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The Alkali-Silica Reaction, Part I: Use of the Double-Layer Theory to Explain the Behavior of Reaction-Product Gels

by Mônica Prezzi, Paulo J. M. Monteiro, and Garrison Sposito

An understanding of the expansion mechanisms resulting from the alkali-silica reaction is essential to the assessment of the susceptibility of a concrete structure to deterioration by these processes and to the planning and implementation of preventive measures. As a result of the alkali-silica reaction between certain reactive aggregates and the highly alkaline pore fluids in a cement paste, a reaction-product gel develops that, in the presence of water, expands and may cause cracking of mortar or concrete. To explain the volume change behavior of mortar bars containing a reactive aggregate, a theoretical model is proposed in this paper. The expansion of the alkali-silica reaction-product gels is attributed to swelling caused by electrical double-layer repulsive forces. For a given colloidal system, double-layer theory indicates that the larger the valence of the counterions in the double layer, or the larger the concentration of these ions, the smaller the double-layer thickness and the repulsive forces that may be generated in the presence of water (aqueous solution). Experimental results available in the literature support the double-layer model. According to these results, the expansion of mortar bars in the ASTM C 1260 test is related to the composition of the reaction-product gels. The reaction-product gels containing larger amounts of equivalent sodium oxide (Na_2O_e) and smaller CaO/Na_2O_e cause larger expansions in the mortar bars.

Keywords: alkali aggregate reactions; concretes; expansion; mineral admixtures; mortars (material).

The alkali-silica reaction occurs between certain reactive aggregates and the highly alkaline pore solution of a cement paste. In general, the aggregates that cause harmful reactions in concrete are those containing amorphous silica (silicate glasses and opal), unstable crystalline polymorphs of silica (cristobalite and tridymite), poorly crystalline forms of silica, and microcrystalline quartz-bearing rocks.

The water-cement ratio (*w/c*) of normal concrete lies in the range 0.35 to 0.60. However, the amount of water required for full hydration of cement is supplied at about 0.38 *w/c* (Philleo[1]). Therefore, some free water is usually present in the capillary cavities of well-cured concrete. During cement hydration, sodium and potassium sulfates, silicates, or aluminates react, and their anions form products of low solubility such as ettringite, calcium-silicate hydrates, or alumino-ferrite hydrates. To maintain charge balance, equivalent amounts of hydroxide are liberated to the pore solution, increasing its pH (Taylor[2]). The highly alkaline pore solution in concrete is able to depolymerize the reactive silica present in some aggregates, forming products of differing composition in the concrete pores. In the presence of the pore solution, the reaction products (gels) increase in volume. They may expand to such a degree that the concrete tensile strength is exceeded and the material cracks. As soon as the integrity of the material is affected, other processes of deterioration may take place.

In this research, a comprehensive experimental study on the alkali-aggregate reaction (Wang[3]) is analyzed and a theoretical model to explain the expansion phenomenon for different mortar mixtures containing a reactive aggregate (microcrystalline quartzite) is proposed. The model is based on fundamental surface-chemistry principles, the expansion characteristics of the mortar bars, and the chemical composition of the reaction-product gels formed in the samples. The expansion of the reaction-product gels is attributed to swelling caused by electrical double-layer repulsion.

RESEARCH SIGNIFICANCE

The causes of concrete deterioration by the alkali-silica reaction have been investigated for a long time, but understanding of the mechanisms of expansion is still limited. The quantification of the expansive potential and its relationship with the chemistry of the reaction products are complex problems that remain poorly understood. Based on fundamental concepts related to the surface properties and volume change behavior of colloidal systems, a model is proposed to explain the expansive characteristics of the alkali-silica reaction products and the resulting expansion of mortar bars.

INTERACTION OF CEMENT PORE FLUIDS WITH SILICA

The structure of crystalline tekto silicates is built by repetition of a basic unit—the silicon tetrahedron—in an oriented three-dimensional framework. The silicon tetrahedron consists of a silicon ion, Si^{4+}, in the center of the tetrahedron,

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