Alkali-Aggregate Reaction in Reinforced Concrete Structures

Reinforced concrete structures can suffer from alkali-aggregate reaction (AAR).

2. AAR is a chemical process in which alkalis, mainly from the cement, combine with certain types of minerals in the aggregate, when moisture is present. This reaction produces a gel that can absorb water and expand to cause cracking and disruption of the concrete. The cracks accelerate the corrosion of the reinforcement in the concrete. Moreover, reduction in the compressive strength of the concrete reduces the strength of the concrete members.

3. The following factors are essential for AAR to occur in concrete:

(a) There must be reactive minerals present in the aggregate.

(b) There must be sufficient alkali in the concrete to react with the aggregates.

(c) There must be sufficient moisture available to enable the chemical reaction.

4. A range of minerals, including opal, tridymite, cristobalite, volcanic glasses, cryptocrystalline to microcrystalline quartz and poorly-crystalline quartz, have been reported by overseas researchers as capable of causing AAR. The occurrence of AAR depends on both the type and percentage by mass of reactive minerals present.

5. The alkalis in the concrete come mainly from the cement. An effective means of reducing the risk of AAR includes proper control on the amount of cement used in the concrete mix, use of a low alkali cement, and appropriate use of cement replacement such as pulverised fuel ash (PFA).

6. In 1992, a programme of studies on AAR was started by the Public Works Laboratories of the Hong Kong Government. These included tests on concrete cores obtained from suspected structures, as well as investigations on the AAR potential of aggregates from a number of local quarries. The investigations are still on-going and the long-term tests may take a few years to complete. However, in view of the potential risks in the event of AAR occurring in structures and the long duration required for the experimental work, specification items (Appendix A) have been introduced on all future Works Branch contracts.

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7. To avoid the risk of AAR occurring, authorized persons / registered structural engineers should consider incorporating the specification clauses for the control of AAR in concrete into contracts for private development projects. In such cases, plans for approval should clearly indicate that the reactive alkali of concrete expressed as the equivalent sodium oxide per cubic metre of concrete should not exceed 3.0 kg when determined in accordance with the specification items given in Appendix A.

8. The authorized person or registered structural engineer should ensure that the concrete mix complies with the limit on reactive alkali by requiring the specification clauses to be complied with, unless he is in the opinion that the concrete element will not be subject to ingress of moisture throughout its design life.

(Helen C P Lai YU)
Building Authority

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Model Specification Clauses for for the Control of Alkali-Aggregate Reaction in Concrete

Control Measures

1. Measures to control the occurrence of alkali-aggregate reaction (AAR) in concrete shall be submitted to the authorized persons / registered structural engineers (AP/RSE) for approval. In the absence of alternative proposals, such control shall be achieved by limiting the reactive alkali content of the concrete as described in clauses 2 to 4 below unless in the opinion of the AP/RSE the concrete element will not be subjected to moisture ingress throughout its design life.

Limit on Reactive Alkali

2. The reactive alkali of concrete expressed as the equivalent sodium oxide per cubic metre of concrete shall not exceed 3.0 kg.

Equivalent Sodium Oxide (Na_2O) Content

3. The equivalent sodium oxide (Na_2O) content of the concrete shall be determined in accordance with the following steps:

(1) The equivalent Na_2O shall be calculated by the expression

$$\text{Equivalent } Na_2O = A + B + C$$

where A is the sum of the acid-soluble alkalis (expressed as equivalent Na_2O) of cement, admixtures and water;

B is equal to 1/6 the total alkalis of pulverised fuel ash (PFA) (expressed as equivalent Na_2O); and

C is equal to 0.76 times the chloride ion (Cl^-) of the aggregate.

(2) The acid-soluble alkali content of the cement shall be determined in accordance with BS 4550:Part 2:1970 (excluding amendment AMD 7285, July 1992) and shall be taken as the average of the latest 25 daily determinations of equivalent sodium oxide plus twice the standard deviation of the results.

(3) The acid-soluble alkali content of admixtures shall be determined in accordance with BS 1881:Part 124:1988.

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(4) The acid-soluble alkali content of water shall be determined in accordance with American Public Health Association (APHA) (17ed. 1989) Sections 3500-K and 3500-Na.

(5) The total alkali content of the PFA shall be determined in accordance with BS 4550:Part 2:1970 (excluding amendment AMD 7285, July 1992) and shall be taken as the average of 25 weekly determinations plus twice the standard deviation of the results.

(6) The equivalent sodium oxide content of the coarse and fine aggregates shall be calculated from the quantity of chloride ion present which shall be measured in accordance with BS 812:Part 4:1976.

Test Certificates and Calculations

4. The following particulars of the concrete mix should be submitted by the concrete supplier to the AP/RSE:

(1) HOKLAS-endorsed test certificates not older than six months giving the results of tests required in clauses 3 (2) to (6);

(2) Calculation of the reactive alkali of the proposed mix; and

(3) New HOKLAS-endorsed test certificates giving the results of tests required in clauses 3 (2) to (6) to be submitted at quarterly intervals together with any necessary further calculations to demonstrate that the mix continues to comply with the limit on reactive alkali.