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Detection of Alkali-Silica Reactivity using Field Exposure Site Investigation

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The main objective of this research is to study the impact of supplementary cementitious materials (SCMs) on mitigating Alkali-Silica Reactivity (ASR) of hardened concrete. ASR is a deleterious reaction between alkali content within the cement and highly reactive silica content available in some aggregate sources across the United States. ASR results in the formation of an expansive white-like gel that adds internal tensile stresses within hardened concrete. Increased tensile stress results in the formation of cracks, dissipation of additional moisture, and reinforcement corrosion. In this research project, large scale concrete blocks, with aggregates from different sources, were poured using different percentages of SCMs. An exposure site was developed for the poured blocks to investigate ASR possible impact on concrete. ASR impact was measured by calculating concrete blocks expansion over a time span of two years. The outcomes of the research showed that different aggregates result in different rates of expansion. The use of SCMs resulted in mitigating ASR and limit concrete expansion. The replacement of 25% to 30% of cement weight with SCMs (fly ash) is sufficient to halt ASR, and improve the long-time performance of concrete structures.

Keywords: Alkali-silica reactivity, Expansion, Cracking, Concrete blocks, Supplementary cementitious materials

Introduction and Literature Review

Alkali-Aggregate Reaction (AAR) is an important parameter that partially or fully contribute to the deterioration of concrete structures, and results in poor serviceability, deterioration, and/or premature failure of infrastructure projects. Alkali-Silica Reactivity (ASR), discovered in the 1940s in California, is the main type of AAR that results in internal concrete cracking, surface cracking, and concrete spalling. ASR is a deleterious reaction between alkali content on cement and highly-reactive silica content available in some aggregates -source-dependent- within the United States. ASR is expedited in the presence of high moisture content. ASR results in the formation of expansive white

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gel-like material inside hardened concrete members (Figure 1). The expansion of developed gel material induces internal tensile stresses that could potentially result in concrete cracking. Crack location, number, and size depends on the amount of alkaline content, type, nature, and reactivity of silica content within aggregates, and the amount of free moisture available to catalyze the reaction.

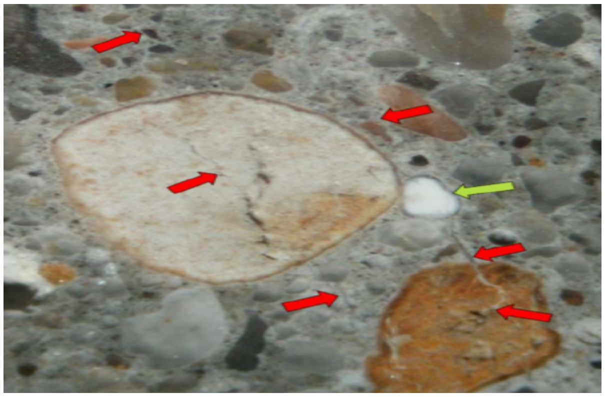

Figure 1. Expansive white gel-like material resulting from ASR

After initial ASR damage detection in the 1940s (Stanton, 1940), several research projects, funded by the Federal Highway Administration (FHWA) and Departments of Transportation (DOTs) studied ASR, parameters contributing to ASR activity, ASR damage magnitude, and how to mitigate, and possibly halt ASR. Typically, ASR damage is more noticeable in heavy construction projects due to the large concrete surface exposure to adverse environmental conditions, and moisture (Figure 2).

Figure 2. Infrastructure concrete cracking due to ASR

Due to the severity of losses caused by ASR, current research focuses on early detection of ASR in hardened concrete (Folliard et al., 2012; Deschenes and Hale, 2017a, 2017b). Alternative research programs target the detection of reactive aggregate sources to eliminate their use in future concrete construction projects, and/or proportion concrete mixes to mitigate the ASR deleterious effect, when reactive aggregates are used (Folliard et al, 2003, 2007). The main objectives of this research are: 1) Develop field exposure site for concrete specimens fabricated using aggregates obtained from different sources to investigate their potential reactivity by measuring samples expansion over time, and 2) Investigate the possibility of using supplementary cementitious materials, mainly class C and class F fly ash, to mitigate and/or halt the ASR damaging effect on hardened concrete.

Research Methodology and Experimental Investigation

ASR Standard Testing Procedures

Recent studies provided detailed explanation to ASR, and how it is initiated. During concrete mixing, the aggregate content including limestone, gravel, crushed granite, and fine sand is encapsulated with hydrated cement paste with high alkalinity (pH value may exceed 13.0). Once hydration process is concluded, free moisture within the hardened concrete dissipates through hardened concrete pores as a high-alkaline solution that reacts with specific silicious content within the aggregates (Folliard et al. 2012; Deschenes and Hale 2017a, 2017b; Akhnoukh et al. 2017) The alkali-silica reaction tends to form the expansive gel that results in the ASR damaging effect. Similarly, the alkaline solution may attack specific carbonates present in the aggregate to form a damaging alkali-carbonate reaction (ACR). Both ASR and ACR reactions are extremely damaging, and may cause premature failure to concrete structures. ASR and ACR damages are similar to other types of deterioration due to weathering, effect of de-icing salts on concrete structures, and the impact of freeze-thaw cycles. In order to differentiate between ASR and other types of concrete damages, a petrographic analysis of concrete specimens is required to identify the nature of the reaction causing deterioration. In a typical ASR petrographic testing, a concrete core is drilled in the structure, and the obtained sample is shipped to the lab (Figure 3), where reagents are applied on the concrete surface under consideration. Based on the reagent reaction outcome, ASR could be confirmed or denied.

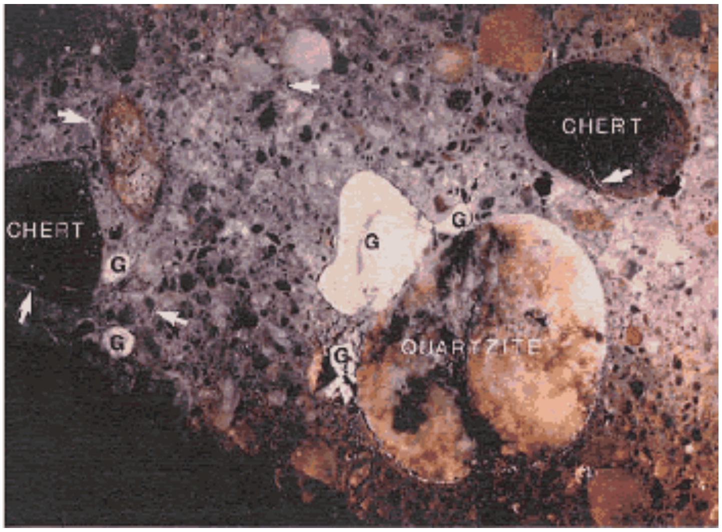

Figure 3. ASR petrographic scanning of hardened concrete (Fournier et al. 2010)

The detection of ASR depends on calculating the length changes (expansion) of concrete specimens over time. Due to the duration required for alkali-silica deleterious reaction detection, ASR is detected through the exposure of standard concrete bars to harsh/extreme laboratory conditions aiming to expedite potential ASR formation. Laboratory detection of ASR is done using Accelerated Mortar Bar Test (AMBT) according to ASTM C 1260. In the AMBT, precast bars are immersed in sodium hydroxide solution at 176 F (80ºC) to ensure harsh environmental exposure, and length changes are measured for 14 days (Figure 4). Expansion in excess of 0.1% of the original bar length indicates a potential reactivity for the used aggregates.

Figure 4. ASR measurement using AMBT (Akhnoukh et al., 2016)

Alternatively, ASR can be detected by exposing concrete specimens to normal environmental conditions, and measure concrete expansion due to ASR reaction over time (Thomas et al, 2011; Ideker et al., 2012). The process of concrete exposure to regular conditions is more accurate. However, several months of testing (up to 24 months) are required to detect ASR. In this research, concrete specimens of dimensions 13.8 in. x 13.8 in. x 35.4 in. (350 mm. x 350 mm. x 900 mm.) are poured, with different concrete mix designs to investigate the reactivity of different aggregates, obtained from different sources. In addition, different SCMs were incorporated in the mix to assess their ability to mitigate ASR by limiting concrete expansions. Exposure site soil was covered by large-sized limestone; and concrete specimens were placed on wooden logs to ensure consistent environmental exposure to all specimen sides (Figure 5)

Figure 5. Concrete specimens and field exposure site setup

Specimens Design for ASR Field Exposure Test

In this research, Type I/II Portland cement and a water-to-cement ratio of 0.5 is used in all concrete mixes. Three different types of aggregates were used including regular weight crushed limestone (CLS), lightweight expanded shales (ES), and light weight expanded clay (EC), and two types of fine aggregates including Arkansas River Sand (ARS), and Pine Bluff Sand (PBS). In addition, two different types of fly ash (Type C and Type F) were used in mix proportioning to investigate the SCM impact on block expansion. Fly ash percentage was kept at 25% by weight (of total cement). Eighteen different combinations for mix designs were used in pouring 54 exposure blocks (Table 1).

Table 1

Blocks combination for ASR exposure site investigation

Block #	Coarse Aggregate	Fine Aggregate	Fly Ash
1-3	CLS	PBS	No FA
4-6	CLS	PBS	C
7-9	CLS	PBS	F
10-12	CLS	ARS	No FA
13-15	CLS	ARS	C
16-18	CLS	ARS	F
19-21	ES	PBS	No FA
22-24	ES	PBS	C
25-27	ES	PBS	F
28-30	ES	ARS	No FA
31-33	ES	ARS	C
34-36	ES	ARS	F
37-39	EC	PBS	No FA
40-42	EC	PBS	C
43-45	EC	PBS	F
46-48	EC	ARS	No FA
49-51	EC	ARS	C
52-54	EC	ARS	F

Detached mechanical (DeMec) gages were installed on concrete blocks, and strain gage reader was used to record the developed expansion generated due to the exposure to environmental conditions DeMec gage readings were performed every 3-month, and results were recorded to develop strain profile for two-year of expansion. Average strain was generated for every combination using the results recorded from the three identical blocks poured for that specific combination. The following section provides the detailed results of the research.

Results and Discussions

The use of crushed limestone CLS with different combinations of fine sand did not result in significant expansion (expansion measured was less than 0.04%) which indicates no ASR. The incorporation of class C and class F fly ash resulted in a significant drop in the expansion, as compared to the sample with no-fly ash. Similar results were obtained when expansive clay EC was used as coarse aggregate in replacement of CLS. However, when expanded shales ES were used as coarse aggregate, higher expansion rates were measured for different specimen combinations. This is attributed to the higher tendency of ES to store moisture at initial specimen pouring. The excess moisture was dissipated to the hardened concrete during the project duration, which catalyzed the ASR, and resulted in higher expansion (Akhnoukh, 2018). It was noted that the use of class C and class F fly ash resulted in significant reduction of specimen expansion. Specimens poured with ARS had their expansion below 0.04% when both types of fly ash were used in specimen fabrication. Thus, potential ASR was halted (Table 2). SCMs results in ASR mitigation or halting due to the fine size of SCMs granular particles, which reduces the hardened concrete permeability (Akhnoukh 2013, 2019). Thus, it hinders the moisture dissipation to the inside of hardened concrete.

Table 2.
Expansion results for different concrete blocks

Block #	Coarse Aggregate	Fine Aggregate	Fly Ash	Expansion %
1-3	CLS	PBS	No FA	0.04
4-6	CLS	PBS	C	0.03
7-9	CLS	PBS	F	0.029
10-12	CLS	ARS	No FA	0.039
13-15	CLS	ARS	C	0.029
16-18	CLS	ARS	F	0.01
19-21	ES	PBS	No FA	0.07
22-24	ES	PBS	C	0.06
25-27	ES	PBS	F	0.058
28-30	ES	ARS	No FA	0.042
31-33	ES	ARS	C	0.031
34-36	ES	ARS	F	0.024
37-39	EC	PBS	No FA	0.04
40-42	EC	PBS	C	0.03
43-45	EC	PBS	F	0.03
46-48	EC	ARS	No FA	0.033
49-51	EC	ARS	C	0.03
52-54	EC	ARS	F	0.02

Conclusions

ASR is initiated when silica content within reactive aggregates reacts with alkaline content of the cement. The reaction is catalyzed by high moisture content. The ASR results in the formation of expansive gel that induce internal tensile stresses within hardened concrete. Increased tensile stresses results in concrete cracking, spalling, and reinforcement corrosion due to the increased moisture ingress in concrete structures. The magnitude of expansive reaction, hence concrete deterioration, is dependent on multiple parameters including the type of used aggregate, the type and quantity of used SCMs in partial replacement of cement. ASR investigation using field exposure site - though labor intensive, time-consuming, and requires an extended testing duration up to 2 years - is successfully used in ASR detection. ASR, measured by calculating concrete specimen expansion over time, shows that the incorporation of SCMs results in significant reduction in the concrete tendency to expand, hence, mitigate ASR. The incorporation of SCMs (class C and class F fly ash) with a 25% of cement content by weight is sufficient to halt ASR, prevent concrete cracking, improve the concrete project conditions, and minimize the need for maintenance and/or repair. Additional research to explore the impact of other types of SCMs as blast furnace slag, nano-silica, metakaolin, and multi-wall carbon nanotubes (MWCNTs) and the percentage of their incorporation in the concrete mix design on the mitigation of ASR in hardened concrete is needed. Different sample sizes should be considered in future research, and multiple samples per combination may be considered for improved statistical validation of results.

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