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ASR Effectiveness of High Volume Fly Ash Cementitious Systems Using Modified ASTM C 1260 Test Method

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Abstract

The role of high volume Class F fly ash in reducing expansion due to Alkali-Silica Reaction (ASR) was investigated. A series of modified ASTM C 1260 tests were performed under three different levels of NaOH normality, extending the test period to 28 days, using high- or low alkali cement, and Class F fly ash up to 58 % by mass of cement. A reactive siliceous fine aggregate was used. The test results confirm that HVFA replacement in a cementitious system significantly helps in controlling expansion caused by ASR.

Keywords: high volume fly ash, alkali-silica reaction, modified ASTM C 1260 test, normality

1. Introduction

Fly ash has often been used as a supplementary cementing material to control expansion due to Alkali-Silica Reaction (ASR) in concrete. In fact, the effectiveness of fly ash reducing expansion due to ASR had been mildly reported in both extensive laboratory test and field experience.[1,2) However, most of the published data are based on using smaller quantities of fly ash, typically in the range of 20-35 % by mass of cement. Current level of knowledge concerning the use of high volume fly ash up to 60 % by mass of cement in concrete is still insufficient to draw definite conclusions about the overall effectiveness.[3)

Many different test methods have been used to measure the alkali-silica reaction in portland cementitious system. Among the different test methods available, ASTM C 1260-Accelerated Mortar Bar Test is one of the most commonly used method because results can be obtained within as little as 16 days. This test involves measuring the length change of mortar bars made with the sample aggregate stored in a strong alkaline solution at an elevated temperature 80 °C. Aggregates having a mean mortar-bar expansion of 0.10 % or less at 14 days are considered as innocuous. Expansions of more than 0.20 % are indicative of reactive aggregates by this rapid screening method. Between 0.10 % and 0.20 %, the aggregates may be potentially reactive; they might exhibit either innocuous or deleterious behavior in field performance. However, one criticism about this test method is the severity of test conditions. This test measures potential aggregate reactivity, not the reactivity of specific alkalinity-aggregate combination. Furthermore, aggregates with good field track record and no history of ASR can sometimes be classified as reactive when tested according to ASTM C 1260 method. An experimental program was devised by modifying ASTM C 1260 test to evaluate the effectiveness of HVFA in controlling expansion due to ASR. Three different levels of alkalinity of NaOH solution were used to test the reactivity of a quartz aggregate in the presence of high volume of fly ash (58 %) by mass of cement. The other variables in this program included high- or low-alkali cement and extended testing period of 28 days. This paper reports the effective-ness of high volume Class F fly ash in reducing expansion caused by ASR.

2. Experimental

Materials used in this study included a Class F fly ash

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and two ASTM Type I portland cements, one that had an alkali content of 0.51 % as Na_2O_{eq} was designated as "low alkali content cement" for this study. The second source of cement that had an alkali content of 0.58 % as Na_2O_{eq} was designated as the "high alkali content cement." The chemical and physical properties of the cementitious materials are given in Table 1.

Reactive fine aggregate used in this research is originated from Texas.[4)]

The selected replacement levels of Class F fly ash were 20, 35, and 58 % by mass of high- and low-alkali cements, where 58 % replacement represents the high volume for system, 20 or 35 % replacement represent conventional replacement levels, and the plain cement mixture represents the control specimens.

Three mortar bar specimens, 25×25×225 mm in size were cast from mortar mixtures whose mixture proportions are given in Table 2. Immediately after casting, the test specimens were covered and moist cured at 23 °C for a period of 24± 2hrs. After tabulating the readings, the specimens were immersed in water in a sealed container at room temperature for 4-5 hours and then the container was transferred to an oven kept at constant temperature of 80 °C to reduce the risk of thermal shock to prisms. After 24 hours, the prisms were removed to ambient temperature of 23 °C, and before any significant cooling took place, their length was measured. This was the zero reading. Then, prisms were fully immersed in 1 N, 0.5 N, and 0.25 N NaOH solution kept at 80 °C. The length change of the mortar bars was periodically measured over a 28-day period instead of the normal 14 days period recommended in ASTM C 1260 procedure.[5)]

Table 1 Physical properties and chemical analysis of cementitious materials

Composition	Cement (% by mass)		Fly ash (% by mass)
	Low-alkali	High-alkali	
SiO_2	20.98	20.1	58
Al_2O_3	4.85	5.4	19.6
Fe_2O_3	1.8	3.2	5.3
CaO	65.38	65.4	10.9
MgO	1.43	0.7	2.5
SO_3	3.17	3.3	0.5
Na_2O equivalent	0.51	0.58	0.4
Loss on Ignition	1.09	0.9	0.2
Fineness, passing 45 μ m	92.7	95.3	20.1
Specific gravity	3.14	3.11	2.37
Initial set, min	183	150	-
Final set, min	303	270	-

Table 2 Mortar mixture proportion

Mixture	W/C	Unit weight (g)			
		Water	Cement	Fly ash	Fine aggr.
Control	0.47	207	440	-	990
20%FA			352	88	990
35%FA			286	154	990
58%FA			184.8	255.2	990

Control: plain cement mortar mixture containing high- and low-alkali cement

20 % FA, 35 % FA, and 58 % FA: percentage of fly ash in mortar

3. Results and discussion

3.1 Control mortars

Expansion for the control samples with time (i.e. those without fly ash) immersed in various alkali solutions is shown in Fig. 1 and Table 3. The initial expansion up to 4 days is nominal, irrespective of normality of NaOH solution and cement alkali content. At the end of 7 days, the expansion of high alkali cement mortar bar in 1N NaOH solution is nearly 0.2 %, and at 14 days it is 0.3 %, which confirms its 'reactive' criterion. When the normality of NaOH solution is reduced to 0.5 N, expansion observed at the corresponding early age occurs slightly as seen with 1 N NaOH solution. This suggests that a combination of very strong alkalinity of test solution and elevated temperature (80 °C) can initiate some expansion at early ages. However, a steep increase in expansion is observed later.

Expansion of high alkali cement mortar bars in 0.5 N NaOH solution is close to the potential reactivity level of 0.2 % at 14 days, but which is substantially lower than what is observed for 1 NaOH solution. From these test results it emerges that sufficient alkali level has been achieved to the pore solution of the mortar specimen to cause expansion.

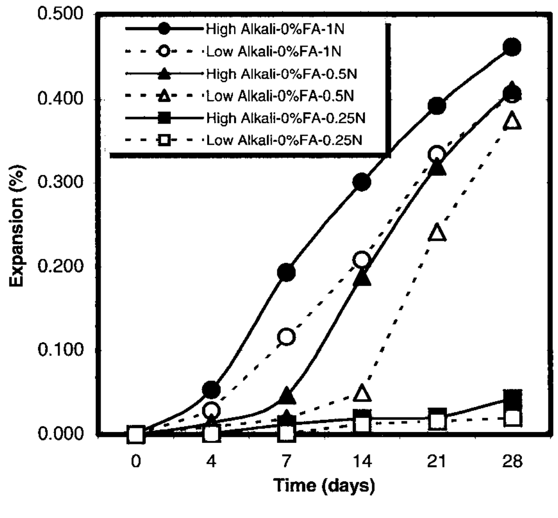

Fig. 1 Expansion curves for control mortar bars

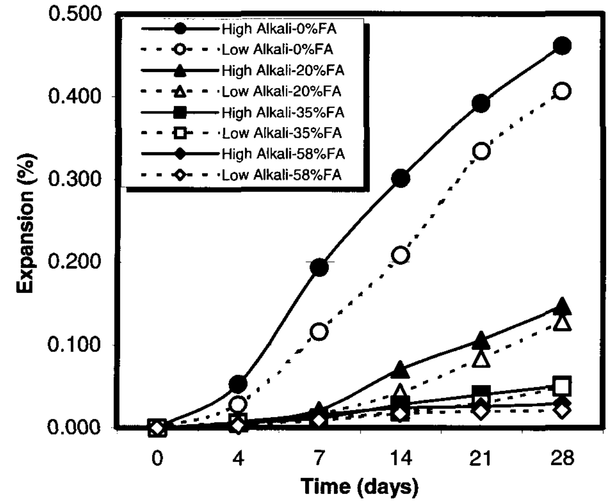

Fig. 2 Expansion curves for mortar bars containing fly ash in 1N NaOH solution

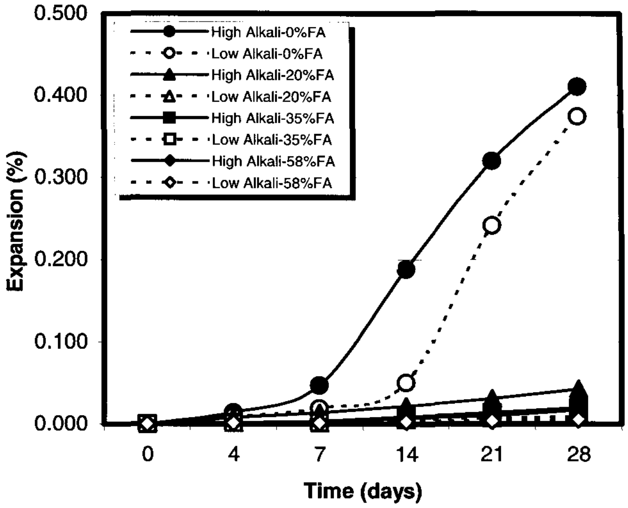

Fig. 3 Expansion curves for mortar bars containing fly ash in 0.5N NaOH solution

Table 3 Expansion of control mortars and mortar mixtures incorporating fly ash at 14 days and 28 days

Mixture: cement-FA	Expansion, %@0.25N NaOH		Expansion, %@0.5N NaOH		Expansion, %@1N NaOH	
	14 days	28 days	14 days	28 days	14 days	28 days
High alkali 0%FA	0.019	0.043	0.188	0.411	0.301	0.461
Low alkali 0%FA	0.012	0.020	0.050	0.375	0.208	0.406
High alkali 20%FA	0.008	0.016	0.022	0.043	0.071	0.147
Low alkali 20%FA	0.006	0.015	0.009	0.019	0.043	0.128
High alkali 35%FA	0.006	0.013	0.009	0.020	0.028	0.051
Low alkali 35%FA	0.004	0.011	0.005	0.009	0.019	0.049
High alkali 58%FA	0.003	0.008	0.007	0.017	0.024	0.029
Low alkali 58%FA	0.002	0.004	0.003	0.006	0.017	0.021

When the period is prolonged to 28 days, significant expansion between 14 days and 28 days was noted for mortar bars kept in 1 N and 0.5 N solutions. A constant rise in slope specifies not only the increase in the potential reactivity is fairly gradual, but also further expansion is possible beyond 28 days. Interestingly, at 28 days expansion cures for mortar bars immersed in 1N and 0.5 N NaOH solution cross the 0.3 % expansion level irrespective of cement alkali content qualifying the aggregate as a 'reactive one.'

Mortar bars immersed in 0.25 N NaOH solution fail to demonstrate any appreciable expansion even at 28 days despite the fact that reactive aggregate was used. To test expansion of mortar bars at the lowest normality of 0.25, it is necessary to continue the test for a much longer period of time.

3.2 High volume fly ash mortars

Table 3 and Fig. 2 show the expansive behavior of mortar bars immersed in 1N NaOH solution containing reactive aggregate and 20, 35, or 58 % Class F fly ash by mass of cement. Expansion of mortar bars containing 20 % Class F fly ash was below 0.10 % at 14 days, but exceeded 0.13 % at 28 days whereas with 35 % and 58 % Class F fly ash replacement, expansion was lower than 0.10 % at both 14 days and 28 days. Very limited expansion up to 14 days of mortar bars with 58 % fly ash replacement suggests that the use of high-volume fly ash definitely helps to reduce the expansion. Even when the test period is extended to 28 days, no change in the expansion rate was observed. These results support that high volume fly ash is very effective in reducing the alkalinity of the pore solution.6) Expansion of the mortar bar containing 58 % fly ash at 28 days is about 0.021 which is around 20 times less than that observed in control prisms made with only high-alkali cement and stored in 1 N NaOH solution.

The expansion of low-alkali cement and 58 % fly ash replacement by mass was very similar to that of made with high-alkali cement. Very little expansion occurred until 14 days, and the expansion at the end of 28 days was 0.017 % that is only about 15 % less than seen in the prisms made with high-alkali cement.

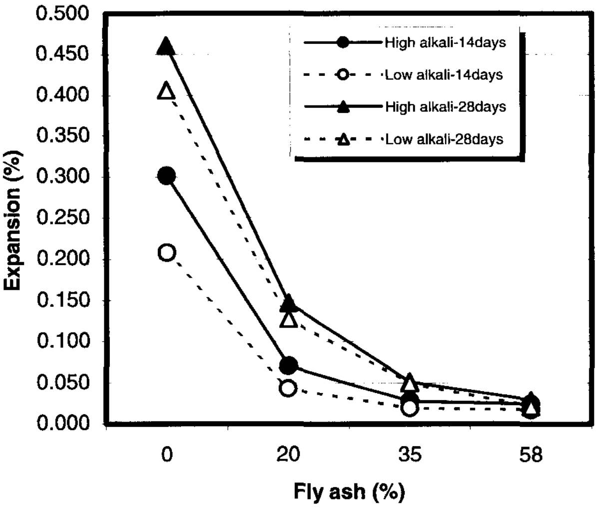

Fig. 4 Effect of high volume fly ash on ASR

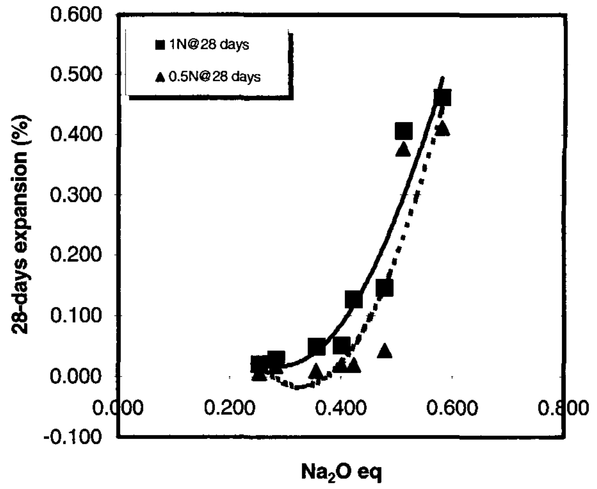

Fig. 5 Rate pf expansion at 28 days as a function of equivalent alkalis for mortar bars

Table 4 Total effective alkali content with contribution from cement and fly ash

Mixture: cement-FA	A_c (%)	A_e (%)	A_{TE} (%)	Expansion, %@0.5N NaOH		Expansion, %@1N NaOH	
				14 days	28 days	14 days	28 days
High alkali 20%FA	0.58	0.4	0.478	0.022	0.043	0.071	0.147
Low alkali 20%FA	0.51	0.4	0.422	0.009	0.019	0.043	0.128
High alkali 35%FA	0.58	0.4	0.401	0.009	0.020	0.028	0.051
Low alkali 35%FA	0.51	0.4	0.355	0.005	0.009	0.019	0.049
High alkali 55%FA	0.58	0.4	0.283	0.007	0.017	0.024	0.029
Low alkali 55%FA	0.51	0.4	0.254	0.003	0.006	0.017	0.021

Fig. 3 illustrates expansion of the mortar bars containing different levels of fly ash and immersed in 0.5 N NaOH solution. The results were similar to the specimens immersed in 1 N NaOH solution. In fact, the magnitude of the expansion was much lower. Although replacement levels of 35 % and 58 % resulted in innocuous behavior both at 14 days and 28 days, mortar bars with a 58 % fly ash replacement expanded less than the specimens with a 35 % replacement. Increasing amounts of fly ash resulted in a reduction in the expansion, and no deleterious proportion was observed.

3.3 Effect of high volume fly ash on ASR

The rate of reaction of expansion due to ASR as a function of fly ash replacement is shown in Figure 4. Expansion of mortar bars due to ASR decreased with the increase of fly ash content. The results show that the expansion due to alkali-silica reaction is dramatically reduced in the presence of high volume fly ash.

When the fly ash content is up to 58 %, the expansion decreases greatly. It is claimed that the low mobility of calcium hydroxide liberated during cement hydration due to the reduced cement content as well as from changes in Ca/Si ratio of the CSH that allows more alkalis to be trapped in the CSH by the activated pozzolanic reaction under high temperature (80 °C).[7]

3.4 Effective alkali content on expansion

The effective total alkali content of cement on ASR expansion does not apply to mortar or concrete containing mineral admixtures such as slag, silica fume, or fly ash. Although there are no limits specified for the alkali content of cementitious materials on ASR expansion, the available alkali in mortar containing mineral admixture would be less than that of portland cement. In fact, higher the replacement of cement by a mineral admixture, lower would be the alkali content. An attempt was made to analyze the effect of alkali content on the expansion due to ASR using the Kollek test.[8] Kollek's results demonstrated that if the effective alkalis derived from portland cement are taken as 100 % and used from fly ash as 17 %, the constants, K_C and K_e are taken as 1.0 and 0.17 respectively. Kollek assumed K_C=1 for simplifying his argument since all mineral admixtures would be replaced by mass of cement. This assumption was made in order to normalize the equation for the contribution of alkalis. The total effective alkali content of a hydraulic binder is the sum of the effective alkali content of the portland cement and the effective alkali content of the mineral additive that may be intermixed with it and can be written as:

$$A_{TE} = K_C \cdot A_C \cdot (1-P) + K_e \cdot A_e \cdot P$$

where,

A_{TE} = total effective alkali content of the mixture

A_C = total alkali content of the portland cement

A_e = total alkali content of the mineral admixture, i.e., fly ash or slag

p = the level of cement replaced by a mineral admixture

K_C = coefficient of alkali effectiveness in portland cement

K_e = coefficient of alkali effectiveness in the mineral admixture

Table 4 presents total effective alkali content with contributions from both cement and fly ash for mortar bars stored in 1 N and 0.5 N NaOH at 14 and 28 days, respectively. Although replacement of a portion of a portland cement with fly ash increases the total alkali content of mortar bars, the total effective alkali content decreases. This suggests that the alkali present in fly ashes is less vulnerable to reaction due to limited solubility in water and being in combined form unlike the free and water-soluble alkalies of portland cement. Fig. 5 shows satisfactory regression analysis results for mortar bars in 1N and 0.5 N NaOH solution. This might be due to the fact that the fly ash has started to participate in the reaction suggesting that the effective alkali content of the mix might have indeed been reduced. The fit of the expansion data points stored in 0.5 N NaOH solution is suggestive that assuming there is reduction in the alkali content due to fly ash, 0.5 N NaOH storage might predict similar results to those stored in 1N NaOH solution.

4. Conclusions

The effort thus far has examined the prospects of using modified ASTM C 1260 test method to study the alkali-silica reactivity resistance relative to high volume Class F fly ash. The following conclusions can be made based upon the above analysis.

(1) Mortar bars kept in 1 N NaOH solution show higher expansion than those in 0.5 N and 0.25 N NaOH solutions irrespective of the replacement of fly ash and cement alkali content

(2) Prolonged test period increased the amount of expansion, regardless of the cement alkali content and amount of fly ash replaced. Reactive aggregate used in this study demonstrates nearly 2 times expansion between 14 days and 28 days than the expansion that occurs at 14 days.

(3) The higher the fly ash content, the lower the expansion of ASR. The expansion of mortar bars due to alkali-silica reaction is greatly reduced in the presence of high volume fly ash.

(4) As predicted by Kollek test, increasing replacement of a portion of portland cement with fly ash decreases the total effective alkali content, and reduces the expansion caused by ASR.

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