Alkali-Silica Reactivity in Concrete—Importance of Cement Content and Alkali Equivalent

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ABSTRACT

The effect of cement content and alkali equivalent on alkali-silica reactivity is evaluated in terms of expansion up to age 5 years for concrete prisms made with crushed glass as the coarse aggregate. What happens with each cement-aggregate combination depends strongly on the amount of alkali in the concrete available to fuel the reaction, which in turn is related to the product of cement content and alkali equivalent. Three categories of reactivity can be identified: apparently innocuous for alkali contents in concrete less than about 0.05%, rapid and highly deleterious for alkali contents more than 0.10%, and slowly expansive, potentially dangerous, and classifiable as deleterious only after 1 year or more of testing for alkali contents of 0.05-0.10%.

INTRODUCTION

The standard mortar bar test (ASTM, 1981) for evaluating the potential alkali-silica reactivity of cement-aggregate combinations employs a mortar of specified proportions corresponding to about 27% by weight of cement. Concrete mixtures rarely contain more than 20% (480 kg/m^3) and often as little as 10% (240 kg/m^3) of cement, and the reactive material is coarser than in mortar. This investigation examines how cement content and cement alkali equivalent affect the development of expansion and cracking in concretes moist-cured at 23°C throughout the testing period.

MATERIALS AND METHODS

Aggregates: The coarse aggregate was either crushed bottle glass screened to remove material finer than 2.36 mm, designated the reactive aggregate, or natural gravel, designated the inert aggregate, both of nominal maximum size 19 mm and the same as used in an earlier study (Johnston, 1974) of the strength of concrete made with waste glass or glass-bearing waste as aggregate. The fine aggregate was a natural unreactive concrete sand.

Cements: Three normal Portland cements were selected to give as wide as possible a range of alkali composition (Table 1). One is definitely high-alkali, and the other two are classifiable as low-alkali, ie. alkali equivalent less than 0.60.

Table 1 - Alkali Composition of Cements

Cement	Na_2O-%	K_2O-%	Alkali Equivalent
High alkali	0.66	0.71	1.13
Low alkali	0.13	0.69	0.58
Low alkali	0.14	0.49	0.46

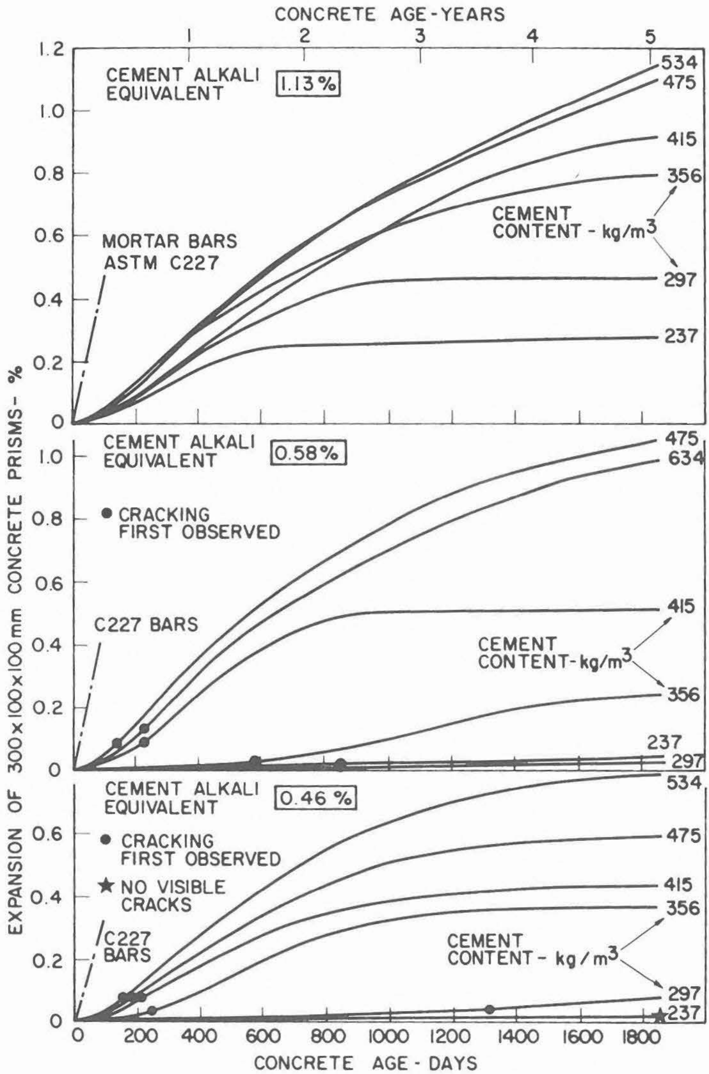

Fig. 1 - Expansion of Standard Mortar Bars and Concretes with Reactive Aggregate to Age 5 Years

Measurement of Expansion: The mean of eight measurements over a 200 mm gauge length on two 300X100X100 mm concrete prisms is the expansion plotted in Fig. 1, 2 and 3.

RESULTS

The expansion at any age up to 5 years and the rate at which it develops increase with increase in cement content (Fig. 1). Also, the higher the cement alkali equivalent, the more rapid the development of the expansion and the greater its terminal value. Compared with ASTM C227 mortar bar expansion (Fig. 1), which is accelerated due both to the higher curing temperature and the greater surface area of reactive aggregate available in mortar, the concretes expand more slowly but nevertheless substantially and deleteriously in most cases.

Range of Expansions Possible for Concrete: The most important feature of Fig. 1 is the wide variation in both the 5-year expansion and the rate at which it develops. Even though the selected aggregate is as highly reactive as any likely to occur naturally, ie. a worst case, concrete expansions range from less than 0.02% for the lowest cement content and alkali equivalent after 5 years to as much as 1.0% for the highest cement content and alkali equivalent.

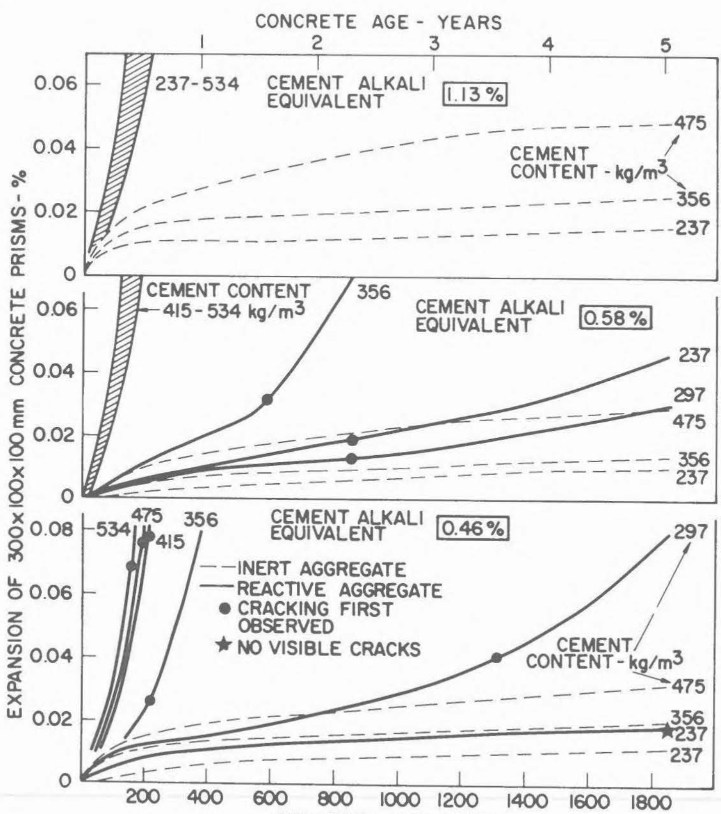

Fig. 2 - Rapidly Expansive, Slowly Expansive, and Innocuous Behavioral Categories for Reactive and Inert Aggregates

The development of expansion and whether it is deleterious or not in terms of visible cracking is assessed both in terms of the point at which cracking was first observed and in terms of the expansion of control concretes with inert aggregate (Fig.2). What is particularly interesting is that, for the two lowest alkali equivalents, seven concretes did not exhibit visible cracking at 6 months and four remained visibly undamaged after 1 year, but all seven eventually developed cracking and expansions significantly greater than their equivalents with inert aggregate. Only the concrete with the lowest alkali equivalent and cement content remained

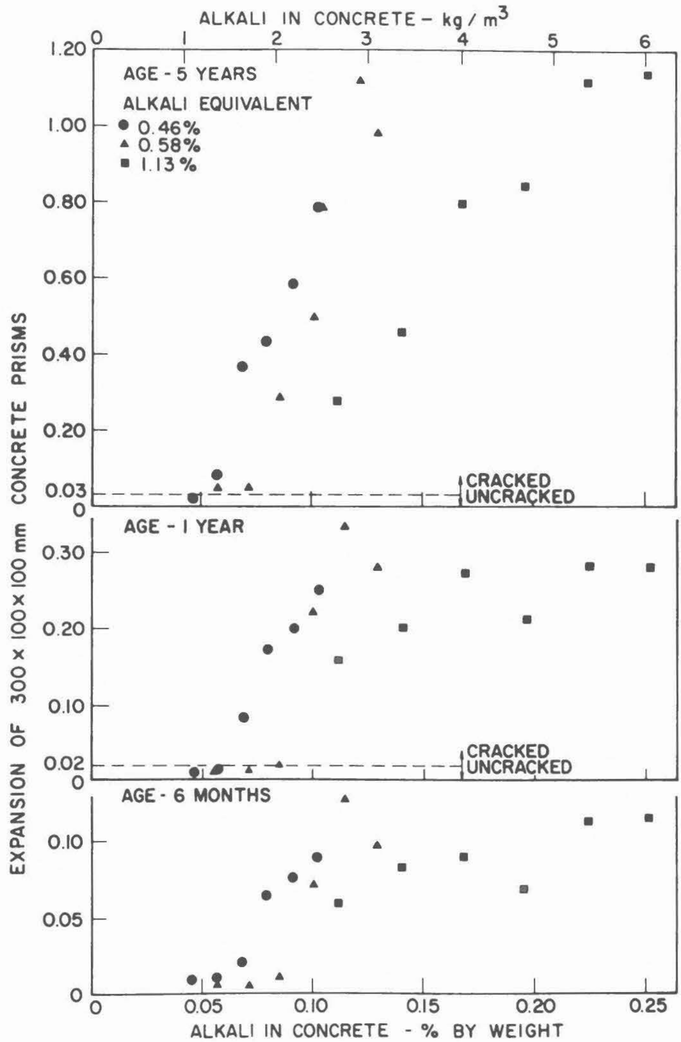

Fig. 3 - Effect of Alkali Content of Concrete on Development of Alkali-Silica Expansion

visibly undamaged with an expansion comparable to its equivalent with inert aggregate after 5 years. Clearly, a significant proportion of the cement-aggregate combinations evaluated exhibit slow but eventually deleterious expansion which cannot be detected in tests of 1 year duration. This suggests that even the most highly reactive of natural aggregates may not produce a deleterious reaction in concrete if the cement content and alkali equivalent are low enough, or, on the other hand, that the reaction may not become deleterious until later than 5 years.

Criterion for Deleterious Expansion: Even for the inert gravel aggregate, expansion increases both with cement content and alkali equivalent (Fig. 2). Definite safe limits for expansion are therefore difficult to establish. However, for the given reactive aggregate, a limit of 0.03% at 5 years appears to cover all but the high alkali cement, which would not normally be considered for use with a questionable aggregate. Unfortunately, there is no obviously safe limit applicable to all cement-aggregate combinations at the normal test duration of 1 year. Data for the inert aggregate compared with the reactive aggregate (Fig. 2) show that an expansion of more than 0.02% at 1 year is deleterious, but there are three combinations which expanded less than 0.02% after 1 year and subsequently exhibited cracking at a later age.

Effect of Total Alkali Content in Concrete: Clearly, concrete expansion and the degree of damage associated with it are a function of the total soluble alkali in the concrete available to fuel the reaction, which is in turn related to, if not equal to, the product of cement alkali equivalent and cement content expressed as kg/m^3 or percent based on a concrete unit weight of 2400 kg/m^3 (Fig. 3). At all ages, it appears that there is a limiting alkali content of 0.05% (1.2 kg/m^3) below which the reaction is not deleterious. Also, there is a higher limit of about 0.10% alkali above which the reaction is rapid and highly deleterious. Between the two limits is a potential problem zone involving slowly expansive cement-aggregate combinations, some of which cannot apparently be proven deleterious in tests lasting up to 1 year.

CONCLUSIONS

1. Crushed glass, a highly reactive siliceous aggregate, can produce widely varying degrees of reactivity in concrete. What happens with each cement-aggregate combination depends strongly on cement content, which is not a variable in the standard mortar bar test, and on cement alkali equivalent, both of which determine the amount of alkali in the concrete available to fuel the reaction. Less than about 0.05% alkali in the concrete produces a non-expansive and apparently innocuous reaction up to 5 years, while more than 0.10% produces a rapid and highly deleterious reaction in 6 months or less. The 0.05-0.10% range includes a potential problem category of slowly expansive combinations where the reaction cannot be proven deleterious in tests lasting 6 months or 1 year. Awareness and detection of this category are important to avoid concrete deterioration in the long term.

2. Natural reactive siliceous aggregates, although usually less reactive than glass, can reasonably be expected to exhibit qualitatively similar behavior. In practice, detection of any slowly expansive cement-aggregate comibations will be particularly important when the concrete is continuously moist. Also, in view of the limited availability of low alkali cements, the merit of reducing cement content to reduce the severity of the alkali-silica reaction should be recognized as practical given the capability of superplasticizers, silica fume, and some fly ashes to compensate for the cement reduction.

REFERENCES

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