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ALKALI-AGGREGATE REACTION IN FLY ASH CONCRETE

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1. INTRODUCTION

The availability and price range of fly ash makes it the most used mineral concrete admixture. One of several beneficial attributes of mineral admixtures such as fly ash when added to concrete mixtures is the potential for reduction of deleterious expansions of hardened concrete due to alkali-aggregate reaction (AAR). The main objective of the paper presented herein is to investigate the influences of the constituents of portland cement, aggregates, and mineral admixtures on alkali-silica reaction in concrete.

2. MATERIALS

One nonreactive aggregate and two reactive aggregates were used in this project. Pyrex glass served as a control for the tests, as per ASTM C 441. To distinguish between the two reactive aggregates, they will be referred to as the "highly reactive" aggregate and the "moderately reactive" aggregate.

From the four cements used, two Type I cements reflected the extremes in alkali content of cement produced in Texas (0.43 percent and 0.66 percent) while a Type IP cement utilized local cement and Class F fly ash. The third Type I cement was a cement with a 1.03 percent total alkali content. Finally, the fourth cement was the same one used in the manufacturing of the Type IP cement. All five cements are described in Table 1.

Table 1. Cements used in the test program.

CEMENTS		
I.D.	ASTM TYPE	TOTAL ALKALI CONTENT (percent)
1	I	0.43
2	I	0.66
3	IP	0.50
4	I	1.03
5	I	0.53

This investigation included fly ash from nine different sources. Four fly ashes were Class F and five were Class C. These fly ashes are listed in Table 2. Chemicals are often added to the fly ash to enhance the effectiveness of the collection process. When such a chemical agent is used, the fly ash may contain an objectionable amount of alkalies. One Class C fly ash treated with such an agent (#7 in Table 2) was obtained for testing along with another Class C fly ash of similar alkali content (#6 in Table 2), which had not been treated. The rest of the fly ash sources were selected on the basis of their classification and alkali content so a wide range of alkali content could be studied for both Class F and Class C fly ashes.

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Table 2. Fly ashes used in the test program.

No.	ASTM Class	Coal Rank	Available Alkalies	Special Characteristics
1	F	Lignite	0.31%	Used in Type IP cement tested in this program
2	F	Lignite	0.57%	
3	F	Lignite	1.38%	
4	C	Subbituminous	1.67%	
5	F	Bituminous	1.76%	
6	C	Subbituminous	2.04%	Similar to #7 but not treated with agent
7	C	Subbituminous	2.35%	Treated with alkaline precipitating agent
8	C	Subbituminous	3.75%	
9	C	Subbituminous	4.35%	

During the third year of the research program fly ashes #4, #7, #8 and #9 were sampled again and tested to investigate the effect of their fineness on the fly ash effectiveness in reducing AAR. Although the fly ashes were sampled from the same original sources, the difference in time of sampling accounted for a slight difference in alkali content reported. Their available alkali contents and the fineness to which they were ground are shown in Table 3. The different levels of fineness, expressed in terms of amount retained in #325 sieve (325S), were obtained by grinding of the fly ash using a laboratory type grinding ball mill.

Table 3. Available alkalies and percent retained in sieve #325 for the fly ashes used in the portion of the test investigating he effects of fineness on AAR.

Av. Alkali Content (%)	Fineness (Retained in #325 sieve)		
	Original	Intermediate	Fine
0.96	18.3	6.7	0.9
1.90	16.4	7.3	1.2
3.73	11.3	5.9	1.4
4.35	13.3	6.7	0.9

3. EXPERIMENTAL

ASTM C 227, **Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)**, served as the primary guideline for the testing program described herein, providing specifications for facilities and equipment, test procedures, and interpretation of results.

4. TEST RESULTS AND DISCUSSION

Test results indicate that the 0.60 percent limit on alkalies suggested in ASTM C 150 is not a reliable guideline. The mixtures containing the two reactive aggregates and the 0.66 % alkali content cement, with no fly ash replacement, did not exceed the 180-day expansion limit, not even after 900 days of exposure testing, as shown in Figure 1. On the other hand, the mixture containing the control aggregate and the 0.43% alkali content cement, with no fly ash replacement, exceeded both expansion limits.

The use of the cement having an alkali content of 1.03 percent resulted in significant increases in expansions, as can be seen in Figure 2. These results indicate that reactive materials can be combined in concrete if careful attention is paid to the proportions of materials used.

ASTM C 618, **Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete**, includes a suggested limit of 1.5 percent available alkalies for fly ashes to be used with reactive cement-aggregate combinations. Test results show that when sufficient amounts of fly ash were used, expansions were reduced below the ASTM limits at

180 days for all cement-aggregate combinations, even when fly ash available alkalies exceeded the 1.5 percent suggested limit, as shown in Figure 3. Based on these results, the limit of 1.5 percent available alkalies in fly ashes suggested by ASTM does not appear to be an adequate guideline.

Figure 4 shows the results obtained for the fly ash treated with a chemical precipitating agent. No conclusive data was collectred due to the difficulty in determining the amount of alkalies added to the fly ash by the precipitating agent or the availability of these alkalies to participate in deleterious reactions. Research is needed to determine the quantity of alkalies added to the fly ash by these agents and their effect of the behavior of fly ash.

A total of eight different fly ashes were tested in mixtures containing highly reactive aggregate and 0.43% alkali or 0.66% alkali cement. Figure 5 illustrates the effect that the alkali content of these fly ashes had on the expansions of these mixtures. This graph shows that expansions generally became greater as the alkali content of the fly ash increased. Expansions tended to increase sharply for alkali contents exceeding 2.0 percent. However, it was noted that the replacement of 17.5 percent of the volume (15 percent, by weight) of cement with either Class C fly ash caused expansions much greater than those of corresponding mixtures without fly ash, while additions of 34.3 percent caused reductions in expansions.

These results, which are presented in Figure 6, revealed that the 26 percent replacement was comparable to the 34.3 percent replacement level in effectiveness. Subsequent increases in replacement beyond 34.3 percent had much less effect on expansions. Based on these results, it appears that increasing the percentage of replacement as little as 10 percent beyond the "pessimum" value is sufficient to obtain satisfactory results.

The Type IP cement used in this project proved to be much more effective in inhibiting expansions than the other cement-fly ash combinations tested. Therefore, two mixtures were made later using the same cement and fly ash used to produce the Type IP cement. The cement and fly ash used in one mixture were mechanically blended before batching to simulate the blending received by the Type IP cement during the grinding of the fly ash and clinker. The intent was to determine if the materials used in the Type IP cement, or its fineness or preblending were responsible for its superior performance.

The results shown in Figure 7 indicate that the Type IP cement was more effective than the cement-fly ash mixtures. The two cement-fly ash mixtures behaved similarly, while expanding more than the Type IP mixtures. The increased fineness of the fly ash in Type IP cement, due to fly ash-clinker intergrinding, appeared to be the factor enhancing its effectiveness in inhibiting expansions. To investigate this, four Class C fly ashes were ground down to two fineness levels and then added to the mortar as mineral admixtures. The first level was at about 50 percent of the original fineness, measured as the percent retained in #325 sieve (325S). The second level was at about two percent retained in #325 sieve. All mixtures contained the highly reactive aggregate and the 1.03% alkali cement. The available alkali contents and the fineness of the fly ashes were presented in Table 3. However, no consistent relationship was found between weight percent retained in #325 sieve and mixture expansions.

5. CONCLUSIONS

From the test results it can be concluded that neither the 0.6 percent limit set up by ASTM C 150 for the alkali content of cement or the 1.5 percent maximum available content set up by ASTM C 618 for the fly ash can be used as the only measure to prevent damage to concrete due to alkali- aggregate reaction. However, it is clear from the test results that the degree of alkali-aggregate reactivity of concrete mixtures increases when the alkali content of the cement increases.

The results also show that replacement of a portion of cement with fly ash is an effective measure to reduce the expansion in concrete due to alkali-aggregate reaction. Nevertheless, as the available alkali content of fly ash increases, there is a minimum percentage of cement replaced below which the fly ash causes expansions larger than those of a mixture without fly ash, and above which the fly ash causes smaller expansions. This minimum is known as the "pessimum" limit.

The greater fineness of the fly ash in Type IP cement and not the additional blending of the cement and fly ash, appears to be the factor enhancing its inhibiting effect on alkali-silica reactions. However, there is not a consistent correlation between the variability of Class C fly ash fineness, within the ASTM limits, and mortar bar expansions.

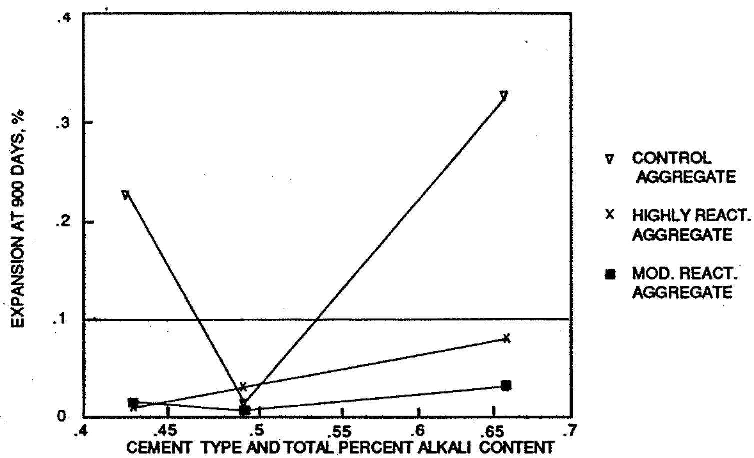

FIG.1. EXPANSIONS OF MIXTURES CONTAINING NO FLY ASH

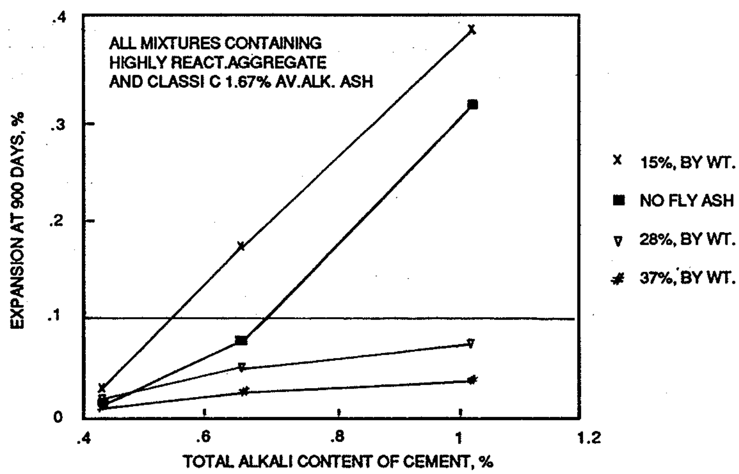

FIG. 2. TOTAL ALKALI CONTENT OF CEMENT

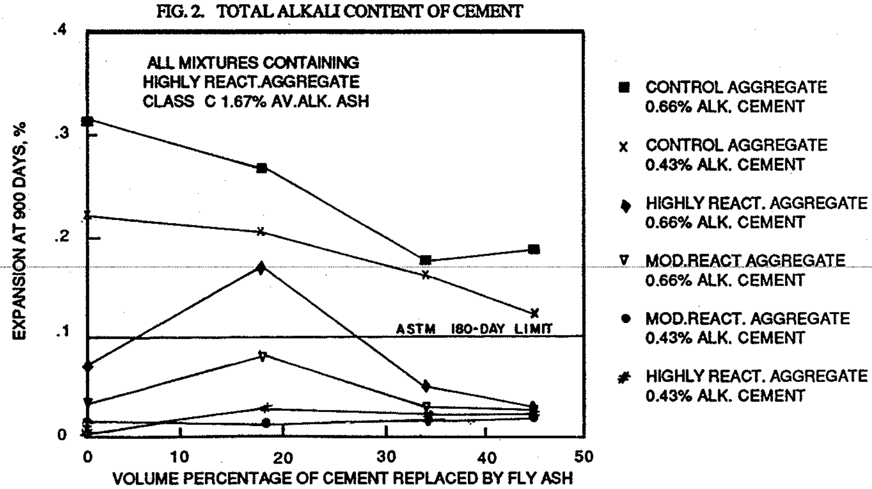

FIG. 3 AMOUNT OF CEMENT REPLACED BY FLY ASH

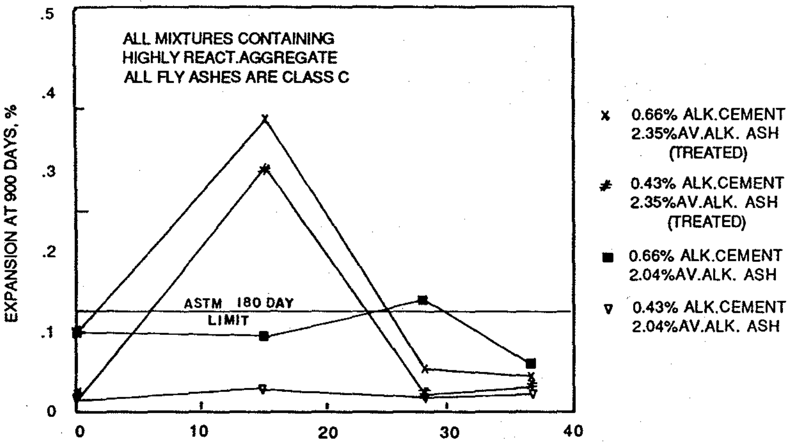

FIG. 4. FLY ASH TREATED WITH A PRECIPITATING AGENT

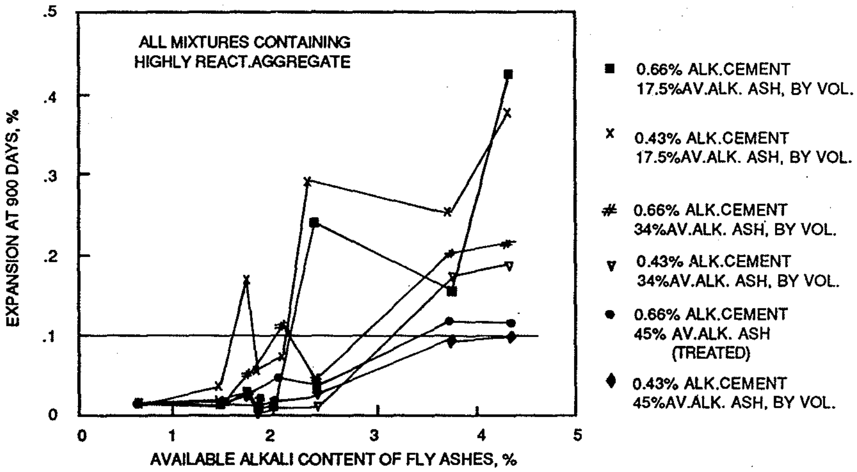

FIG. 5. AVAILABLE ALKALI CONTENT OF FLY ASHES

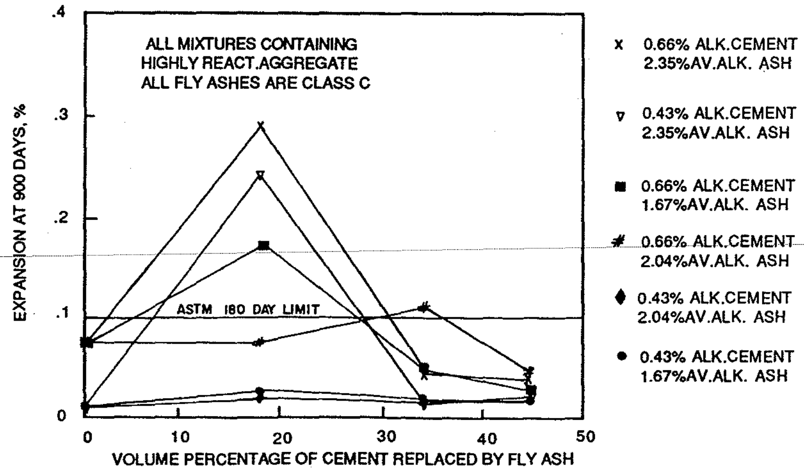

FIG. 6. PESSIMUM EFFECT OF SEVERAL CLASS C FLY ASHES

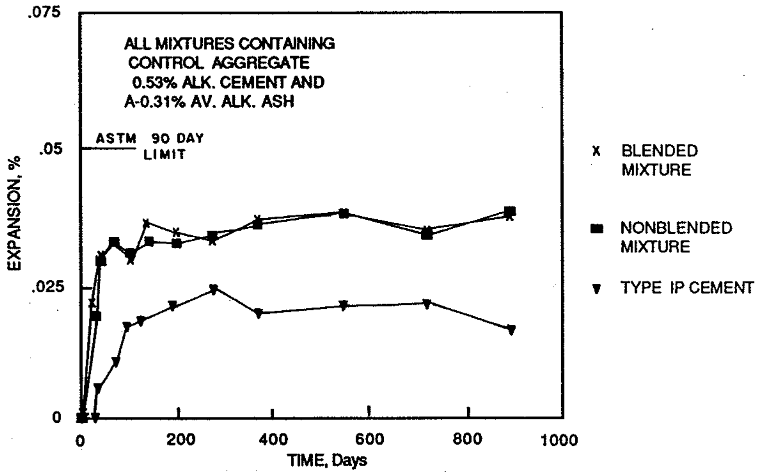

FIG.7. FINENESS AND PREBLENDING OF FLY ASH & CEMENT USED IN TYPE IP CEMENT