ACKNOWLEDGEMENTS

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6. REFERENCES

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TABLE 1: Materials and mixture proportions used for testing program (based on ASTM C 1293)

Material*	Proportions (kg/m^3)	Notes/comments
Portland cement	420	High-alkali cement (0.80% Na_2O_e) + NaOH added to mix water to achieve 1.25% Na_2O_e
Water	177	
Coarse Aggregate	1065	Reactive coarse aggregate (Placitas) used in combination with local fine aggregate OR local coarse aggregate used in combination with reactive fine aggregate (Jobe)
Fine aggregate	708	Reactive fine aggregate (Jobe) used in combination with local coarse aggregate OR local fine aggregate used in combination with reactive coarse aggregate (Placitas)

* A high-range water reducer (polycarboxylate) and set retarder were used as needed to achieve desired workability and handling time.

TABLE 2: ASTM C 1260 (Accelerated Mortar Bar) results for aggregates used in study

Material	ASTM C 1260 results – expansion at 14 days (%)
Reactive fine aggregate (Jobe)	0.82
Local fine aggregate	0.23
Reactive coarse aggregate (Placitas)	0.98
Fine aggregate	0.18

TABLE 3: ASTM C 1293 (Concrete Prism) results for aggregates used in study

Material	ASTM C 1293 results – expansion at one year (%)
Reactive fine aggregate (Jobe) + local coarse aggregate	0.49
Reactive coarse aggregate (Placitas) + local fine aggregate	0.23

TABLE 4: Summary of treatment methods applied to the test specimens (after Resendez [3])

Treatment Details	**Elements Selected**
Electrochemical impregnation with lithium nitrate (LiNO3)	Columns, bridge decks
Vacuum impregnation with lithium nitrate (LiNO3)	Bridge decks
Repeated anti-icing salt application using potassium acetate (KAc)	Slabs
Repeated anti-icing salt application using potassium acetate (KAc) with topical lithium treatment	Slabs
Repeated anti-icing salt application using sodium chloride (NaCl)	Bridge decks, slabs
Repeated anti-icing salt application using sodium chloride (NaCl) with topical lithium treatment	Bridge decks, slabs
Sealer/coating – 40% silane	Columns, bridge decks, slabs
Sealer/coating – 100% silane	Columns, bridge decks, slabs
Topical lithium, one application	Bridge decks, slabs
Topical lithium, weekly application	Bridge decks, columns, slabs
Carbon-fiber reinforced polymer wraps (once wrap)	Columns
Carbon fiber reinforced polymer wraps (two wraps)	Columns
Carbon-fiber reinforced polymer wraps (four wraps)	Columns
Asphalt overlay (2-inch thick)	Bridge decks, slabs
Unbonded concrete overlay (6-inch thick)	Bridge decks, slabs
Polymer membrane	Columns
Polymer overlay	Bridge decks

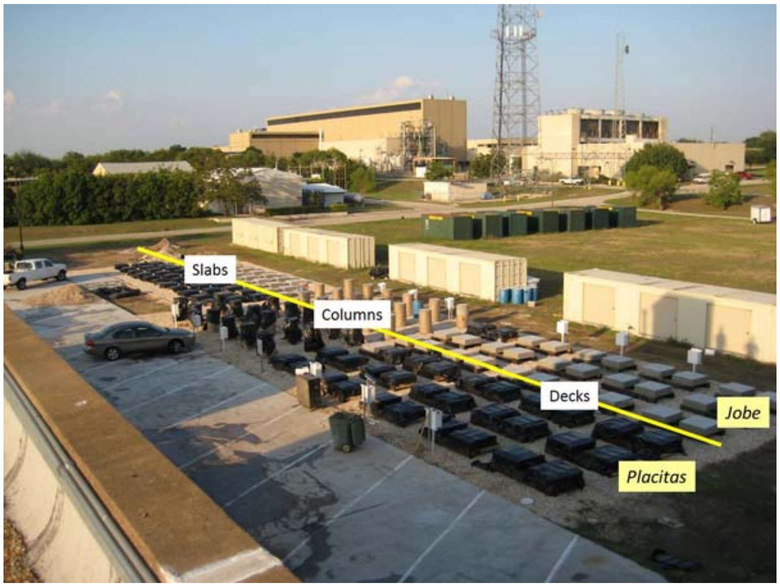

FIGURE 1: Photo of the outdoor exposure site in Austin, TX, showing the two reactive aggregates used (Jobe sand and Placitas gravel) and the three element types (slabs, columns, and decks)

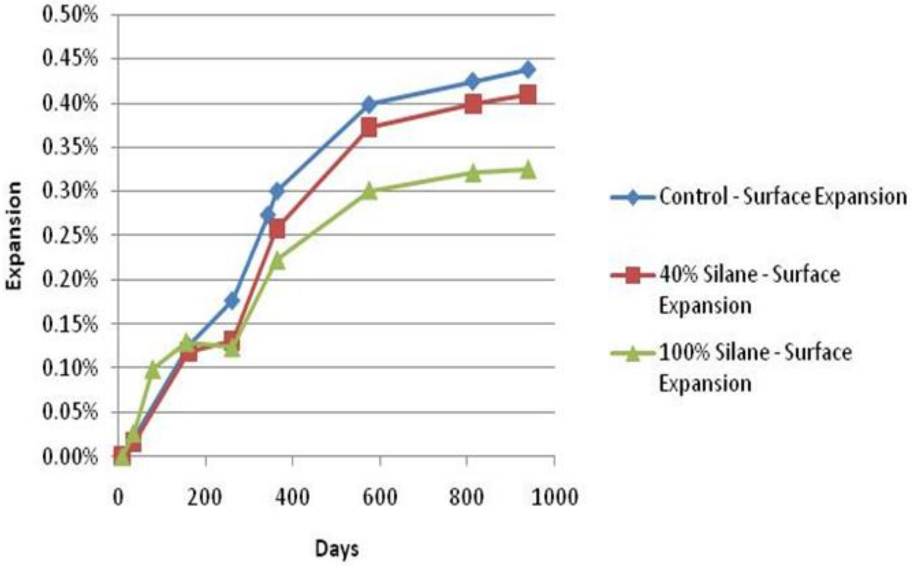

FIGURE 2: Effects of silane (40% and 100% silane content) on surface expansion of bridge deck containing reactive fine aggregate (Jobe)

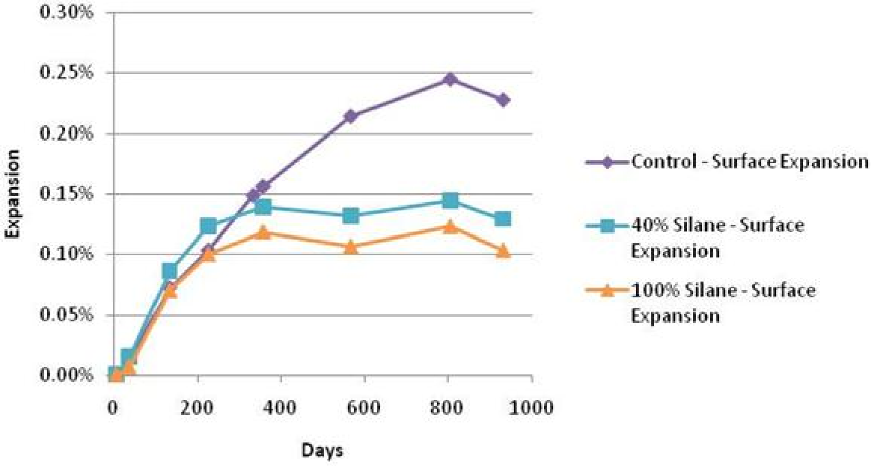

FIGURE 3: Effects of silane (40% and 100% silane content) on surface expansion of bridge deck containing reactive coarse aggregate (Placitas)

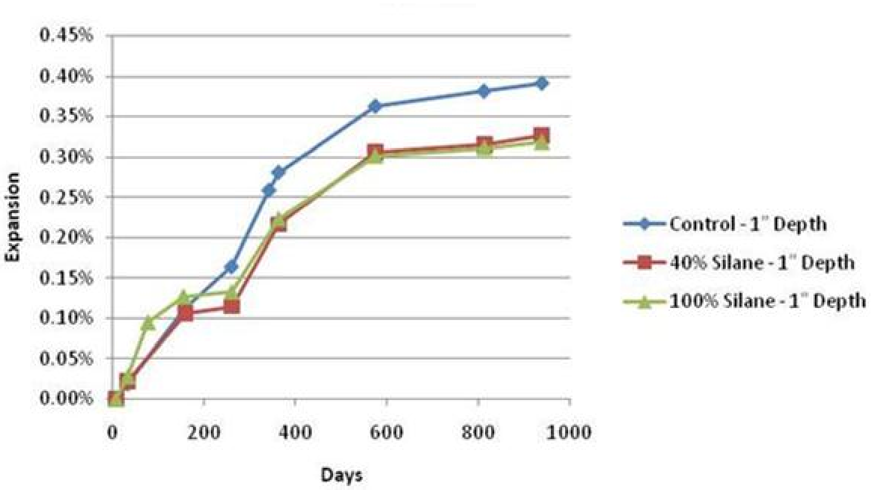

FIGURE 4: Effects of silane (40% and 100% silane content) on expansion 25 mm from surface of bridge deck containing reactive fine aggregate (Jobe)

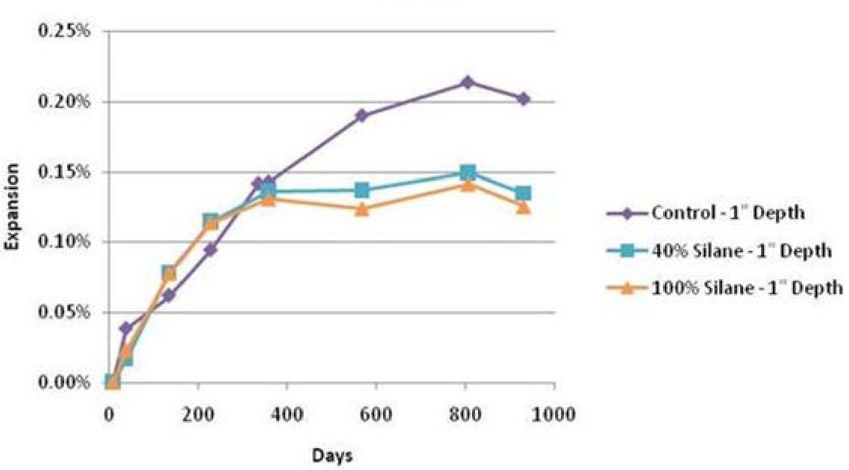

FIGURE 5: Effects of silane (40% and 100% silane content) on expansion 25 mm from surface of bridge deck containing reactive coarse aggregate (Placitas)

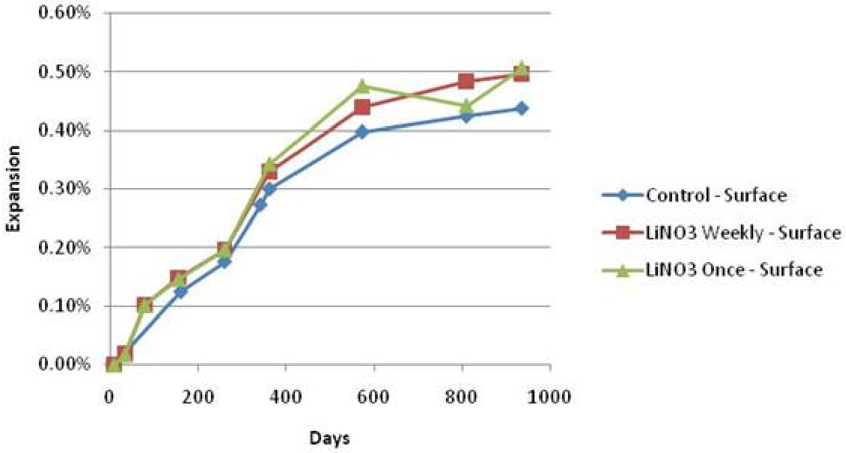

FIGURE 6: Effects of lithium nitrate (30% solution) application on surface expansion of bridge deck containing reactive fine aggregate (Jobe)

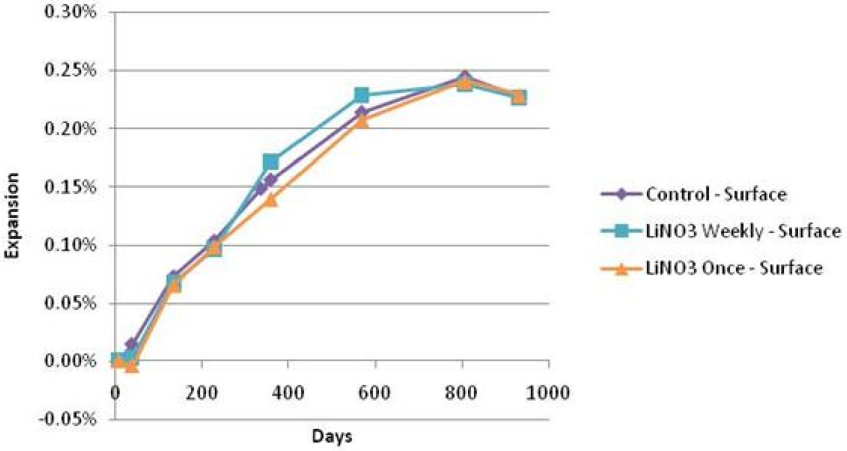

FIGURE 7: Effects of lithium nitrate (30% solution) application on surface expansion of bridge deck containing reactive coarse aggregate (Placitas)