Overview

Despite being minor constituents in concrete aggregate and portland cement, alkalies have been recognized as being an important species in concrete for the past 40 to 50 years. Because aggregates previously thought to be inactive have produced expansion after several years and because the alkali content of portland cements has increased owing to the process changes needed to comply with energy and environmental constraints, the alkali-aggregate reaction is now receiving considerable attention.

A few of the numerous questions raised by the cement and concrete industries concerning the alkali-aggregate reaction are given below:

1. Will 10-year-old structures that show no effect of the alkali-aggregate reaction begin to show map-cracking or become structurally unsound in another 10 years?
2. Is portland cement the only source of deleterious alkali in concrete?
3. Does the distribution of the alkali among the cement minerals affect the rate and extent of the alkali-silica reaction?
4. Can the results of ASTM Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method) (C 227) be related to the long-term life of a concrete structure?
5. Is the use of a pozzolan, such as fly ash, the solution to the alkali-aggregate reaction problem?
6. Does an increase in the alkali content of concrete affect the properties of the concrete other than to increase its susceptibility to the alkali-aggregate reaction (e.g., setting time, entrained air stability, finishability, and compressive strength)?

It is hoped that this ASTM Special Technical Publication (STP) will answer, at least partially, these questions as well as several others that the reader might have in mind. The ASTM Symposium on Alkalies in Concrete (Los Angeles, 25 June 1985), from which this STP was derived, was especially organized to explore the causes of the alkali-aggregate problem and how it can be eliminated, minimized, controlled, and predicted. Papers presenting data which show that alkalies, regardless of their source, influence (or do not influence) the engineering properties of concrete were also solicited, but the response in this area was not enthusiastic.

This STP will be of interest to the structural engineer as well as the supplier of cement and concrete. Certain engineering properties of concrete, other than its compressive strength and cracking, are pointed out as being affected by the alkali-aggregate reaction. The proper finishing and curing of concrete also come into play. The chemistry of portland cement, pozzolans, and aggregates proves to be important to the problem. Those readers who are members of ASTM Committee C-1 on Cement will particularly note the comments of the various authors concerning ASTM C 227. All those involved in the final concrete product will find the reading informative and suggestive.

Currently proposed mechanisms for the alkali-silica, alkali-silicate, and alkali-carbonate reactions are reviewed, and the sources of alkali in concrete are discussed. For example, the alkali present within the concrete aggregate particles can participate in the aforementioned reactions. It is shown by one author that alkali levels much greater than those present in high alkali cements can be leached from certain aggregates, perhaps by ion exchange processes or by partial dissolution of the aggregate. The results of experiments in which the removal of alkali, by leaching, from aggregates, prior to their use in mortar bars, indicate a reduction in alkali-aggregate expansion. Between 7 and 24% of the total alkali content of 10 different aggregates can be leached using a method described in one of the papers herein.

Another source of alkali in concrete is fly ash. The traditional use of fly ash to reduce or minimize the expansion from the alkali-aggregate reaction may actually aggravate the reaction if the ash has a low amorphous silica and a high alkali content. Class F and Class C fly ash (ASTM C 618) are discussed in regard to their possible influence on the rate and extent of the expansive reaction. No mention is made, however, as to how the amorphous silica, or alumino-silicate, in a fly ash can be reliably measured.

Portland cement is usually the first to be accused of contributing alkali to the concrete mix. Mortars made with cements rich in the more readily available forms of alkali (e.g., water-soluble alkali sulfates) are shown in this STP to produce higher levels and greater rates of expansion. A water extraction duration of 1 min is claimed in one paper to be preferable to the 10 min extraction presently specified in ASTM Method for Chemical Analysis of Hydraulic Cement (C 114) for estimating levels of the alkali sulfate phases. It is also shown in this paper that the distribution of the alkalies among the cement minerals affects the expansion due to the alkali-silica reaction, and methods for determining the distribution of the alkali in the cement crystalline phases are described.

Good agreement between water-soluble alkalies and total alkalies for cements from a given cement plant is reported. However, the portion of the total alkalies which is water-soluble varies widely from one cement plant to another. One has to ask if this variation is the result of a different distribution of the alkalies within the cement minerals due to different processing conditions.

A case of surface popouts on a portland cement concrete slab is also discussed. It is concluded by the author that the surface disfigurement was the result of the reaction of the soluble alkalies in the concrete with the siliceous shale in the concrete sand and that the former had been increased in concentration on the concrete slab surface by the evaporation of the bleed water. It is suggested that proper mix design, finishing, and curing might have minimized the problem.

Another paper shows that the alkali-aggregate reaction produces a loss in tensile strength of concrete of almost four times that of the loss in compressive strength. Therefore it is proposed that compressive strength is not a good indicator of the extent of the reaction. The measurement of the dynamic modulus or the ultrasonic pulse velocity, or both, appears to be a more sensitive and reliable test for determining the progress of the reaction.

It is also reported that alkalies in concrete can create advantageous effects on its rheology if it contains a mineral admixture. This conclusion is derived from zeta potential and viscosity measurements.

We see in this STP a typical pyramidal effect; that is, the answer to one question gives rise to at least two others. A review of the papers suggests that several areas be probed to better understand the role that alkalies play in determining concrete properties:

1. If the addition of a fly ash having a low amorphous silica and a high alkali content aggravates the alkali-aggregate reaction in concrete, what is the proper balance between the two needed to make the fly ash effective in reducing that reaction? Or, can we establish "pessimism" limits on alkali content, reactive aggregate, alkali content of the aggregate, and fly ash content and its composition (e.g., alkali and amorphous silica content)?
2. The Danish/Icelandic mortar-bar test for the alkali susceptibility of concrete aggregate may serve as a more satisfactory, and certainly less time consuming, method than that outlined in ASTM C 227. Has the ASTM subcommittee responsible for ASTM C 227 considered this test method?
3. When we discuss the alkalies present in the concrete system and their effect on the properties of that system, are we talking about the soluble sodium or potassium ions, or both? Does one alkali species exert more influence than the other or are both equally effective?
4. No mention is made in this STP of the use of condensed silica fume, which is reported to have a high amorphous silica and low alkali content. It may be a good deterrent for the alkali-aggregate reaction, even when added as an admixture in small quantities. This approach to the problem of deleterious expansion should be investigated.
5. The cement and concrete industries should examine more closely the effect of alkalies, regardless of their source, on the properties of concrete other than the alkali-aggregate reaction potential. The construction industry must realize that chemical admixtures have become an integral part of their final product and that the influence of alkalies on their performance in concrete must be clarified.

6. Since the distribution of the alkalies among the cement minerals influences their effect on the rate and extent of the alkali-aggregate reaction, are there changes in the cement clinkering process that minimize that reaction? Will these changes also affect the influence of the alkalies on the other properties of concrete?

The six papers included in this STP all contain supplemental references. Of course, not all aspects of the subject have been covered, but the attentive reader will gain a better insight into the problems of alkalies in concrete.

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