Alkali-Silica Reaction In Concrete

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The problem of Alkali-silica reaction was believed to be non-existent in India till 1983, when its occurrence was diagnosed in two concrete dams. This paper describes this problem with respect to Indian aggregates and cement. A rapid method of test for alkali-aggregate reaction is investigated and described in the paper.

INTRODUCTION

The most common causes of deterioration in structural concrete with steel reinforcement in it are

- carbonation and chloride penetration leading to corrosion of steel resulting cracking and spelling of the concrete cover.
- inadequate cover to reinforcing steel Less common causes of deterioration in clude,
- freezing and thawing
- sulphate attack
- alkali-aggregate reaction.

There are three types of alkali-aggregate reactions, namely the alkali-silica, alkali-silicate and akali-carbonate reactions. Deterioration due to the alkali-silica reaction is more common and this paper refers to this aspect.

The alkali-silica reaction was first recognized as a problem in North American in 1940, in Denmark in the early 1950s, in West Germany in the early 1960s, in the U.K.in the mid 1970s, in Japan in the early 1980s. There were no known cases of alkali-silica reaction in India till 1983, when its occurrence was diagnosed in two concrete dams. Spillway of Hirakud (Orissa) dam and spillway piers and radial gate pedestals of Rihand Dam (U.P.). These were the first two confirmed cases of cracking due to alkali-silica reaction in India. Upto this time, it was believed that Indian aggregates are not expansively reactive, and not much research in this field was done in India except in 1957 by Jagus and in 1973 by Gogti Jagus as far back as 1957 concluded that India has numerous sources of potentially reactive aggregates with a range of alkali contents and water-cement ratios normally adopted in

India, the molar concentration of alkali can be sufficiently high to give rise to unsafe reactions with reactive aggregates.
The alkali-silica reaction though not true is described as a concrete cancer. A human cancer, if untreated is terminal, whereas the alkali-silica reaction and the expansion it induces, if untreated, eventually stops. No concreted structure or part of a concrete structure any where in the world has collapsed due to alkali-silica reaction alone.

Over 1035 technical papers have been devoted to various aspects of the alkali-silica reaction problems. Since 1974 eight international conferences have been held to discuss alkali-aggregate reaction. Despite the presence of vast amount of literature on the alkali-silica reaction, the subject is incompletely understood and its effects not entirely solved. Indeed, due to lack of understanding of the complexity of the factors involved, the alkali-silica reaction is sometimes being blamed for deterioration which could be attributed to other causes.

ALKALI-SILICA REACTION

Alkali-silica reaction (ASR) in concrete is a reaction between certain silicious constituents in the aggregate and the alkali-sodium and potassium hydroxide which are released during the hydration of Portland cement. A gelatinous product is formed which imbibes pore fluid and in so doing expands, inducing and internal stress within the concrete. The gel will cause damage to the concrete only when the following three conditions occur simultaneously.

- a reactive form of silica is present in the aggregate in significant quantities.
- sodium, potassium and hydroxyl ions are present in the pore solution within the concrete.
- water is available from an external source.

The problem of alkali-silica reaction can be overcome by,

- use of non-reactive aggregates
- use of low-alkali cement, namely cement with an equivalent sodium oxide (Na_2O) content of 0.6% by mass or less. No allowance is made for possible alkali contributions from sources other than the Portland cement.
- limiting the cement content to 500 kg/m^3
- use of pozzolana, slag and other substitutes for part replacement of cement
- use of ASR – inhibiting salts
- controls on service conditions, namely preventing contact between concrete and any external source of moisture.

REACTIVITY OF INDIAN AGGREGATES

Limited data are available on alkali reactivity of natural aggregates in India. Gogti evaluated some common Indian aggregates with emphasis on their susceptibility to alkali-aggregate reactions from a study of a number of samples of rocks aggregates belonging to different Indian geological formation. On the basis of petrographic characters and mortar-bar expansion tests, he concluded that Indian rocks vary widely in the susceptibility to alkali-aggregate reaction. In this experiment the cement used for the test was high-alkali cement with an alkali content of 1.15% (equivalent Na_2O).

Normally the maximum alkali contents of Indian cements are not as high as those one comes across in the USA and the U.K., where maximum percentage of more than 1.0% are known to have been reached. Jagus analysis for alkali content of 26 different brand of Indian cement in sixties was as below:

Total alkali content as Na_2O percentage	No. of samples tested	Percentage of number of samples of the total
Below 0.40	8	30.8
0.40 – 0.60	7	26.9
0.60 – 0.80	5	19.2
0.80 – 1.00	6	23.1
above 1.00	Nil	—-

Eleven samples out of 26 cements found to have total alkali contents higher than 0.60%, and with many reactive rocks which are used in construction, it is necessary to test aggregate for reactivity with the proposed cement to be used in the construction before being allowed to be used in construction.

One method of determining the potential alkali-aggregate reactivity is by `mortar bar' test as given in IS: 2386 (Part VII) – 1963. This method of test covers the determination of reactivity by measuring the expansion developed by the cement-aggregate combination in mortar bars during storage under prescribed conditions of test. The test is more conclusive but has the disadvantage of requiring a time of 6 months or more.

The above I.S. Code also gives a second method of determining the potential reactivity of aggregates by chemical method. This test can be performed in 3 days, but for many aggregates the results are not conclusive.

Petrographic examination of aggregates to evaluate their reactivity with alkalies is an optical inspection to establish the presence and quantity of potentiality reactive forms of silica within the aggregate particles. In this test, it is sometimes difficult to establish which specific particles and minerals are responsible for gel formation.

ACCELERATED TEST FOR AGGREGATE REACTIVITY

As the conventional test method for alkali-aggregate reactivity required considerable time, an accelerated testing method was investigated for this test to get results in 7 days time rather than to wait for 6 months or more.

Materials

Three samples of sand 100% passing on 4.75 mm I.S. sieve and three samples of coarse aggregate crushed and graded as laid down in IS: 2386 (Part VII) – 1963 table II with one brand of OPC having an alkali content of 0.83% (equivalent Na_2O) was taken for reactivity test by accelerated, as well as mortar bar, test methods as laid down in IS Code. Sand samples from Rishikesh, Badarpur, Chambal (Agra) were marked as sample number 1, 2 and 3 respectively. Aggregates from Hardwar, Delhi and Kota were marked as sample number 4, 5 and 6 respectively.

Preparation of test specimens

Eight prisms of size 25x25x250 mm of each sample of aggregates were prepared as laid down in IS: 2386 (Part VII)-1963. Four prisms of each sample of aggregates were tested upto 6 months period as per procedure of IS: 2386 (Part VII)-1963. Remaining 4 prisms of each sample of aggregates were tested for alkali-silica reactivity by accelerated testing method as given below:

Accelerated mortar prism testing

After demoulding at 24 ± 2 hours the mortar prisms are immersed in distilled water maintained at $70^{o}C$ for 24 hours. The length of the prism is then measured before immersion in 1 m sodium hydroxide solution maintained at $70^{o}C$.

The length of the prisms are then measured each day for 7 days. The average expansion in 7 days is taken as a measure of the potential alkali reactivity of the aggregates.

The average expansion of samples obtained are given in table 1. A good correlation exists between 7 days accelerated testing and 6 months mortar bar expansion testing conducted as per IS: 2386 (Part VII)-1963. The results obtained were found to be within $\pm$10%.

Table 1 – Relationship between the expansion measured in the rapid test and the mortar bar test

Sample No.	Description of aggregates	Expansion (percent)	
		7 days rapid testing	6 months mortar bar test
1.	Sand Rishikesh	0.038	0.041
2.	Sand Badarpur	0.044	0.042
3.	Sand Chambal (Agra)	0.041	0.040
4.	Aggregate (Hardwar)	0.045	0.043
5.	Aggregate (Delhi)	0.049	0.047
6.	Aggregate (Kota)	0.030	0.027

CONCLUSIONS

1. Until 1983 it was thought that Indian aggregates are non-reactive. In two dams cracking was observed which was concluded to be attributed by alkali-silica reaction.
2. For long term durability of concrete, the proposed aggregates to be used in the construction should be tested for reactivity with the combination of the same cement which is to be used in the construction.

3. Conventional method of test for alkali-silica reaction is very time consuming, as it requires a time of 6 months or more. A construction site cannot waif for so long period. Keeping this in view, trial was done for accelerated method of test.

4. The accelerated method of testing is still in experimental stage. Further work is in progress, details of which will be published as soon as more data on this test is obtained.

5. In India very little work was done to observe the alkali-aggregate reactions with Indian aggregates and cement. So far in India about six papers on this topic have been published whereas over 1035 papers were published abroad in the study of alkali-aggregate reactions.

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