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The Effect of Mineral Admixtures on Alkali-Silica Reaction in Concrete

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Abstract

This paper presents theoretical and applied information in the field of alkali-aggregate reactivity (AAR) in concrete. The aspects discussed include basic concepts of the reaction and expansion mechanisms, conditions conducive to the development and the sustainability of AAR in concrete, field and laboratory investigation programs for evaluating the potential alkali-reactivity of concrete aggregates, selection of preventive measures against AAR, and the management of structures affected by AAR. Lithium Nitrate inhibitor in the form of liquid solution was used in the concrete mix as an admixture to prevent ASR. This substance will react with silica gel and produces a non-expansive material when absorbing water to prevent cracking. In addition Lithium inhibitor, ground granulated furnace slag, a well-known cement substitution pozolan was used in the specimens as a less expensive material. Silica fume as a cement replacement material was also used to observe its ASR inhibiting effect. Slag and silica fume have a lower Alkali content in comparison to ordinary Portland cement and can reduces the rate of ASR. In this study Effective recommendations to produce durable concrete resistant to ASR are proposed for the new concrete structures.

Keywords: Alkali-Aggregate Reaction, Inhibitor, Slag, Silica Fume, Test Concrete Siliceous, Silica

INTRODUCTION

Historical Background

ASR was first identified and technically described in 1940 in California [1], A great deal of research effort has been directed to understand the mechanism of this deterioration process [2], [3] and [4] and to develop appropriate preventive measures [5], [6], [7], [8] , [9] and [10]. The problem has been a subject of interest for research workers since that time. There have been numerous international conferences on alkali-silica reactivity in concrete. Hobbs, 1988 [17]; Swamy, 1992 [18] and West, 1996 [19] present useful information about the subject in their books.

Chemical Reaction

There are mainly three types of AAR found in concrete. These arealkali-silica reactionalkali-silicate reaction andalkali-carbonate reactionAlkali-silica reaction is a reaction between alkali hydroxides and free silica in aggregate form a alkali-silica gel [11], [12], [13], [14], [15] and [16],.

SiO_2	+	2NaOH	+	H_2O
Silica		Alkali		Water

Alkali-silicate reaction is the same as alkali-silica reaction except that in this case the reactive constituent is not free silica present in the combined form of phyllosilicates.

Alkali-carbonate reaction occurs in concrete when alkalis react with certain dolomitic lime stones containing clay. Reaction causes cracks allowing water to enter which causes the clay to swell and disrupt the aggregate.

Majority of the structures affected by AAR is found due to alkali-silica reaction. Alkali-silicate and alkali-carbonate reaction is relatively rear.

Alkaline components of cement chemically react with existing silica/silicates in certain types of aggregates. The reaction product is an expansive gel. If the relative humidity of the concrete exceeds about 70%, Silica Gel will react with water and produce an expanded material. Since concrete members are internally restrained, the produced expansion will cause tensile stress and subsequent cracking of the concrete.

ASR Crack Diagnostic and Effecting Time

ASR cracks have normally with a mapped (pattern) shape, which make them different from other crack types (Figs. 1 and 2)

In a concrete pavement, where the width is small in comparison to its length, the higher restraining effect in the width direction causes the general trend of the cracks to be longitudinal (Fig. 2). The required time for ASR deterioration has been declared to be 7 to10 years for moderately reactive condition. For highly reactive material it can be started as early as five years. The new AASHTO Uranyl Uranium Acetate

Fig.1. ASR Pattern Cracks [23].

Fig.2. ASR Pattern Cracks with a Longitudinal Trend in a Concrete Pavement [23].

Fluorescence method (AASHTO-299-93) seems to be the most effective method to diagnose the Silica Gel (ASR produced material). This non-destructive field or laboratory method has the advantages of being rapid and economic but since it uses slightly radioactive materials, specific safety precautions are needed during the test. Presence of ASR silica gel patches will be confirmed by observing yellowish green color on the ASR affected concrete.

MATERIALS AND METHODS

Lithium Inhibitors

Lithium ions, Li^+ in several forms are capable to suppress deleterious ASR. Note that different compounds have varying effects on plastic and hardened properties of concrete.

Lithium Nitrate (LiNO3) is considered to have the least adverse effect on concrete properties, while it is safe to handle and seems to have the best ASR preventing effect. It doesn't produce hydroxide ion (Lithium Hydroxide, LiOH is a hazardous material). Lithium salts other than LiNO3 can still be useful depending on the type of application. These salts may be solid Lithium Carbonate (Li2CO3), solid Lithium Hydroxide (LiOH,H2O), or Lithium Hydroxide (LiOH). All admixtures should be tested according to AASHTO M 194 to determine whether they have any adverse effect on the fresh and hardened concrete properties.

ASR Accelerated Testing Methods

ASTM or AASHTO standard testing methods are used to measure the expansion of concrete specimens subjected to accelerated ASR effect.

ASTM Method

ASTM-1260 method has been designed for accelerated detection of concrete. This method has been widely used due to its reliability and efficiency [20]. This method exposes the concrete specimens to a highly reactive (accelerated) environment to observe the effectiveness of additives and/or cement replacements within a relatively short time. Mortar bars are 25x25x290.6 mm with a mix proportion of one part cement (and mineral replacement) plus 2.25 parts (by weight) of aggregates. After curing in 80 Degree centigrade for 24 hours, the mortar bars will be placed in 1 N 80-Degree Temperature NaOH solution for 14 days. Bar expansions then will be measured within 15 seconds of removal at 4,8,12 and 14 days using an extensometer. Following classification are suggested as an indication of deterioration after 16 days from casting: Expansion less than 0.1% considered to be innocuous, expansion between 0.1% to 0.2% will be inconclusive and expansion more than 0.2% is deleterious.

AASHTO Method

AASHTO $T_{3}0_{3}$, Standard Method of Test for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction. This test employs 11.25x1x1 inch mortar bars. Specimens are cured at 80 degree centigrade for 24 hours and the accelerated exposure of specimen to alkali solution (1 N NaOH) will be monitored for expansion measurements at 0, 1,3,57 and 14 days in accordance to the test specification.

RESULTS AND DISCUSSION

Experimental Program

The aim of this investigation was to observe: a) The rate of alkali reaction on different types of reactive aggregates b) The effect of ASR inhibitors to reduce the rate of reaction b) The use of Slag for possible ASR reduction c) The effect of silica-fume on alkali-silica reactivity.

Mix Proportion

Three types of aggregates with different percentages of siliceous materials were used (see Table-1).

Lithium Nitrate in a 30% liquid solution was used as an ASR mitigation agent. The required amount of this material is depends on the total weight of equivalent sodium (Na2O+0.658K2O),[21]. With a 30% liquid LiNO3 solution, 10 to 15 liters per cubic meter of concrete is recommended [22].

Table 1. Aggregate Types

Percentage SiO2	Aggregate Types
50	Aggregate Type 1=AG1
40	Aggregate Type 2=AG2
30	Aggregate Type 3=AG3

Table.2. Mix Proportion for the Test Samples

Inhibitor (LiNO3) Content, Lit/m3	Silica Fume Replace.	Slag Replace.	**Cementicious** Content,kg/m³	**W/C**	**Agg./Cement Ratio**	Test Designation
0	0	0	470	0.55	3.78	AG1
0	0	0	470	0.55	3.50	AG2
0	0	0	470	0.55	3.60	AG3
10	0	0	470	0.55	3.78	AG1-Li
10	0	0	470	0.55	3.78	AG2-Li
10	0	0	470	0.55	3.78	AG3-Li
10	0	20%	470	0.50	3.78	AG1-SL20
10	0	20%	470	0.50	3.78	AG1-SL20-Li
10	0	30%	470	0.48	3.78	AG1-SL30
10	0	30%	470	0.48	3.78	AG1-SL30-Li
10	5%	0	470	0.55	3.78	AG1-SF5
10	5%	0	470	0.45	3.78	AG1-SF5-Li
10	10%	0	470	0.45	3.78	AG1-SF10
10	10%	0	470	0.45	3.78	AG1-SF10-Li
10	15%	0	470	0.45	3.78	AG1-SF15
10	15%	0	470	0.45	3.78	AG1-SF15-Li

Notes for Table-2:
1) Key Examples:
AG1-SL20-Li Represents Aggregate Type 1, Slag 20 Percent, With Lithium Inhibitor
AG1-SF15-Li Represents Aggregate Type 1, Slag 20 Percent, With Lithium Inhibitor
AG2-Li Represents Aggregate Type 2, no Slag or Silica fume, With Lithium Inhibitor
AG3 Represents Aggregate Type 3, no Slag , no Silica fume, no Lithium Inhibitor
2) Other samples, which are not shown in the table, have similar designation.
3) When using liquid lithium inhibitor, W/C includes the water in the inhibitor.
4) Super plasticizer was used for samples containing silica fume to reduce the water demand of the mix.
5) In W/C ratio, C represents the total weight of cementicious materials (cement plus slag or silica fume).

Mix proportions for the test specimens are shown in Table-2. Each test specimen has a designated code from which different mix proportion can be seen.

Testing the Specimens

ASTM-1260 test method was used to measure the expansion of specimens at different ages. The controlling factor for ASR measurement is the change (increase) in the length of specimen.

Test Variables

For three types of aggregates, in addition to their ASR effect, (as the control specimens), lithium nitrate was added to the mix to observe its inhibiting effect. Slag and silica fume was also used as a cement replacement pozolan with or without lithium inhibitor.

EXPERIMENTAL RESULTS

Control Specimens

Figure 3 shows the ASR for three different aggregate type with different SiO^2 content. It is revealed that SiO^2 has a remarkable effect on ASR. Note that the harmful siliceous aggregates are mainly: Opal, Chalcedony, Volcanic Glass, Cryptocrystalline, Quartz, Chert, Tridimite, Cristobalite and Strained Quartz.

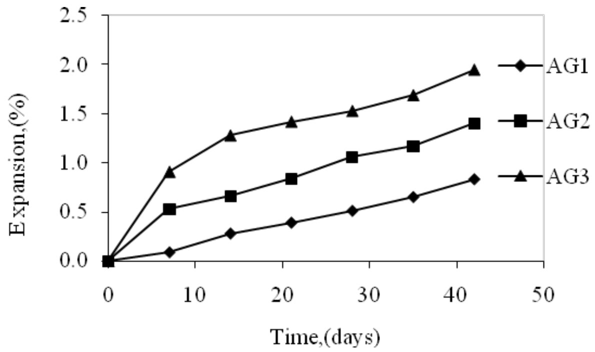

Fig.3. ASR for Three Different Aggregate Type

Inhibitor Effect

As an ASR inhibitor, 30% solution of lithium nitrate with a dosage of 12 lit/m³ was used as an admixture to concrete mortar. It is seen in Figure 4 that for all types of aggregates, the expansion has been reduced.

Slag and Silica Fume Effect

For aggregate type 3 with the highest reactive siliceous materials, the effect of 20% slag, 10% silica fume and also lithium admixture to those two pozolanic materials were

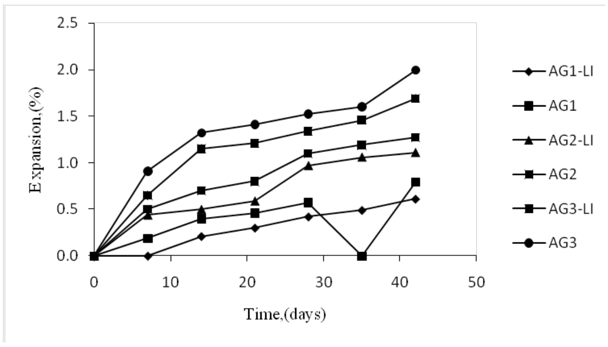

Fig.4. Effect of Lithium Inhibitor on ASR Mitigation

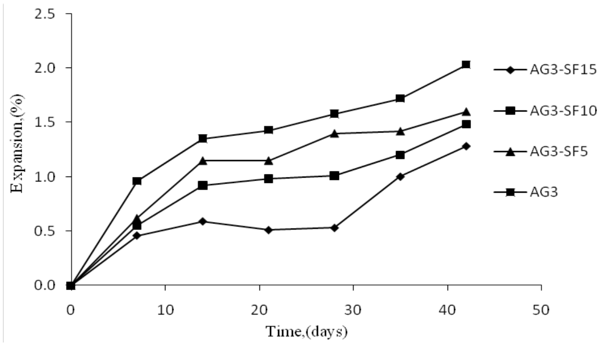

Fig.7. Effect of Silica Fume Replacement Percentage on ASR

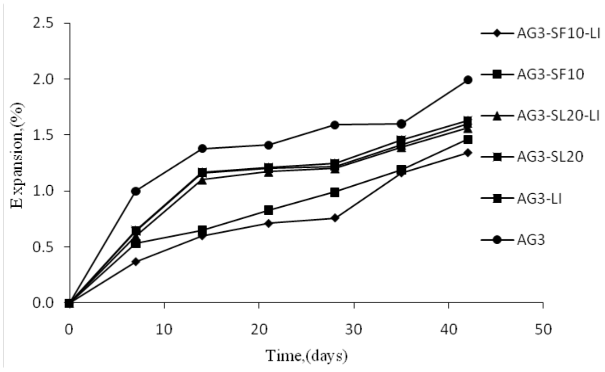

Fig.5. Effect of Slag, Silica Fume and Inhibitor on ASR Mitigation

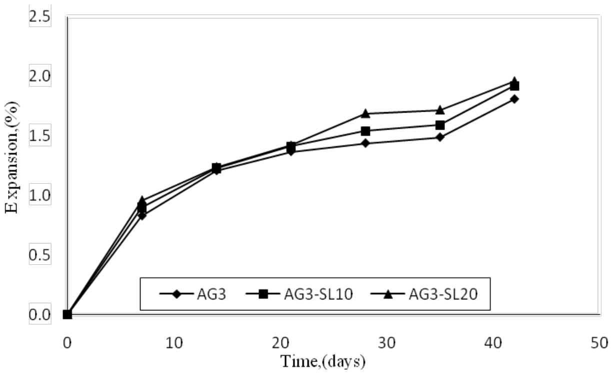

Fig.8. Effect of Slag Replacement Percentage on ASR

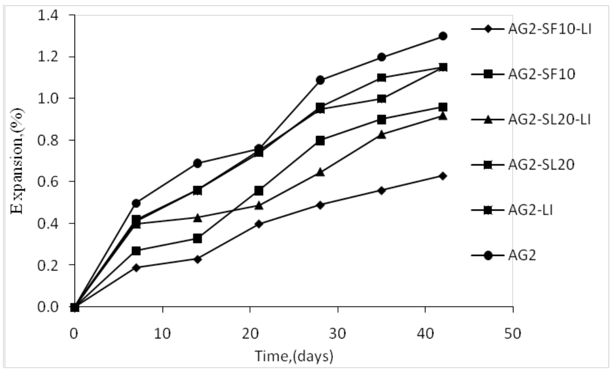

Fig.6. Effect of Slag, Silica Fume and Inhibitor on ASR Mitigation

examined and the result can be seen in Figure 5. The results with the same condition but with aggregate type 2 are shown in Figure 6. It is seen that both slag and silica fume have considerable effect on ASR prevention. This can be attributed partly to low alkali content of these materials and partly to the lower water cement ratio associated with slag and silica fume (with super plasticizer).

Slag or Silica Fume Replacement Quantities

It is generally seen that more cement replacement with these materials result in lower ASR, which are shown in Figures 7 and 8.

Using Slag or silica fume will normally lead to more dense (impermeable) concrete and hence less deterioration. The use of lithium inhibitor in conjunction with slag or silica fume can also reduce the ASR more than the cases without this inhibitor.

Practical Recommendation to reduce ASR

a) Use low alkali cement. Alkali content (equivalent Na2O) should preferably be less than 0.6%. Use cement types IP or IS if possible. c) Cement replacement with pozolanic materials such as slag, silica fume and fly ash can lead to a lower concrete permeability as well as lower alkali content in the mix and hence reduce the ASR. c) Avoid the use of well-known reactive aggregates, which were explained in 5-3-1.

CONCLUSION

This paper provides a evaluation of the various methods available for testing the efficacy of measures for preventing expansion due to alkali-silica reaction (ASR) in concrete containing deleteriously reactive aggregate.

Different aggregates with respect to their siliceous aggregate contents were tested subject to accelerated ASR effect with or without lithium nitrate inhibitor. It was concluded that the inhibitor could mitigate the reaction. As a cement replacement material, different percentages of slag and silica fume were used and in both cases, these pozolans could reduce the amount of expansion due to ASR effect.

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