Effect of Fly Ash on Alkali-Silica Reactivity in Concrete

PETER G. SNOW

Improvements in the properties of portland cement concrete can be achieved through the use of mineral admixtures such as coal fly ash. One such improvement is the potential reduction of alkali-silica reactivity (ASR), which causes an expansive reaction in certain aggregates and can lead to deterioration of the concrete. In sufficient amounts, fly ash may be used to inhibit ASR.

The availability of fly ash and its lower cost relative to portland cement make it the most commonly used mineral admixture for concrete. One of the 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 caused by alkali-silica reactivity (ASR). This laboratory investigation concerned the influence of the constituents of portland cement, aggregates, and mineral admixtures on ASR in concrete.

One nonreactive aggregate and two reactive aggregates were used. Pyrex glass served as a control aggregate for the tests, as required by ASTM C441. In order to distinguish between the two naturally reactive aggregates, they were referred to as the "highly reactive" aggregate and the "moderately reactive" aggregate.

Four Type I cements and one Type IP cement were used, as presented in Table 1. The two Type I cements reflect the range of available alkali content (0.43 to 0.66 percent) of cement produced in Texas. Another Type I cement, from a source outside Texas, had a 1.03 percent total available alkali content. A local Type I cement with an available alkali content of 0.53 percent was used both directly and to produce a Type IP cement with a Class F fly ash that had an available alkali content of 0.50 percent.

This investigation included fly ash from nine different sources. Five fly ashes were Class C and four were Class F as defined by ASTM C618. These fly ashes are presented in Table 2. Seven fly ash sources were selected on the basis of their classification and alkali content, so a wide range of available alkali contents could be studied for both Classes C and F. Also, because chemicals are sometimes added to fly ash to enhance the effectiveness of the collection process, one Class C fly ash treated with such an agent (No. 7 in Table 2) was obtained for testing along with another Class C fly ash of similar alkali content (No. 6 in Table 2) that had not been treated. When such chemical agents are used, the fly ash may contain an objectionable amount of available alkalies.

During the third year of the research study, fly ash Nos. 4, 7, 8, and 9 were sampled again and tested to investigate the effect of fineness of fly ash in reducing ASR. The different levels of fineness, expressed in terms of amount retained on a 45-μm sieve, were obtained by grinding of the fly ash using a laboratory ball mill. Although the fly ashes were sampled from the same sources, the difference in time of sampling accounted for a slight difference in available alkali content reported. Their available alkali content and the fineness to which they were ground are presented in Table 3.

PGS Associates, Inc., 733 Hummingbird Way, North Palm Beach, Fla. 33408.

EXPERIMENTAL

Primary guidance for the work in this study was from ASTM C227, *Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)*, which contains requirements for facilities and equipment, test procedures, and interpretation of results.

DISCUSSION OF TEST RESULTS

Test results indicated that the 0.60 percent limit on available alkalies in ASTM C150 was not a reliable guideline. The mixtures containing the two reactive aggregates and the cement having an available alkali content of 0.66 percent, with no fly ash replacement, did not exceed the 180-day expansion limit, even after 900 days of exposure testing, as shown in Figure 1. On the other hand, the mixture containing the control aggregate and the cement having an available alkali content of 0.43 percent, with no fly ash replacement, exceeded expansion limits at those test ages.

The use of the cement having an available alkali content of 1.03 percent resulted in a significant increase in expansion, as shown in Figure 2.

ASTM C618, *Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete*, includes an optional chemical requirement that limits available alkalies to 1.5 percent for fly ashes to be used with potentially reactive cement-aggregate combinations. Test results from this study, shown in Figure 3, indicated 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 available alkalies in the fly ash exceeded the 1.5 percent limit. On the basis of these results, the limit of 1.5 percent available alkalies in fly ash does not appear to be an appropriate guideline.

Figure 4 shows the results obtained for the fly ash treated with a chemical precipitating agent. No conclusive data were collected because of the difficulties in determining the amount

TABLE 1 CEMENTS USED IN STUDY

Identification No. of Cements	ASTM Type	Total Available Alkali Content, %
1	C 150 - I	0.43
2	C 150 - I	0.66
3	C 150 - I	1.03
4	C 150 - I	0.53
5	C 595 - IP	0.50

TABLE 2 FLY ASHES USED IN STUDY

Identification No. of Fly Ash	Class per ASTM C 618	Coal Rank	Total Available Alkali Content, %
1	F	Lig.	0.31 *
2	F	Lig.	0.57
3	F	Lig.	1.38
4	C	Sub.	1.67
5	F	Bit.	1.76
6	C	Sub.	2.04 **
7	C	Sub.	2.35 ***
8	C	Sub.	3.75
9	C	Sub.	4.35

Notes: * Used in Type IP cement tested in this program.
** Similar to fly ash #7 but not treated.
*** Fly ash treated with alkaline precipitating agent

TABLE 3 EFFECT OF GRINDING ON FLY ASH FINENESS

Identification No. of Fly Ash	% Ret. on 45-Micron Sieve Initial	Level #1	Level #2	Total Available Alkali Content, %	
4	18.3	6.7	0.9	0.96	(1.67)*
7	16.4	7.3	1.2	1.90	(2.35)*
8	11.3	5.9	1.4	3.73	(3.75)*
9	13.3	6.7	0.9	4.35	(4.35)*

Note: * Alkali content in parentheses is from original ash sample tested in year one of this study (see Table 2).

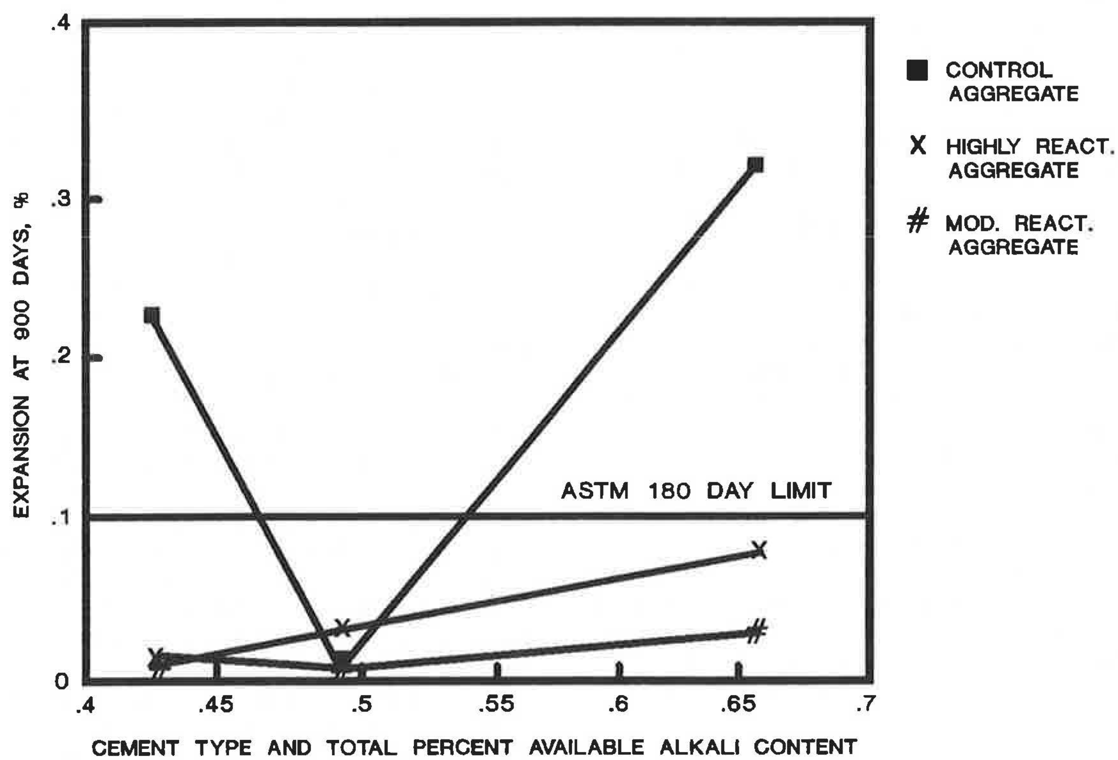

FIGURE 1 Influence of available alkali content of cement on expansion.

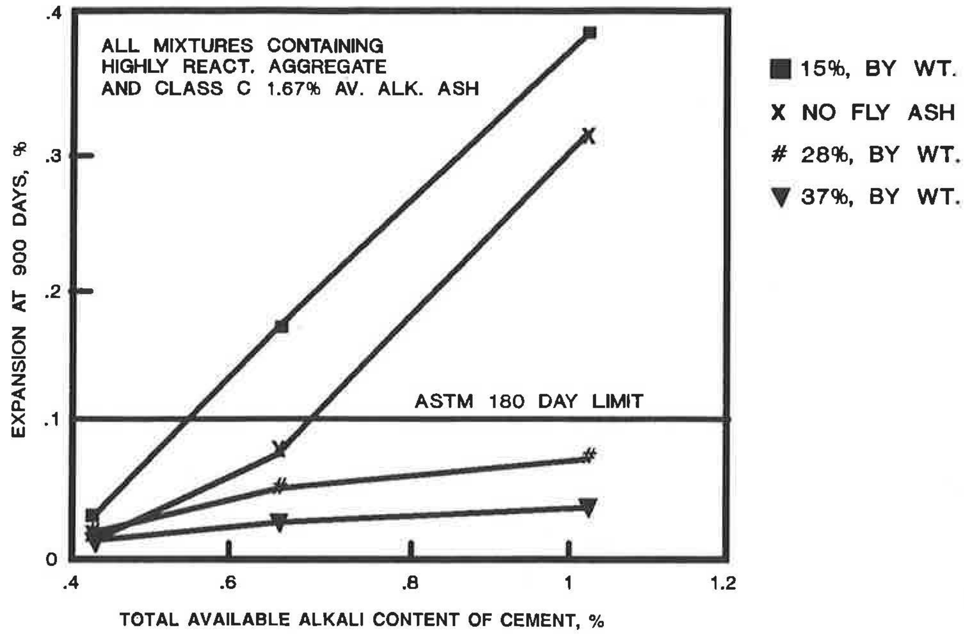

FIGURE 2 Influence of available alkali of cement and fly ash on expansion.

of alkalies added to the fly ash by the precipitating agent, or the availability of these alkalies to participate in deleterious reactions. Further research is needed to determine the quantity of alkalies added to fly ash by these agents and their effect on ASR.

Eight different fly ashes were tested in mixtures containing highly reactive aggregate and two cements with 0.43 and 0.66 percent alkali contents. Figure 5 shows the effect of the alkali content of these fly ashes on the expansion of these mixtures. Figure 5 indicates 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, the replacement of 17.5 percent, by volume (15 percent, by mass), of cement with Class C fly ash caused expansions much greater than those of corresponding mixtures without fly ash, whereas cement replacements

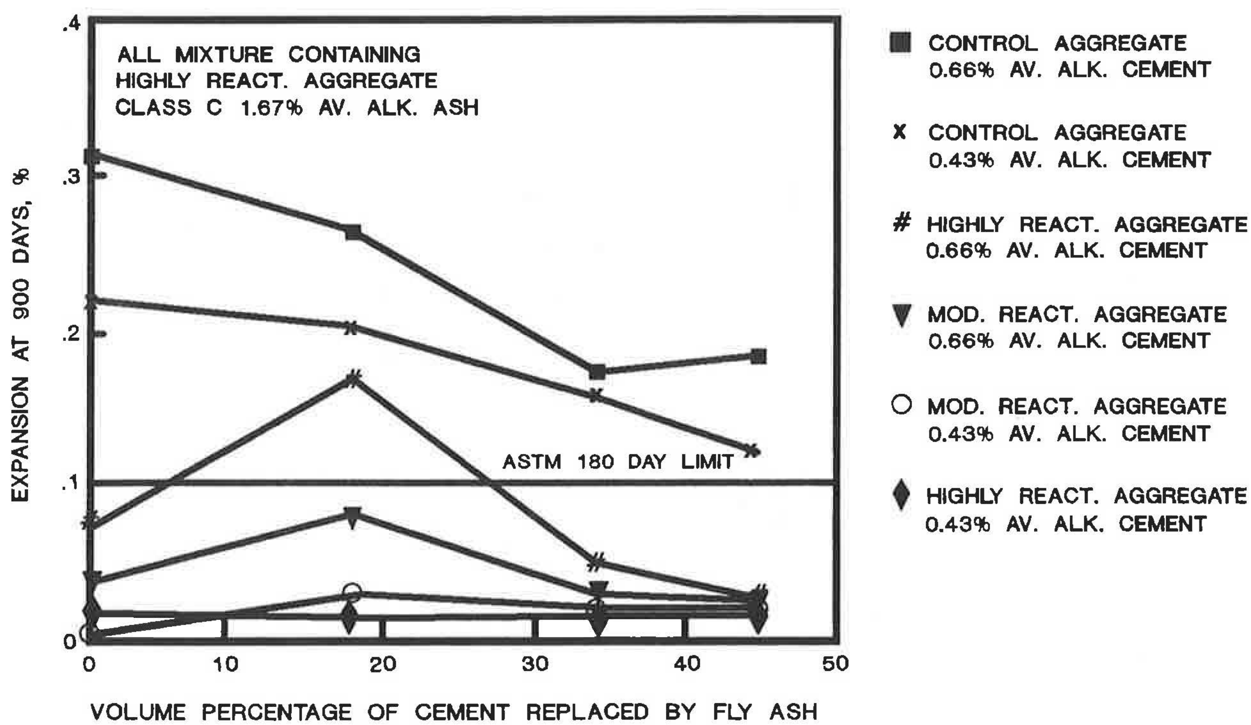

FIGURE 3 Influence of cement and fly ash replacement on expansion.

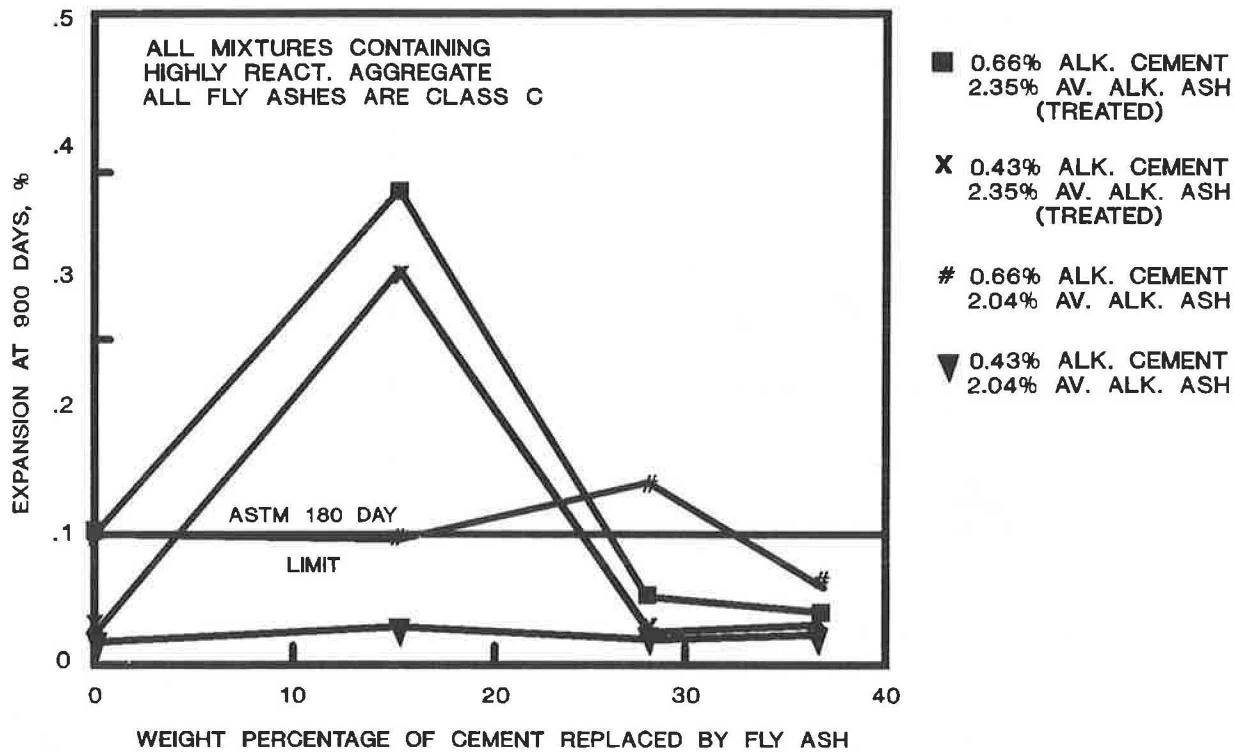

FIGURE 4 Fly ash treated with a precipitating agent.

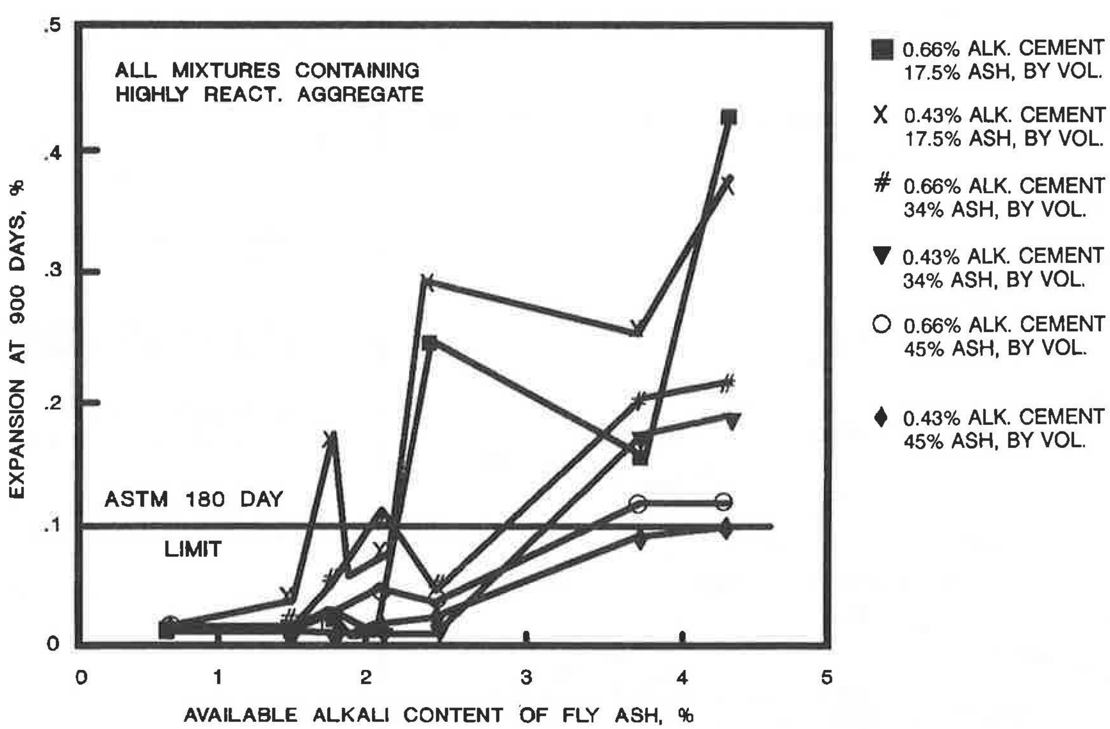

FIGURE 5 Available alkali content of fly ashes.

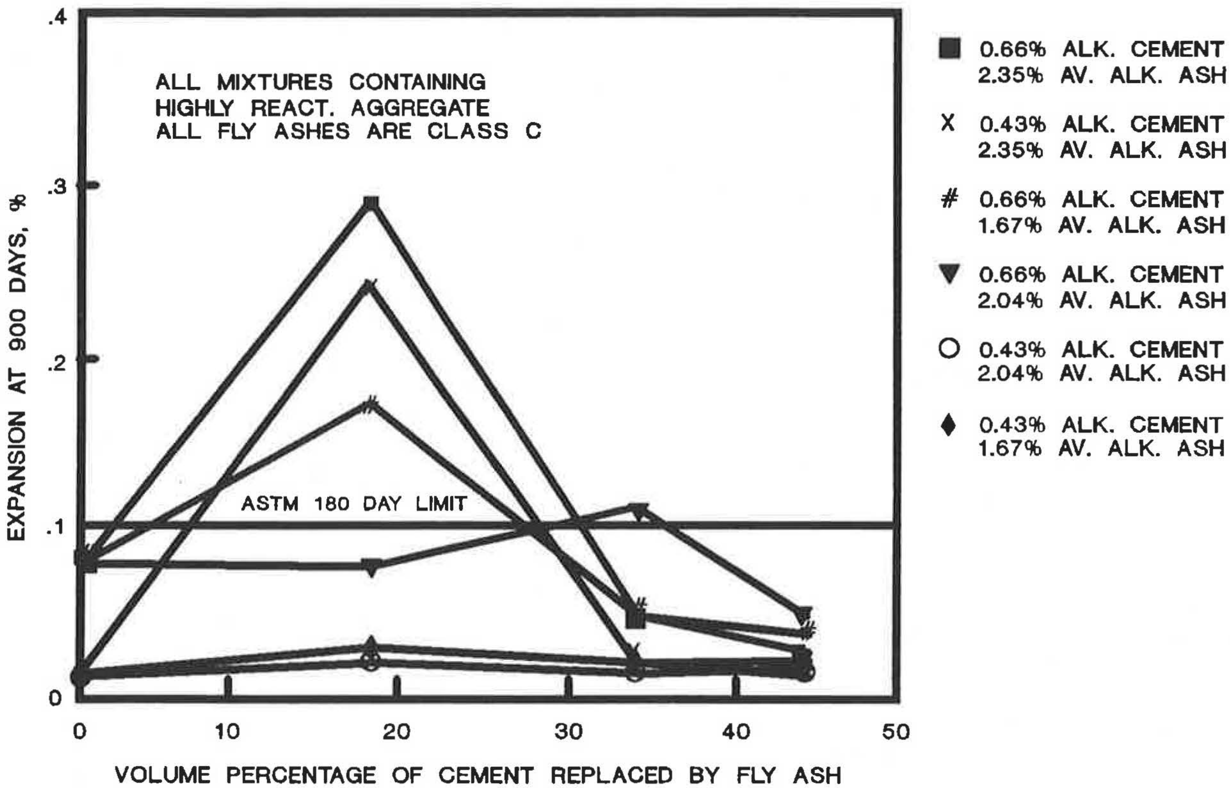

FIGURE 6 Pessimum effect of several Class C fly ashes.

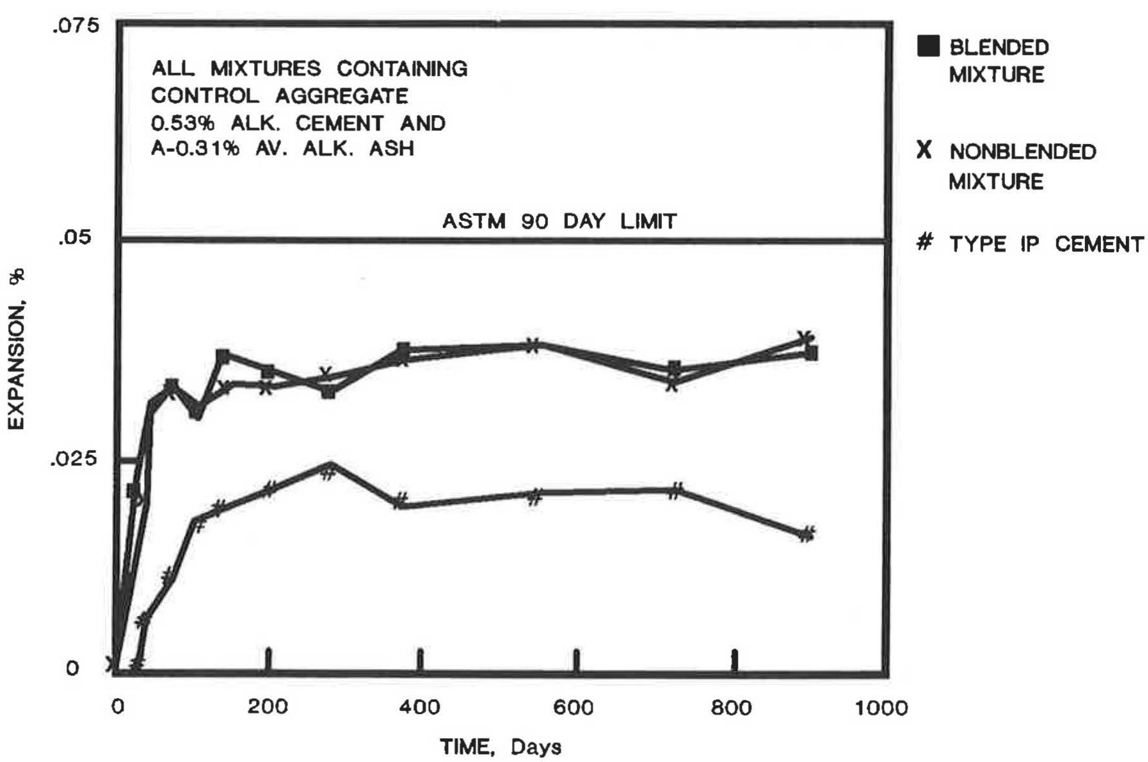

FIGURE 7 Fineness and preblending of fly ash and cement used in Type IP cement.

of 34.3 percent with Class C fly ash caused reductions in expansion.

Additional results, shown in Figure 6, indicated that volume replacements of 26 percent were comparable to the 34.3 percent replacement level in effectiveness. Subsequent increases in volume replacement beyond 34.3 percent had much less effect on concrete expansions. On the basis of these results, increasing the cement replacement as little as 10 volume percentage points beyond the so-called "pessimum" value may be sufficient to obtain satisfactory results.

The Type IP cement used in this study proved to be much more effective in inhibiting concrete expansions than the other cement-fly ash combinations tested. Therefore, two mixtures were made with 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 of the Type IP cement during its manufacture. The intent was to determine what factors associated with the Type IP cement were responsible for its superior performance.

The results shown in Figure 7 indicated that the two cement-fly ash mixtures behaved similarly, and that they expanded more than the Type IP cement mixtures. The increased fineness of the fly ash in the Type IP cement, because of fly ash-clinker intergrinding, appeared to be the factor that enhanced the effectiveness of IP cement in inhibiting expansion. In order to investigate this factor, four Class C fly ashes were ground to two fineness levels and then added to the mortar as mineral admixtures. The first fineness level was approximately 50 percent of the original fineness, measured as the percentage retained on a 45-μm sieve. At the second fineness level, approximately 1 percent fly ash was retained on a 45-μm sieve. All mixtures contained the highly reactive aggregate and the cement with available alkalies of 1.03 percent. The available alkali contents and fineness of the fly ashes are presented in Table 3.

No consistent relationship was found between the percentage of weight retained on a 45-μm sieve and concrete expansions.

CONCLUSIONS

This study has shown that the 0.6 percent limit in ASTM C150 for the available alkali content of cement and the 1.5 percent maximum available alkali content designated by ASTM C618 for fly ash are not sufficient requirements to control deterioration of concrete caused by ASR. However, it is clear from test results in this study that the degree of ASR in concrete mixtures increases when the available alkali content of the cement increases.

The results also demonstrated that replacement of a portion of cement with fly ash is an effective means for reducing expansion in concrete caused by ASR. However, as the available alkali content of fly ash increases, there is a percentage of cement replaced by fly ash, defined as the pessimum limit, at which fly ash causes expansions larger than those of a mixture without fly ash, and above which fly ash reduces expansions.

The finer size of fly ash in Type IP cement appears to be the factor that enhances its performance in reducing ASR by comparison to similar cement-fly ash combinations. However, no correlation was found between Class C fly ash fineness and mortar bar expansion.

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