

Potential for Development of Alkali-Silica Reaction in the Presence of Airfield Deicing Chemicals

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Abstract

This paper focuses on some preliminary studies conducted to investigate the role of alkali-based airfield deicers in causing alkali-silica reaction (ASR) in airfield pavement concrete. A modified ASTM C 1260 test procedure was used in this study, in which mortar bars prepared with reactive aggregate were immersed in deicer soak solution instead of 1 N sodium hydroxide solution. In addition, standard ASTM C 1260 tests were also conducted on mortar bar containing reactive aggregate. Expansion of mortar bars subjected to deicer solutions in the modified ASTM C 1260 test was either equivalent or significantly greater than expansion of mortar bars exposed to the 1 N sodium hydroxide soak solution in the standard test. Based on the findings from this study, it appears that the alkali-based airfield deicers have considerable potential in initiating and accelerating ASR. In parallel studies with a non-reactive aggregate, no significant expansions were observed either in the standard or the modified ASTM C 1260 test.

Introduction

Presently, a majority of the airports across the United States use alkali-based deicers on a routine basis for ice and snow removal operations as well as anti-icing agents. The predominantly employed deicers are based on potassium acetate, sodium acetate and sodium formate. These deicers have gained increasing popularity over traditional deicers such as urea, ethylene glycol and propylene glycol because of their low environmental impact (Gamble et al., 2003; EPA 816-F-02-018, 2002). Coincidentally, there appears to be an increase in the number of reported instances of deterioration in concrete airfield pavements across the United States in recent years, in particular, due to alkali-silica reaction (ASR) in concrete. It is suspected that these

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alkali-based deicers may have a role in initiating or accelerating the deterioration of airfield pavement concrete containing reactive aggregates.

Recent investigations into deterioration of several commercial concrete airfield pavements indicated ASR to be the principal reason for deterioration. These airfields included: Colorado Springs Airport (COS) and Denver International Airport (DIA) (Jack Scott, personal communication, October, 2004); Hartsfield-Jackson Atlanta International Airport (ATL) (Boudreau et al., 2004), Greenville-Spartanburg International Airport (GSP) (Rangaraju, 2004; Erlin, unpublished manuscript, 1996), and Memphis International Airport (MEM) (Joe Polk, personal communication, November 2004). In some of these airports, it has been suspected that the exposure of the concrete pavement to the new deicers may have played a role in accelerating the deterioration of concrete.

This paper presents results from a preliminary investigation conducted to assess the effect of selected deicer salt solutions in initiating and accelerating ASR in mortar bar specimens containing aggregates with established ASR potential.

Standard and modified ASTM C 1260 tests were conducted on mortar bars prepared with reactive and non-reactive aggregates to study the influence of deicer soak solution on the expansions. In addition to the expansion measurements in the ASTM C 1260 tests, the physical distress of the mortar bars was studied and quantified by measuring the dynamic modulus of elasticity. The composition of the soak solutions (Na^+ , K^+ , Ca^+ , OH^- , SO_4^{2-}) and pH were also monitored to ascertain if any leaching of alkalis and other species was occurring during the 14-day storage of specimens in soak solution. In this paper, only the pH data is presented. Scanning electron microscopy and energy dispersive X-ray analyses were conducted on selected specimens to investigate the nature of the reaction and composition of the reaction products.

Research Significance

Considerable research has been conducted in studying the influence of traditional deicers such as sodium chloride and calcium chloride on initiating or aggravating ASR in concrete (Chatterji et al., 1987; Kawamura and Ichise, 1990; Sibbick and Page, 1996; Berube et al., 2000). In these studies it has been shown that these chloride-based deicers have an accelerating effect on ASR, although other factors such as test specimen size and cement characteristics (C_3A content and alkali content of cement) appear to have an influence on the observed distress. However, the influence of the new generation of deicers, such as alkali-acetate and alkali-formate based deicers, on the potential to cause or accelerate ASR in concrete has not been extensively studied. In light of the increasing number of reported instances of premature airfield pavement deterioration, there is an urgent need to understand the role of these deicers in causing or promoting ASR in concrete pavements.

Scope and Experimental Program

Materials

Deicers. In this study, three deicers that are commonly used on airfield pavements were selected. These included a 50% solution of potassium acetate (liquid deicer), granulated sodium acetate and granulated sodium formate (solid deicers).

Aggregates. Two types of aggregates were selected in this study - a reactive siliceous limestone aggregate from Spratt quarry near Ottawa, Ontario; and a non-reactive fine aggregate (graded Ottawa sand conforming to ASTM C 778). Spratt limestone primarily consists of calcite with minor amounts of dolomite and about 10% insoluble residue (Rogers, 1999). The reactive component of the rock is reported to consist of 3% to 4% of microscopic chalcedony and black chert, which is finely dispersed in the matrix. The reactivity of Spratt limestone has been well-established in numerous previous ASR-related studies (Rogers, 1999; Fournier and Malhotra, 1999).

Cements. Two types of cements - a high alkali cement (with Na_2O equivalent of 0.82% and an autoclave expansion of 0.12%) and low alkali cement (with Na_2O equivalent of 0.31% and autoclave expansion of 0.08%) were used in this study.

Test Methods

Standard ASTM C 1260 Test. In this test, mortar bars (25 mm x 25 mm x 285 mm) are cast with embedded gage studs at the ends and cured for 24 hours in a moist curing room. After demolding, the bars are cured for an additional 24 hours in an 80°C water-bath. At the end of water-bath curing, the bars are placed in an 80°C bath of 1 N NaOH solution for 14 days. Periodic length change measurements are taken over the course of 14 days and percent expansion is calculated. Based on the guidance provided in ASTM C 33, expansions less than 0.1% after 14 days of soaking in 1 N NaOH solution are typically considered to be representative of non-reactive aggregates. Expansions over 0.2% at 14 days are considered to represent the potentially reactive aggregates. Expansion in between 0.1% and 0.2% require additional confirmation by either conducting ASTM C 1293 test or reviewing field performance records, to ascertain the reactivity of aggregates. In all the ASTM C 1260 tests conducted in this research study, the reported expansion values represent an average of readings obtained from 4 mortar bars. Although the standard ASTM C 1260 procedure does not have restrictions on the alkali content of the cements that can be used for the test, in the present study a high and a low alkali cement were used to evaluate the influence of cement alkalinity on the observed expansions. Both cements used in the study met the requirements of 0.2% maximum autoclave expansion.

Modified ASTM C 1260 Test. In the modified ASTM C 1260 tests, the 1N NaOH soak solution was replaced by the solution prepared with deicers. Among the deicers, the potassium acetate deicer was commercially available in a liquid form (at a

concentration of 50% solution by weight), and this liquid was used as soak solution. The 50% solution has a molar concentration of 6.47. In order to assess the influence of reduced concentrations of the potassium acetate on the expansions of the mortar bars, soak solutions of 3 M, 1 M and 0.3 M concentrations were also prepared and studied.

The other two deicers - sodium acetate and sodium formate - were commercially available in solid granular form. Soak solutions of these solid deicers were prepared by saturating deionized water with the deicer at room temperature. At saturation, the sodium acetate and sodium formate solutions yielded solutions of 35% and 33.3% by weight percent, respectively.

The reason for selecting the saturation concentrations for each of the solid deicers used in modified ASTM C 1260 tests was to simulate the worst possible level of concentration of deicer that a pavement would likely experience. Although it is likely that with potassium acetate deicer, a pavement could possibly see a saturated solution of the deicer (66.7% solution by weight), the 50% solution as supplied by manufacturers was used in this research.

Other than the soak solution compositions, the modified ASTM C 1260 test procedure was identical to the standard ASTM C 1260 test procedure. The length-change observations in all cases (both standard and modified versions of ASTM C 1260 test) were carried out to 28 days or beyond, instead of the typical 14 days.

Dynamic Modulus of Elasticity. The physical distress in the mortar bars was quantified by measuring the dynamic modulus of elasticity (DME). The DME values were determined using the resonant frequency method based on impulse excitation technique (ASTM E 1876-01). A GrindoSonic™ instrument was used in determining the resonant frequencies of the mortar bars. The mass and resonant frequency of the mortar bars were measured at the same time when the bars were removed from the soak solution for expansion measurements. For sake of simplicity, the dimensions of the mortar bars were assumed to be constant (i.e., 25 mm x 25 mm x 285 mm) and the effects of gage studs at the ends of the bars were neglected as it was a common factor for all measurements and would have a relatively small effect on the dynamic modulus of elasticity results.

pH Values and Chemical Composition of the Soak Solution. In order to determine if any leaching of alkali and hydroxyl ions from the mortar bars into the soak solution occurred, the soak solutions in the standard and modified ASTM C 1260 tests were sampled at end of 14 days of soaking and analyzed for pH and concentration of Na^+ , K^+ , Ca^+ , SO_4^{-2} and OH^- species. Similar readings were also taken for the plain soak solutions (i.e. solutions in which no mortar bars were immersed). The composition of the soak solution was determined by sampling 100 ml of the solution at 14 days. The OH^- ion concentration was determined by titration; Na^+ , K^+ and Ca^+ concentration was determined by Atomic Absorption Spectroscopy; and SO_4^{-2} concentration was determined by Ion Chromatography. The pH of the soak solution was measured using a Corning 125 pH meter calibrated to buffer solution with pH 12.6. In this paper, only pH data is presented.

Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Analysis (EDX). Scanning electron microscopy (in back-scattered mode) and energy dispersive X-ray analysis were conducted on polished sections of mortar bars from the standard and modified ASTM C 1260 tests, using a Hitachi S3500N electron microscope. The instrument was operated in a variable pressure mode.

The samples for the investigation were prepared by slicing the bars using a slow speed diamond saw followed by polishing the samples on a series of magnetic lapping wheels with embedded diamond grit. The final polishing step involved the use of a 0.5 micron diamond paste on a cloth lap.

Sample Identification. Since various combinations of materials were used in this study, a specific notation scheme was employed for ease of understanding the combination of materials being evaluated. The high and low alkali cements were identified as HA and LA, respectively. The soak solutions comprised of potassium acetate, sodium acetate and sodium formate based deicers were identified as PA, SA, and SF, respectively. One normal sodium hydroxide solution is identified as 1 N. For example, a combination identified as PA-HA-Spratt, would therefore indicate potassium acetate deicer soak solution with high-alkali cement and Spratt limestone aggregate.

Results and Analysis

Results of Standard ASTM C 1260 Test. Figure 1 shows the expansion behavior of Spratt limestone and Ottawa sand in the standard ASTM C 1260 test, using 1 N NaOH solution at 80°C as soak solution.

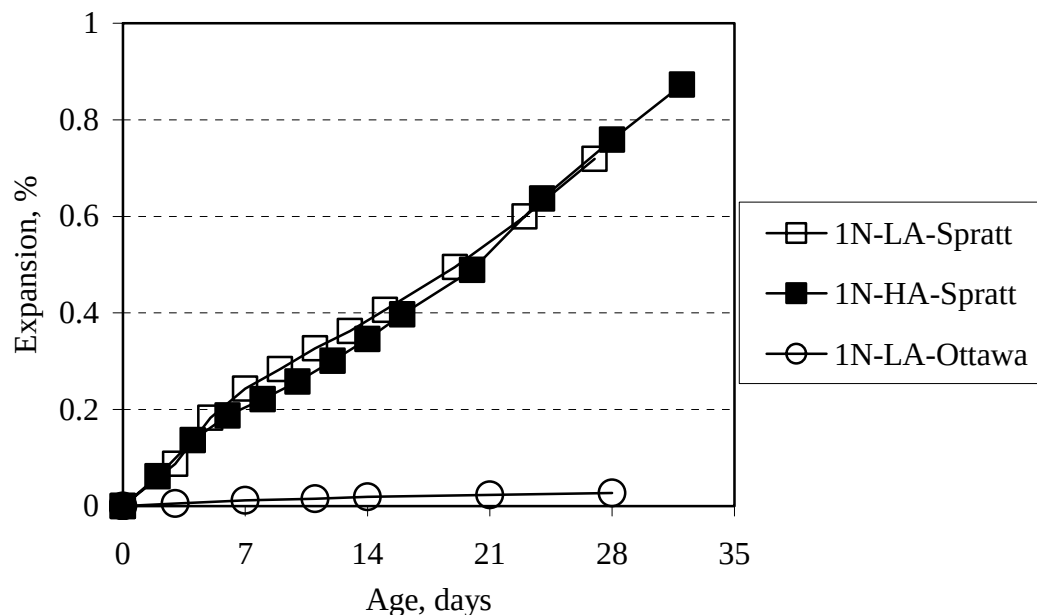


Figure 1. Expansion of mortar bars containing Spratt limestone and Ottawa sand in standard ASTM C 1260 test.

It is apparent from Figure 1 that Spratt limestone has an expansion of 0.35% and 0.38% at 14 days, with high-alkali and low-alkali cements, respectively. This level of expansion is considered to represent a deleteriously reactive aggregate. The graded Ottawa sand shows almost no expansion at 14 days, which indicates its relatively innocuous nature. Also, the alkali content of the cement did not appear to have any appreciable influence on the level of expansion observed.

Results of Modified ASTM C 1260 Test

Influence of Potassium Acetate-Based Deicer Soak Solution on Expansions of Mortar Bars

Figure 2 shows the expansion behavior of mortar bars containing Spratt limestone and non-reactive Ottawa sand, soaked in 50% solution of potassium acetate-based deicer in the modified ASTM C 1260 test. Also, the influence of alkali content of the cement on the observed expansions with both the aggregates is shown.

It can be observed from Figure 2 that mortar bars containing reactive Spratt limestone, soaked in 50% solution of potassium acetate solution have shown considerable expansion at 14 days (~0.8% for HA cement) and continue to expand at similar rates up to 28 days with no sign of abatement in expansion. In fact, the test on mortar bars prepared with high-alkali cement and Spratt limestone had to be terminated at 14 days, as the samples had expanded so much that they developed a well-pronounced arch that interfered with taking measurements. Figure 3 shows the typical curvature in these samples. It should be noted that in each of these samples, the hand-finished surface of the mortar bar always curled towards the inner side of the curvature. The bars were also significantly cracked as shown in Figure 3b.

It is evident from the results shown in Figure 2 that the alkali content of cement has a definite influence on the observed expansion in the mortar bars. Bars with high-alkali cement consistently yielded higher expansion than bars with low-alkali cement.

In contrast, mortar bars prepared with non-reactive Ottawa sand show very little expansion with time when immersed in the potassium acetate deicer soak solution, even up to 28 days of testing. This trend appears to be consistent, regardless of the alkali content of the cement used in the study.

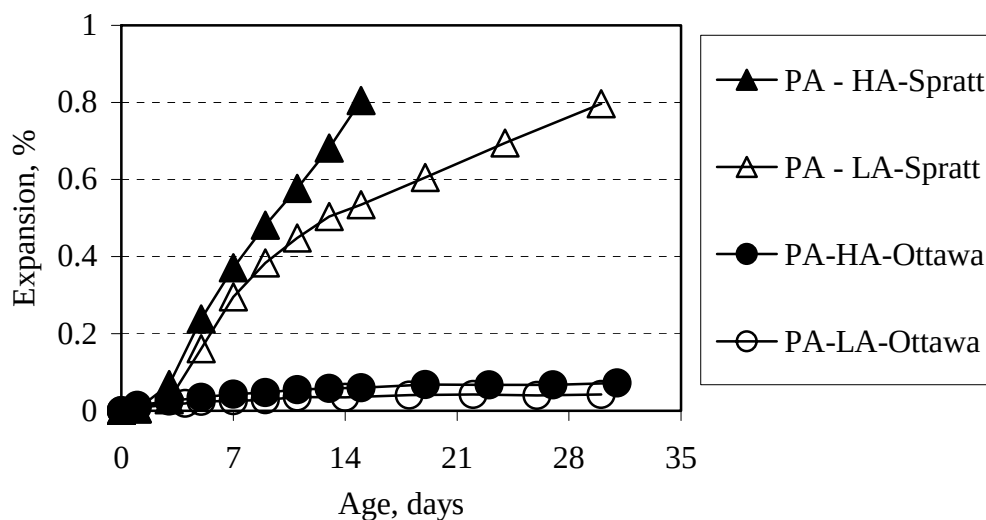


Figure 2. Influence of potassium acetate-based deicer soak solution (50% solution) on expansion of mortar bars in modified ASTM C 1260 test.



Figure 3. (a) Mortar bars soaked in 50% potassium acetate-based deicer soak solution showing development of arch and (b) Cracking on surface of mortar bars

Influence of Concentration of Potassium Acetate Deicer Soak Solution on Observed Expansions in Modified ASTM C 1260 Tests

Figures 4 and 5 shows the results of modified ASTM C 1260 tests, in which influence of different concentrations of the potassium acetate deicer soak solution on the expansions observed in the mortar bars was evaluated, with Spratt limestone and high and low-alkali cements, respectively.

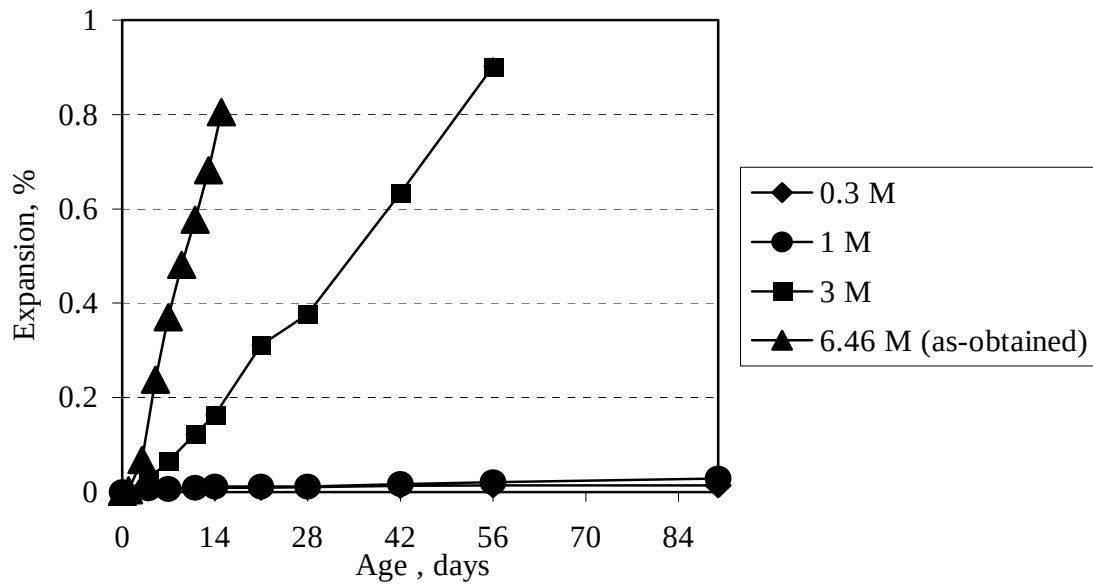


Figure 4. Influence of concentration of potassium acetate deicer soak solution on expansions of mortar bars prepared with Spratt limestone and high-alkali cement in modified ASTM C 1260 tests.

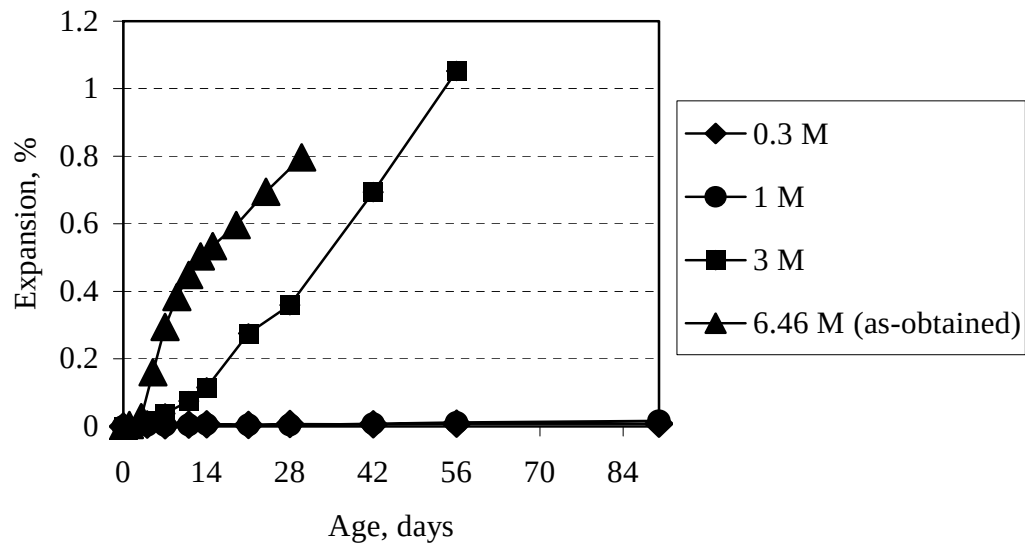


Figure 5. Influence of concentration of potassium acetate deicer soak solution on expansions of mortar bars prepared with low-alkali cement in modified ASTM C 1260 tests.

The concentrations considered in this study were 6.46 M (as-obtained 50% by weight solution), 3 M, 1 M and 0.3 M solutions. It can be observed by comparing the curves in Figures 4 and 5 that mortar bars exposed to lower concentrations of soak solutions yielded lower expansions, regardless of the alkali-content of the cement used.

Interestingly, even though the expansion of mortar bars in a 3 M concentration of soak solutions was less than 0.2% at 14 days, it increased to 0.38% by 28 days. The rate of expansion showed no sign of slowing down, even beyond 28 days. Based on this study, it appears that at a concentration of 1 M potassium acetate deicer soak solution no significant expansion of the mortar bars could be observed, even at ages well beyond 28 days. This suggests that a critical level of concentration may exist for a given aggregate below which no significant expansion may occur in the modified ASTM C 1260 test.

Influence of Sodium Acetate Deicer Soak Solution on Expansions of Mortar Bars

Figure 6 shows the expansion behavior of mortar bars containing Spratt limestone and non-reactive Ottawa sand, soaked in saturated solution of sodium acetate-based deicer in the modified ASTM C 1260 test. The solution is saturated with sodium acetate-deicer salt at room temperature. It can be observed from Figure 6 that mortars bars containing Spratt limestone have shown considerable expansion, regardless of the alkali content of the cements used.

Mortar bars prepared with non-reactive Ottawa sand show very little expansion with time when soaked in sodium acetate deicer solution, even up to 28 days of testing. This trend appears to be consistent, regardless of the alkali content of the cement used in the study.

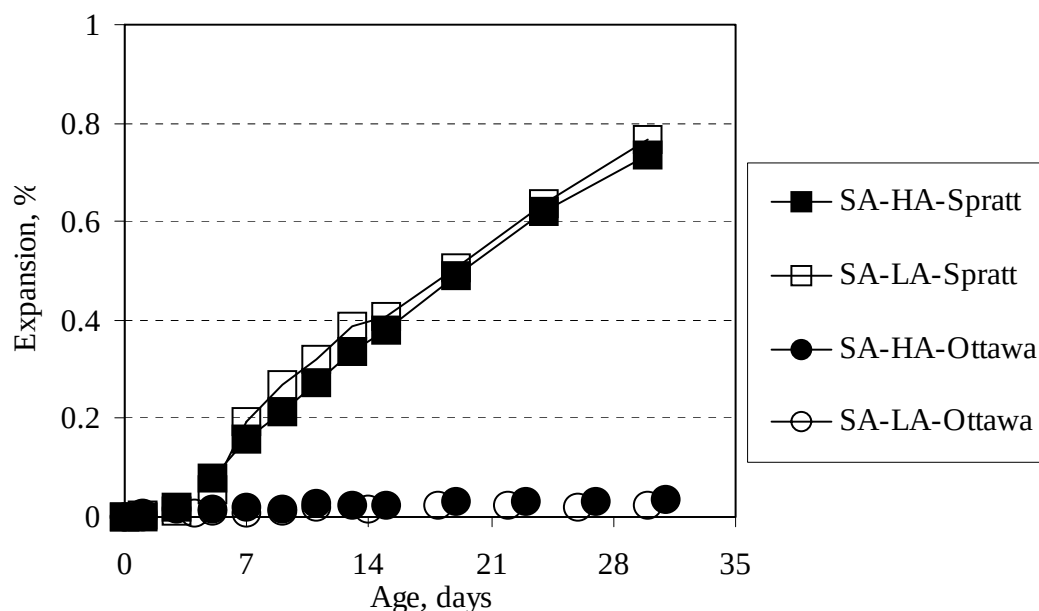


Figure 6. Influence of saturated soak solution of sodium acetate deicer on expansion of mortar bars in modified ASTM C 1260 test.

Figure 7a shows an overall appearance of the mortar bars with Spratt limestone soaked in sodium acetate deicer solution and Figure 7b shows a close-up view of the surface of one of bars. It is evident from observing Figure 7 that the bars

did not exhibit appreciable arching behavior, unlike those soaked in potassium acetate soak solution. However, moderate level of surface cracking was evident.



Figure 7. (a) Mortar bars soaked in saturated solution of sodium acetate-based deicer showing (no significant arching) and (b) Mild-cracking on surface of mortar bar

Influence of Sodium Formate Soak Solution on Expansions of Mortar Bars

Figure 8 shows the expansion behavior of mortar bars soaked in saturated solution of sodium formate-based deicer in the modified ASTM C 1260 test. The saturated solution was prepared by dissolving the deicer salt to saturation at room temperature. The expansion readings for mortar bars prepared with Spratt limestone were taken only at 0, 14, and 21 days. The reason for these discrete sets of data are because these mortar bars were part of a leaching study, wherein the composition of the soak solution was being monitored for any leaching of ionic species from the mortar bars. In that study, in order to avoid any evaporation of the soak solution in the process of removing mortar bars for periodic length-change measurements (and hence affect any changes in concentrations) the bars were continuously soaked in the solution for a period of 14 days. It can be observed from Figure 8 that significant expansion of mortar bars containing Spratt limestone had occurred. However, no such deleterious expansions resulted in mortar bars containing non-reactive Ottawa sand.

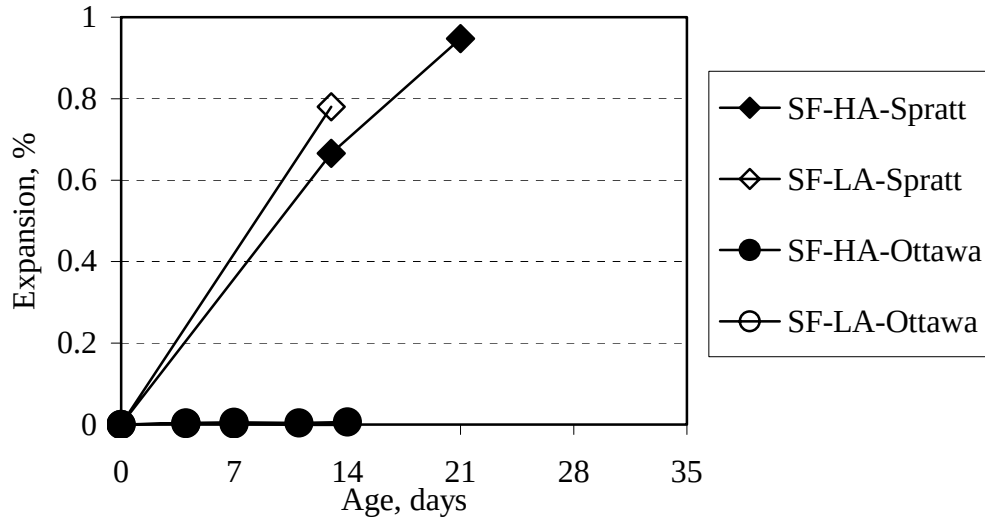


Figure 8. Influence of saturated soak solution of sodium formate-based deicer on expansion of mortar bars in modified ASTM C 1260 test.

Figure 9a shows a general view and Figure 9b shows a close-up view of the surface of the mortar bar containing Spratt limestone, subjected to sodium formate-based deicer soak solution. It is interesting to observe that even though considerable expansion of the mortar bars was observed, no arching of the mortar bars was noticed, unlike previously observed for the bars soaked in potassium acetate-based deicer soak solution. Also, no noticeable cracking on the surface of the mortar bars could be observed, unlike the bars stored in potassium acetate or sodium acetate based deicer soak solutions.



Figure 9. (a) Mortar bars containing Spratt aggregate soaked in saturated solution of sodium formate-based show no arching effect and (b) No evidence of distress on surface of mortar bars.

Dynamic Modulus of Elasticity. Figures 10 and 11 show the influence of soak solution on the dynamic modulus of elasticity (DME) of mortar bars prepared with high-alkali and low-alkali cements, respectively. Table 1 shows the percent loss in DME at 28 days relative to initial day.

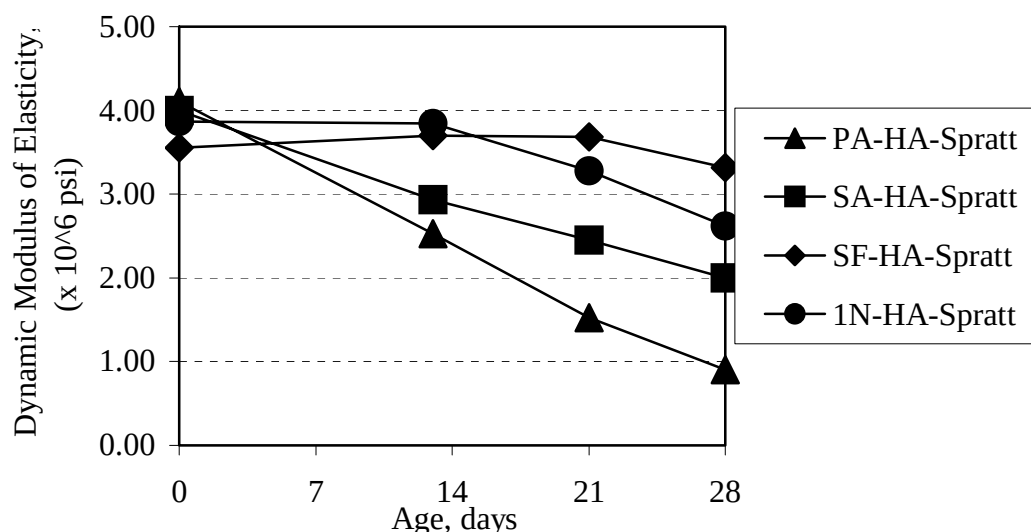


Figure 10. Changes in DME values of mortar bars (prepared with Spratt aggregate and HA cement) subjected to three different (PA, SA & SF) deicer solutions in modified ASTM C 1260 test and 1N NaOH solution in standard ASTM C 1260 test.

It is evident from Figure 10 that, of all the soak solutions potassium acetate solution had the most severe effect on the DME values of mortar bars prepared with high-alkali cement followed by sodium acetate solution. In case of mortar bars prepared with low-alkali cement (see Figure 11); the effect of sodium acetate appears to be slightly more deleterious than potassium acetate soak solution. Sodium formate and 1 N sodium hydroxide soak solutions show lesser impact on the DME values of mortar bars.

It is important to note that in this study the strengths (molar concentrations) of different deicer soak solutions were not the same.

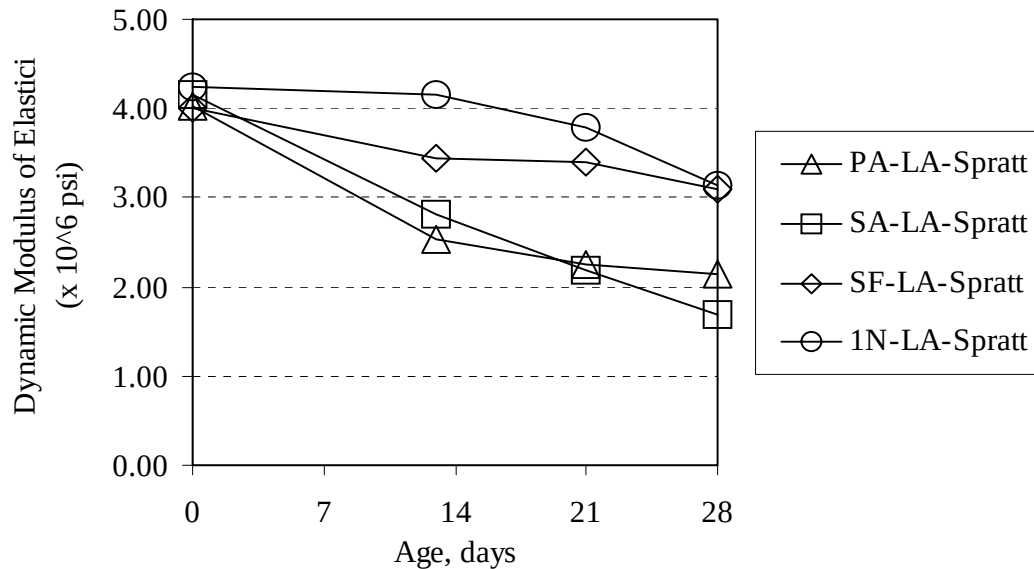


Figure 11. Changes in DME values of mortar bars (prepared with Spratt limestone and LA cement) subjected to three different (PA, SA & SF) deicer solutions in modified ASTM C 1260 test and 1N NaOH solution in standard ASTM C 1260 test.

Table 1. Influence of type of soak solution on percent loss in dynamic modulus of elasticity of mortar bars.

Soak Solution	% Loss in Dynamic Modulus of Elasticity at 28 days	
	HA Mortar Bars	LA Mortar Bars
Potassium Acetate	78	47
Sodium Acetate	50	60
Sodium Formate	7	23
1N Sodium Hydroxide	33	26

Comparing the expansion data for mortar bars shown in Figures 2, 6 and 8 and the percent loss in dynamic modulus of elasticity in Table 1, a peculiar behavior can be observed in mortar bars soaked in sodium formate deicer solution. Although the 14 days expansion of mortar bars soaked in sodium formate deicer solution is similar to that of bars exposed to potassium acetate deicer solution (~ 0.7 - 0.8%) and significantly more than bars soaked in sodium acetate (~0.4%), the drop in the DME values of corresponding bars is not identical. Bars soaked in sodium formate showed only 7% drop in DME in bars with high-alkali cement and 23% with low-alkali cement. Relatively, bars soaked in potassium acetate and sodium acetate solution showed much higher drop in DME values. Visual observation of mortar bars, at the end of the test period, showed very little cracking in bars soaked in sodium formate deicer solution (see Figure 9b). However, bars soaked in potassium acetate solution

had severely cracked (see Figure 3b). This indicates that, the expansion of mortar bars is not necessarily related or proportional to the physical distress.

pH Measurements of Soak Solutions. pH measurements of soak solutions were taken to identify any significant changes that occur due to exchange of ionic species between the mortar bar and the soak solution.

It is evident from Figure 12 that the pH of 1 N NaOH solution is not affected to any significant extent, by the presence or absence of mortar bars in the solution, or the alkali-level of the cement used. It is likely that, this is due to the higher pH of the 1 N NaOH soak solution compared to that of a typical pore solution in plain cement mortars (Andersson et al., 1989)

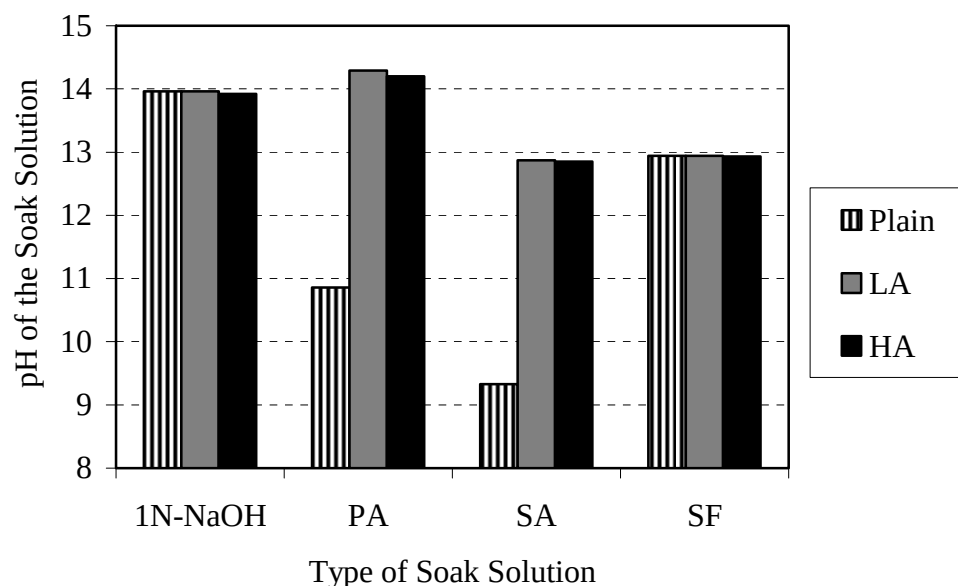


Figure 12. pH values of plain soak solution and soak solutions in which mortar bars prepared with low-alkali and high-alkali cement and Spratt limestone were immersed.

In case of potassium acetate and sodium acetate soak solutions, there is a dramatic jump in the pH between the plain solutions and the solutions in which mortar bars were immersed. This suggests that certain chemical interactions between the soak solution and mortar bars may be at play. The high pH environment resulting from these interactions is likely to have an accelerating effect on the expansions associated with ASR.

The behavior of sodium formate soak solutions with regards to its pH is distinctly different than other deicer soak solutions. The pH value of sodium formate based deicer soak solution does not appear to be influenced appreciably, either by the presence or absence of the mortar bars in the soak solutions, or by the alkali-level of the cement itself. However, significant expansion of mortar bars containing reactive Spratt limestone can be observed in the presence of sodium formate based deicer soak solutions (see Figure 8). In this regard, the behavior of the bars soaked in sodium

formate deicer solution is similar to that of bars soaked in 1 N sodium hydroxide solution.

Scanning Electron Microscopy and Energy Dispersive X-ray Analysis

Mortar Bars Soaked in Potassium Acetate Deicer Soak Solution

It became apparent in the sample preparation and later in the SEM analysis, that the mortar bars soaked in potassium acetate exhibited an intense hygroscopic nature. Due to this characteristic feature, it was difficult to keep the sample dry before being introduced into the SEM chamber. When the vacuum was applied in the SEM chamber, the absorbed water in the sample evaporated, leaving a residue of the salt on the surface of the specimen, thus making it difficult to examine the microstructure and determine the composition of the products.

Figure 13 shows a photomicrograph of a mortar bar (with Spratt limestone) soaked in potassium acetate deicer solution, in which extensive cracks can be observed. However, most of the cracks in the mortar bar did not appear to have significant amount of ASR gel.

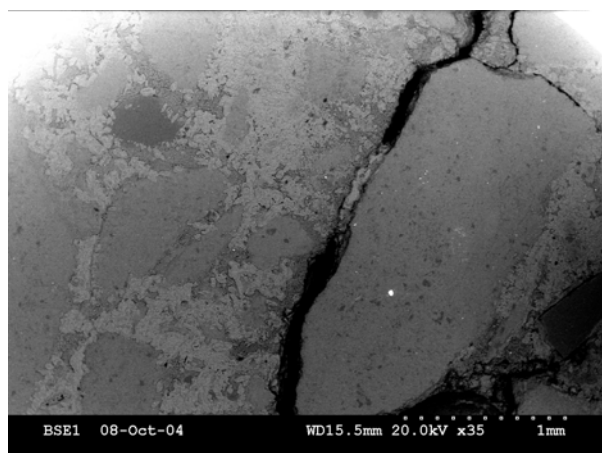


Figure 13. Photomicrograph of a polished section of mortar bar subjected to potassium acetate soak solution in modified ASTM C 1260 test using high-alkali cement

Mortar Bars Soaked in Sodium Acetate Deicer Soak Solution

Figure 14 shows a photomicrograph from a mortar bar (with Spratt limestone) soaked in sodium acetate deicer solution. Although extensive cracking can be observed in the matrix, no appreciable amounts of ASR gel could be observed in the vicinity of the cracks.

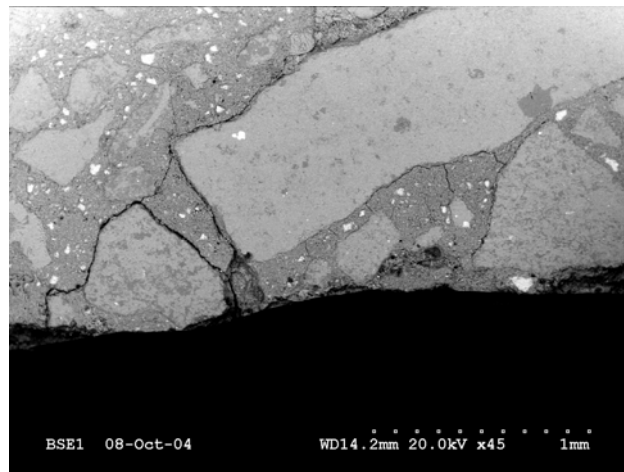


Figure 14. Photomicrograph of a polished section of mortar bar subjected to sodium acetate soak solution in modified ASTM C 1260 test using high-alkali cement.

Mortar Bars Soaked in Sodium Formate Deicer Soak Solution

Figures 15a and 15b show a photomicrograph of an interior of a mortar bar (with Spratt limestone) soaked in sodium formate deicer solution, in which extensive cracks through out the matrix can be observed. In contrast to cracks that are wide-open in bars soaked in other deicers (see Figures 13 and 14), the cracks in bars soaked in sodium formate deicer soak solution tend to be in-filled with significant amount of ASR gel. It is likely that the nature of the ASR gel produced in reactions with sodium formate deicer soak solutions is different than other soak solutions. Also, the presence of rather dense ASR gel bridging the crack perhaps explains the large expansion observed in mortar bars (see Figure 8) and yet the lack of drop in dynamic modulus of elasticity and the relative absence of surface cracking.

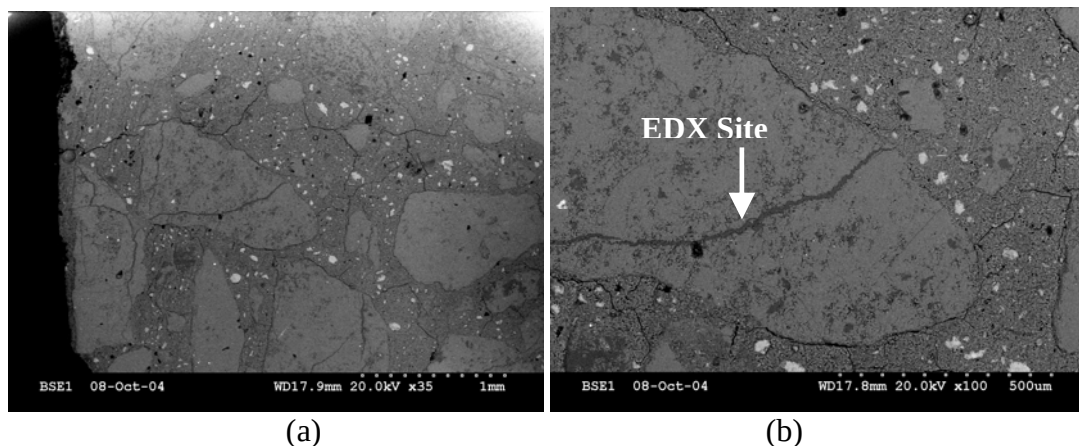


Figure 15. (a) Photomicrograph of a polished section of mortar bar subjected to sodium formate soak solution in modified ASTM C 1260 test using high-alkali cement (b) Close-up view of ASR gel in a crack within the aggregate particle.

Figure 16 shows an EDX spectrum of the in-filled product (ASR gel) in mortar bars soaked in sodium formate deicer solution. The composition of the product is typical of ASR gel composition.

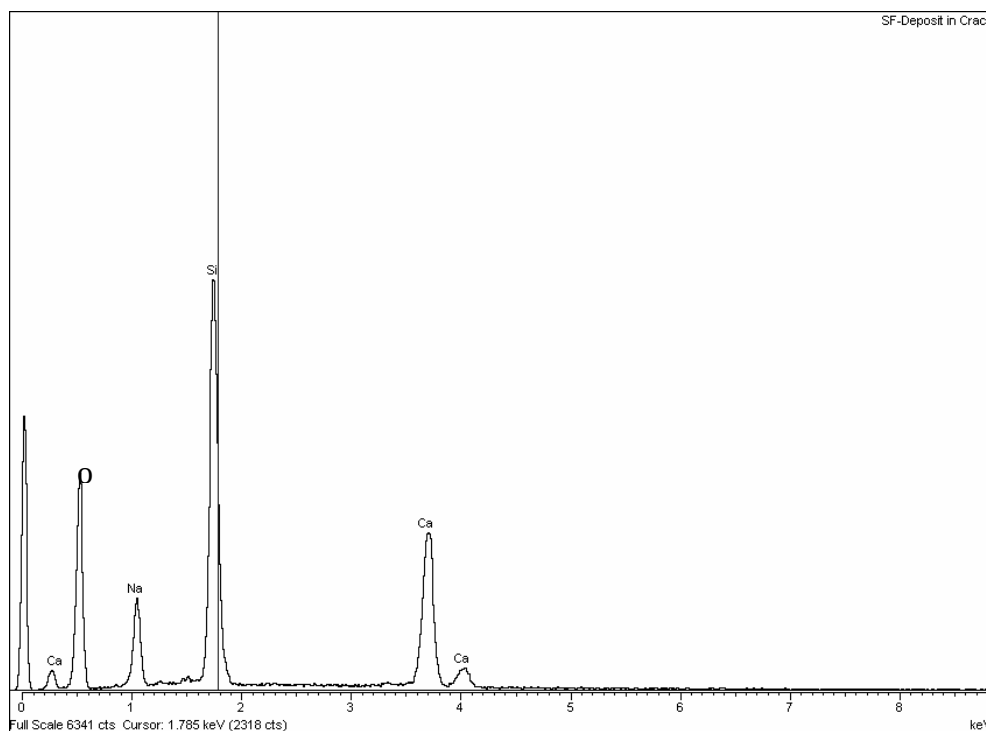


Figure 16. EDX spectrum of in-filled material (ASR gel) in crack in mortar bar soaked in sodium formate deicer solution (identified in Figure 15 (b)).

Mortar Bars Soaked in 1N Sodium Hydroxide Soak Solution

Figures 17a and 17b show a photomicrograph of a mortar bar (with Spratt limestone) soaked in 1 N sodium hydroxide solution. Similar to mortar bars soaked in sodium formate deicer solution, the bars soaked in 1 N sodium hydroxide showed extensive, internal cracking. Unlike the bars soaked in potassium acetate and sodium acetate deicers, the cracks in bars soaked in 1 N sodium hydroxide soak solution tended to be in-filled with significant amount of ASR gel. In this regard, the bars soaked in sodium hydroxide behave similar to those soaked in sodium formate deicer solution.

Figure 18 shows an EDX spectrum of the in-filled reaction product (obtained from the site identified in Figure 17b) in mortar bars soaked in 1 N sodium hydroxide soak solution. The composition of the reaction product is consistent with typical composition of ASR gels.

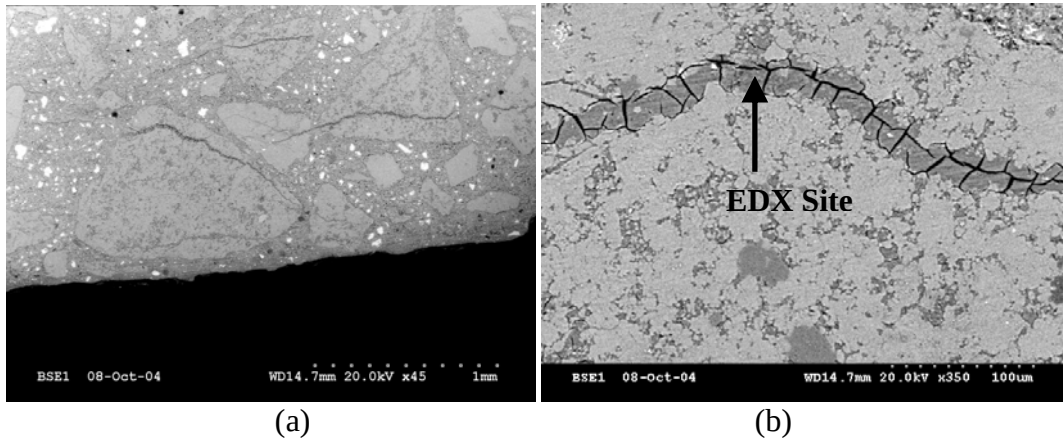


Figure 17. (a) Photomicrograph of a polished section of mortar bar subjected to 1 N sodium hydroxide soak solution in standard ASTM C 1260 test using high-alkali cement (b) Close-up view of ASR gel in-filling a crack within the aggregate particle.

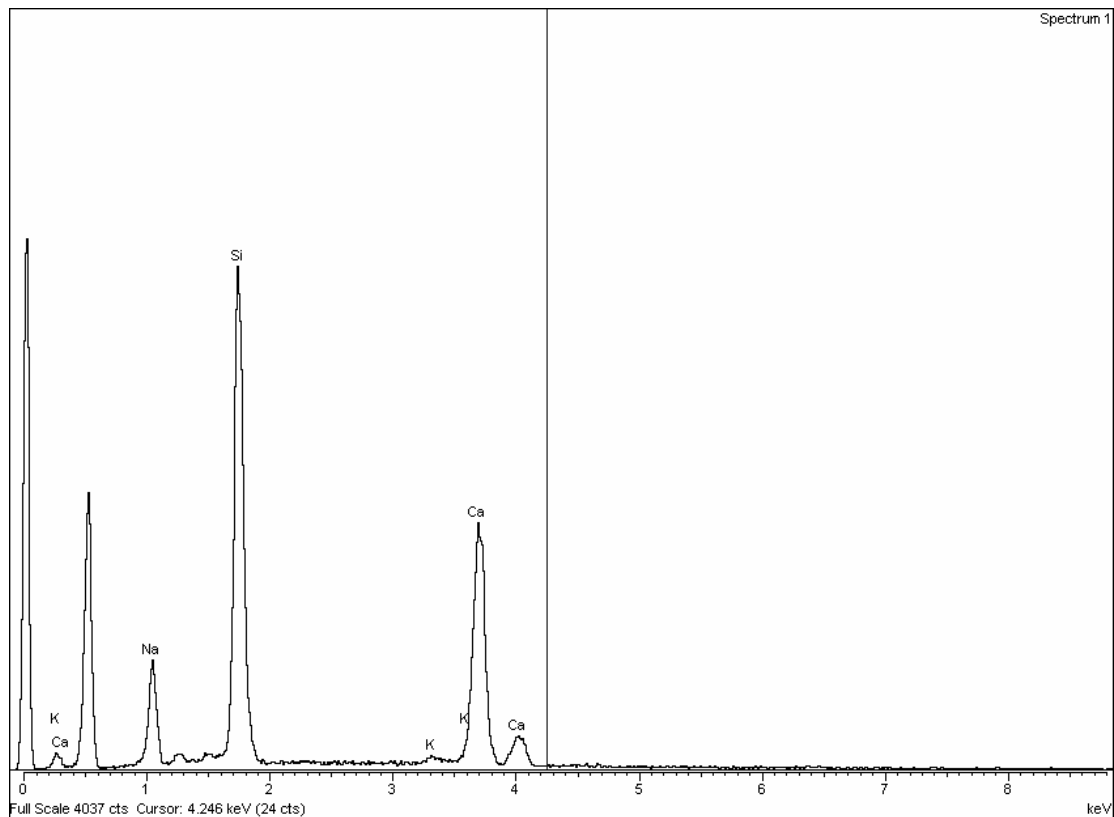


Figure 18. EDX spectrum of in-filled material (ASR gel) in crack in mortar bar soaked in 1 N sodium hydroxide soak solution (identified in Figure 17 (b)).

Summary of Findings

A summary of important findings from this investigation is presented below:

1. The presence of an alkali-silica reactive aggregate in the mix is essential to observe a deleterious level of expansion in mortar bars, when subjected to deicer soak solutions in the modified ASTM C 1260 test procedure.
2. All deicer solutions studied in this research produced significant levels of expansion in mortar bars containing reactive aggregates in the modified ASTM C 1260 test. The level of expansions observed would be considered deleterious based on the existing guidelines with 1 N sodium hydroxide solutions.
3. With potassium acetate deicer soak solutions, the magnitude of expansion observed in mortar bars showed a direct dependence on the concentration of the soak solution. At a concentration of one molar and below, the potassium acetate deicer soak solution does not appear to cause or accelerate the deleterious reaction in the modified ASTM C 1260 test.
4. The level of cement alkalinity appears to have an appreciable influence on the expansion observed with the use of 50% potassium acetate solution as soak medium. However, cement alkalinity does not appear to be a significant factor with the use of sodium acetate and 1 N sodium hydroxide as soak solutions. With sodium formate based deicer, the influence of cement alkalinity has not been clearly established in this study.
5. Mortar bars exposed to 50% solution of potassium acetate deicer and saturated solution of sodium acetate deicer showed greater loss in dynamic modulus of elasticity over time, compared to either 1 N sodium hydroxide solution or saturated solution of sodium formate deicer. Bridging of the cracks by the gel is most likely responsible for this behavior.

Conclusions

Based on the findings in this study, the following general conclusions are drawn:

1. The modified ASTM C 1260 test has the ability to identify and distinguish the deleterious influence of deicer soak solutions on mortar mixtures containing reactive aggregates.
2. All the deicers studied in this investigation - 50% solution of potassium acetate, saturated solutions of sodium acetate and sodium formate – have shown the potential to cause deleterious expansions in mortar bars containing reactive aggregates tested at 80°C.
3. The influence of alkali level of cement on the expansions observed in the modified ASTM C 1260 test appears to depend on the specific type of deicer solution being evaluated.
4. Dynamic modulus of elasticity, as measured by resonant frequency method proved to be a valuable tool in quantifying the physical deterioration observed in the mortar bars. However, it does not provide an ideal means to assess the degree of reactivity of aggregates.

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