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Alkali-silica reaction mitigation using high volume Class C fly ash

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HIGH VOLUME CLASS C FLY ASH

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INTRODUCTION

Alkali-Silica Reaction

Thomas Stanton discovered alkali-silica reaction (ASR) in the 1930s when he investigated the cause of map cracking that occurred in the King City Bridge in California. The difference between the cracked concrete and the acceptable concrete was the aggregate used in the concrete mix. During his research, Stanton identified an expansive reaction between high alkali cement and certain aggregates [1].

When hydroxyl ions from cement react with silicon dioxide in aggregates in the presence of moisture, a gel with an alkali-silica base forms. When the gel absorbs water, it swells and applies an internal pressure in concrete. When the internal pressure of the expansion exceeds the tensile strength of the concrete, microcracking occurs and premature concrete deterioration begins [2].

Fly Ash

Fly ash is a byproduct of coal combustion. It is a pozzolanic material, which chemically reacts with calcium hydroxide in the presence of moisture to form compounds possessing cementitious properties [3]. Fly ash is a fine, powdery substance produced in the coal combustion chamber and is captured by emissions controls in a flue gas stack [4]. Fly ash's spherical glassy particles are composed of non-combustible, inorganic minerals such as quartz, calcite, gypsum, pyrite, feldspar and clay [4].

The combination of minerals and chemical compounds determine the classification of a fly ash sample. ASTM International generalizes Class F fly ash as having a low lime and high iron content, and Class C fly ash as having a high lime, high calcium content [5]. Class C fly ash is composed of at least 50 percent silicon dioxide, aluminum oxide, and iron oxide, while the combination of those compounds needs to be at least 70 percent to meet the Class F requirements [5]. Class F fly ash is normally produced by burning older anthracite and bituminous coal, while Class C fly ash is normally produced by burning younger lignite or subbituminous coal [5]. The younger coal sources typically produce fly ash containing high levels of calcium [6]. Fly ash with high calcium oxide content (more than 20 percent) rarely meets the 70 percent Class F minimum threshold [6]. Because of Class C fly ash's high lime content, it is generally more cement-like and offers high compression strength to concrete mixtures.

Treatment and Mitigation of Alkali-Silica Reaction

Substituting a portion of cement with a pozzolan in the concrete mix, reduces the formation of the alkali-silica gel that expands and causes deterioration [7]. Other supplementary cementitious materials, such as slag cement, silica fume, and lithium, can be used as effective ASR preventative measures. When portland cement is mixed with water, calcium hydroxide is released. Fly ash reacts with calcium hydroxide to produce calcium-silicate hydrates and calcium-aluminate hydrates, rendering less calcium hydroxide for ASR [6].

In proper proportions, this reaction with fly ash improves the long-term strength of the concrete and reduces its permeability [8, 9, 10, 11]. Typically, ASR is prevented by replacing 15 to 25 percent by mass of the cement with Class F fly ash or 15 to 40 percent by mass of Class C fly ash [12]. Studies show that Class F fly ash is more effective in preventing ASR than Class C fly ash due to its chemical composition [13, 14]. The reaction between Class F fly ash and cement results in a lower calcium to silicon ratio, allowing absorption of more alkalis than Class C would at the same replacement rate. Cement mixes containing pozzolans form smaller and less permeable capillary pores, allowing less moisture to penetrate the concrete and be absorbed by the gel, thus further reducing ASR [15, 16].

Objective

Class C fly ash is readily available in Arkansas, and costs associated with shipping Class F fly ash to Arkansas can prohibit its use. There are at least 19 km of pavement (Fig. 1) and 7 km of median barriers (Fig. 2) in Arkansas that have been identified as exhibiting distress due to ASR [17]. The goal of this research is to decrease ASR occurances by determining the amount of Class C fly ash that is necessary to prevent alkali-silica reaction.

Figure 1. Map cracking in pavement.

Figure 2. Barrier wall exhibiting ASR deterioration.

EXPERIMENTAL PROCEDURE

Methods

The ASTM C1567 method was followed for evaluating each blended cement [18]. For this accelerated mortar bar test, specimens were cast with 0, 20, 30, and 40 percent cement replacement ratios of Class C fly ash by mass. Three 25 mm x 25 mm x 285 mm mortar bars were cast for each mixture. After initial curing, the bars were placed in tap water for one day and then placed in an 80°C 40 g/L sodium hydroxide solution for 14 days. A digital micrometer was used to determine the expansion of each mortar bar.

Since the test conditions are severe, the test can cause false positives in slowly reactive aggregates due to the short 14 day test span. However, if the concrete expands less than 0.1 percent after 14 days of exposure in a severe testing condition, it is considered to have a low risk of deleterious expansion when used in concrete under field conditions. If the expansion is equal to or greater than 0.1 percent after 14 days of exposure, it is considered potentially expansive, and if expansion is 0.2 percent or more, it is considered expansive.

Materials

In this study, one type of potentially reactive fine aggregate, four Class C fly ash varieties, and Type I portland cement were used. A coarse aggregate was not used for this research because the coarse aggregate tested was not reactive. The fine aggregate is Arkansas River Sand from Van Buren, Arkansas. The Arkansas River is the main source for fine aggregate for most of the state. The sand has a high enough chalcedony content to potentially cause alkali-silica reactivity. The chemical compositions and physical properties of the fly ash sources experimented upon are presented in Table 1. All four fly ash varieties meet the Class C standards in ASTM C618.

Table 1. Chemical Compositions and Physical Properties of Fly Ash Sources.

Lab Code	Fly Ash Name			
	Muskogee	*Newark*	*Sikeston*	*White Bluff*
Loss on Ignition, %	0.22	0.38	0.43	0.24
Specific Gravity	2.69	2.65	2.65	2.64
Fineness (P 325)	11.20	7.87	14.17	9.14
Moisture, %	0.08	0.05	0.00	0.01
SiO_2, %	36.68	36.42	42.43	36.73
Al_2O_3, %	20.99	20.07	21.33	21.49
Fe_2O_3, %	6.01	6.20	5.43	5.68
CaO, %	25.17	24.24	20.28	22.70
MgO, %	5.14	4.72	4.43	4.30
Na_2O, %	data unavailable	1.52	1.18	1.48
K_2O, %	data unavailable	0.56	0.71	0.57
TiO_2, %	data unavailable	1.54	1.31	1.49
P_2O_5, %	data unavailable	0.84	0.97	1.11
SO_3, %	1.39	1.40	0.65	1.44
Available Na_2O, %	1.45	1.05	0.58	1.09
Available K_2O, %	data unavailable	0.37	0.61	0.37
Total Available Alkali as Na_2O, %	data unavailable	1.29	0.98	1.33

RESULTS

Fig. 3, 4, and 5 contain the results of the accelerated mortar bar tests for replacement rates of 20, 30, and 40 percent, respectively. The average expansion of the control specimens after 14 days of exposure was approximately 0.12 percent, which is potentially reactive. The 20 percent cement replacement mixture with the Muskogee fly ash is also potentially reactive. This expansion may be attributed to the pessimum limit, which is the percentage replacement for which the expansive reaction is the greatest. A replacement level below the pessimum limit will cause equal or greater expansion than if fly ash was not used [19]. Muskogee fly ash has the highest calcium oxide content of the fly ash sources tested, which may explain why the other fly ash sources did not cause expansion to be greater than the control. The expansion levels are below 0.1 percent after 14 days of exposure for the other three fly ash sources at 20, 30 and 40 percent replacement rates and Muskogee fly ash at replacement rates of 30 and 40 percent. Those mixtures are considered to have a low risk of deleterious expansion when used under field conditions.

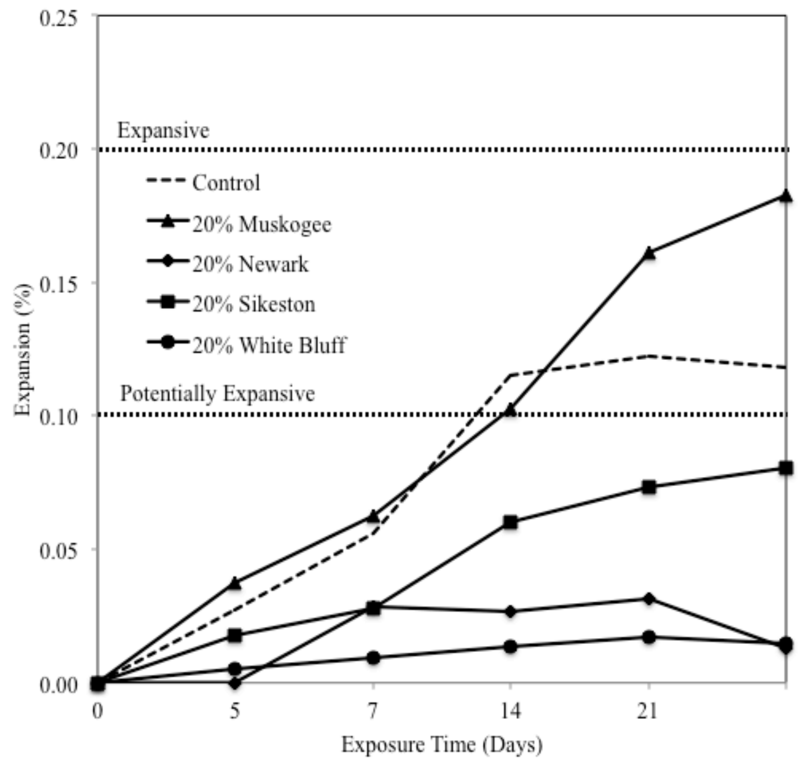

Figure 3. Effect of 20% fly ash replacement on ASR expansion.

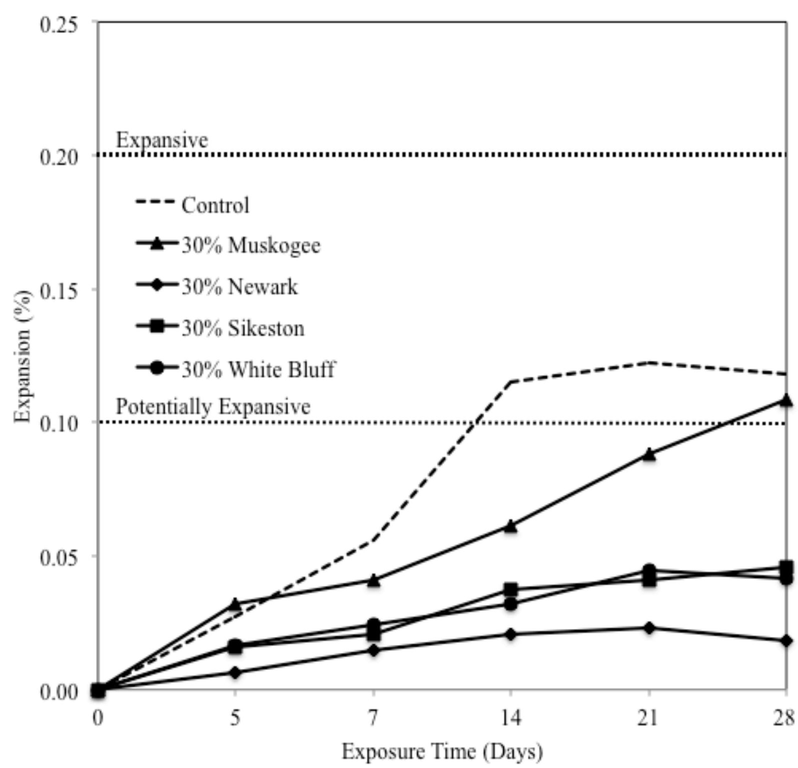

Figure 4. Effect of 30% fly ash replacement on ASR expansion.

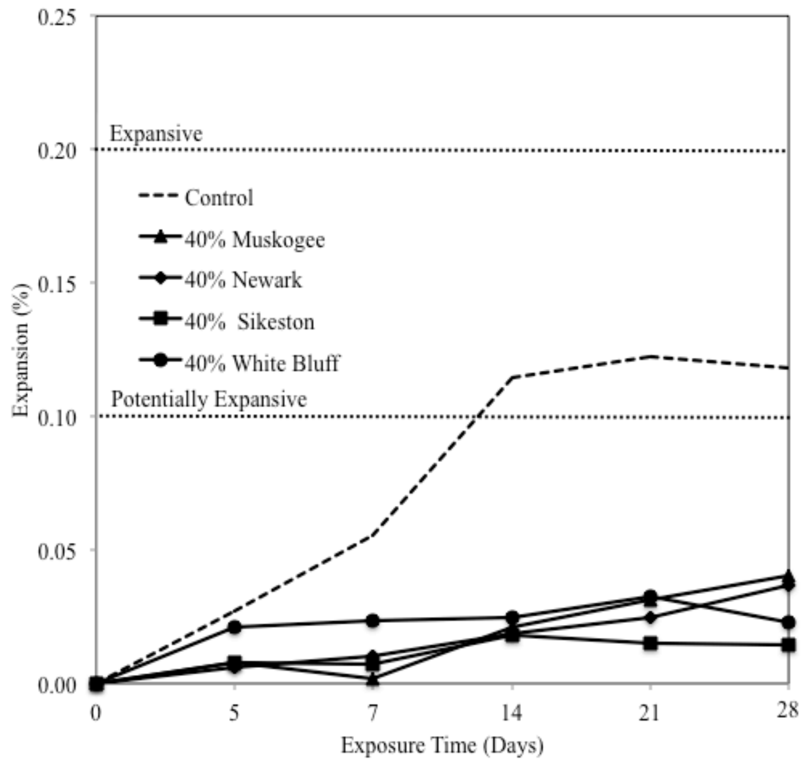

Figure 5. Effect of 40% fly ash replacement on ASR expansion.

CONCLUSION

All of the Class C fly ash sources tested improved the behavior of the cementitious system, except Muskogee fly ash used at a 20 percent replacement rate. Since expansion was less than 0.1 percent, a minimum cement replacement rate of 20 percent Class C fly ash from Newark, Sikeston, or White Bluff is recommended to mitigate ASR. Fly ash from Muskogee can be used to control expansion at a minumum replacement rate of 30 percent.

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