Alkali-Aggregate Reaction in Concrete Containing Fly Ash

Josef Farbiarz and Ramon L. Carrasquillo
University of Texas at Austin
Austin, Texas

Peter G. Snow
Ash Management Systems
Houston, Texas

INTRODUCTION

When the alkali-aggregate reaction was first recognized more than 40 years ago, intensive research was initiated trying to find solutions to this corrosion process within the concrete. The use of nonreactive aggregate was a trivial solution. The very first alternative solution suggested was the use of cement containing less than 0.60 percent by weight of alkalies, but the fact that water migration within concrete can alter the alkali concentration and eventually increase it to levels at which the alkali-aggregate reaction causes unacceptable damage to the concrete (Butler 1982) rendered it impractical. Finally, researchers suggested (Ramachandran et al, 1981) the use of pozzolans such as fly ash to replace a portion of the cement in the concrete mixture to control the alkali-silica expansion and reduce the damage it causes in concrete. However, the beneficial effect of fly ash in reducing this expansion depends on both intrinsic and extrinsic characteristics such as, among other, fly ash type and percent of cement being replaced (Farbiarz, 1986). This paper depicts the first steps taken to answer the urgent need of developing guidelines for proper, economical and efficient use of fly ash to reduce alkali-aggregate reaction damage in concrete.

More than 1300 mortar-bars were cast and tested according to the Mortar-Bar Test Method, ASTM C 227, with 0, 17, 26, 34, 45 and 62 percent replacement of the volume of cement in the mixture with fly ash. The effect of silica fume in the mixture was compared to that of fly ash at 17, 34 and 45 percent cement replacement. The variables studied included: type of aggregate, alkali content of the cement, type of pozzolan, percent of cement being replaced and blending of the cement with the fly ash. Both ASTM Class C and Class F fly ashes were investigated.

RESULTS AND DISCUSSION

The results indicate that the replacement of a portion of the volume of cement by an equivalent volume of fly ash tends to reduce the reactivity between alkalies and silica in the concrete mixture, provided the proper amount of cement is replaced. This amount depends on the alkali content of the fly ash and on the chemical composition of the fly ash used, as can be seen in Figure 1. Further, tests are being conducted to verify if the observed behavior could be explained in terms of the lime to silica (C/S)

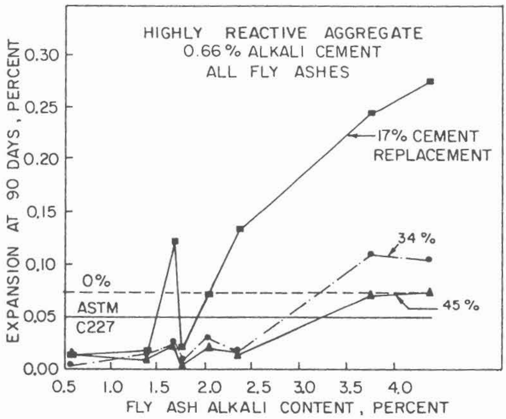

Figure 1. Mortar-bar expansion vs. fly ash alkali content for all 0.66% alkali cement mixtures containing highly reactive aggregate.

mole ratio of the calcium silicate hydrates. Bhatty (1985) has shown that low (C/S) mole ratio calcium silicate hydrates can retain more alkali than high C/S mole ratio calcium silicate hydrates.

Figure 2 shows that for some high calcium fly ashes having more than 1.5 percent available alkalies content, a "pessimum limit" was observed. such a limit represents a percent replacement under which the addition of

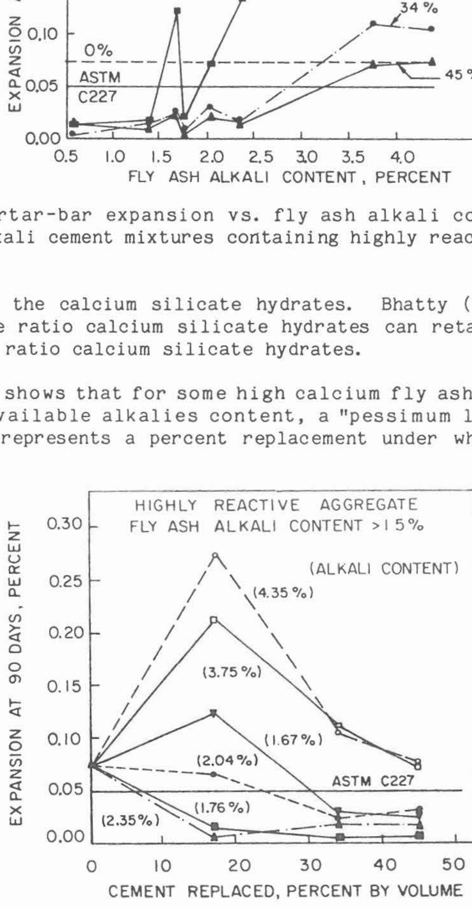

Figure 2. Mortar-bar expansion vs. percentage of cement replaced for all highly reactive aggregate mixtures containing fly ash with more than 1.5% alkalies.

fly ash causes equal or greater expansions in the mortar-bars than that of the mixture without fly ash, and above which the expansions are reduced. In some instances more than one "pessimum limit" was detected for a given combination of materials as seen in Figure 3.

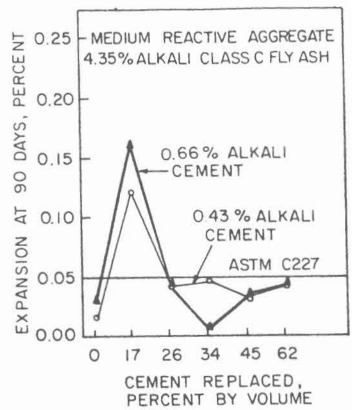

Figure 3. Mortar-bar expansion vs. percentage of cement replaced for all medium reactive aggregate mixtures containing 4.35% alkali Class C fly ash

As for the replacement of cement with silica fume, results suggest that silica fume is effective in reducing alkali-silica reaction in concrete, as can be seen in Figure 4. However, Figure 5 shows that silica fume can eventually become the source of silica to react with the alkalies when nonreactive aggregate is being used in the concrete.

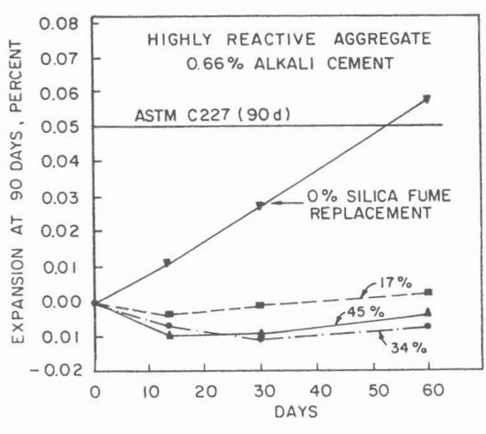

Figure 4. Mortar-bar expansion vs. times for all highly reactive aggregate mixtures containing different percentges of 0.66% alkali cement replaced with silica

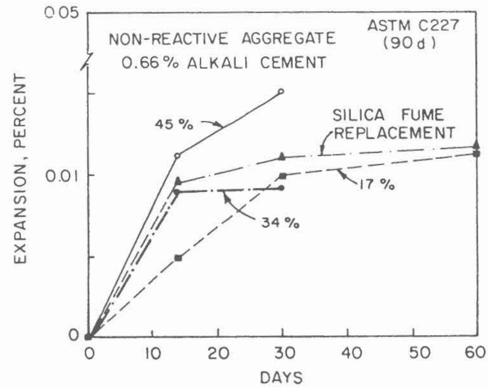

Figure 5. Mortar-bar expansion vs. time for all nonreactive aggregate mixtures containing different percentages of 0.66% alkali cement replaced with silica.

Figure 6 shows that a mixture where the fly ash was blended with the cement at mixing time and a nonblended mixture behaved almost the same while a mixture containing Type IP cement showed considerably smaller mortar-bar expansions. This can be explained in terms of the finer particle size given to the blend at the manufacturing plant after the fly ash is added to the clinker.

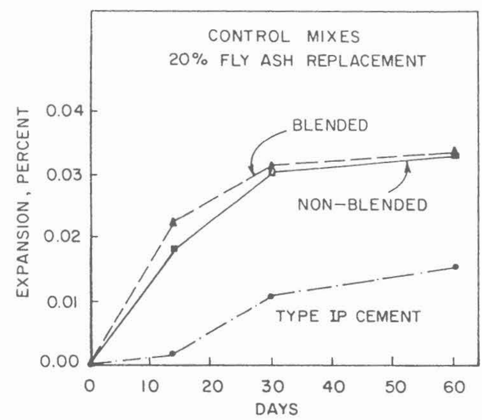

Figure 6. Mortar-bar expansion vs. time for all control aggregate mixtures containing 20% fly ash.

CONCLUSIONS

The test results summarized above indicate that the replacement of a portion of the volume of cement with fly ash may reduce the alkali-aggregate expansions, regardless of whether the fly ash is blended or not with the cement at the time of mixing, depending on the proper combination of the following factors:

1. Fly Ash Alkali Content: Fly ash alkalies are released into the pore solution contributing to the alkali-aggregate reaction.

2. Cement Replacement with Fly Ash: In general, the more cement replaced with fly ash, the more effective the fly ash in reducing the alkali-aggregate expansions. However, for fly ashes with more than 1.5 percent alkali content there is a "pessimum limit" below which no beneficial effect is achieved. This limit is inherent to each particular fly ash.

3. Test results suggest that the replacement of a portion of the volume of cement with silica fume is equally or more effective in reducing the alkali-aggregate expansions. However, more research is needed since it seems that the silica fume can eventually become the source of silica to react with the alkalies in the mixture.

ACKNOWLEDGEMENTS

This work was sponsored by the Texas State Department of Highways and Public Transportation (TSDHPT) and several private entities. The authors express their gratitude to the personnel of the Materials and Test Division of the TSDHPT and the Phil M. Ferguson Structural Engineering Laboratory of The University of Texas at Austin and to the graduate students who helped conduct the study.

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