



National Council for Cement and Building Materials

ALKALI-AGGREGATE
REACTIONS IN CONCRETE :
CAUSES, DIAGNOSIS AND
PREVENTION

PART I

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ALKALI-AGGREGATE REACTIONS IN CONCRETE : CAUSES, DIAGNOSIS AND PREVENTION*

PART I

INTRODUCTION

COARSE and fine aggregates comprise nearly 75% of the volume of concrete. Such aggregates are generally expected to be chemically inert to the cement-water system of concrete. However, in some cases, active silica present in certain types of responsive aggregates may react chemically with the dissolved alkalis (sodium oxide and potassium oxide) essentially derived from the cement. In addition, the alkalis present in the environment or even from the aggregates may enter the reaction. The product of this alkali-silica reaction (ASR) is an alkali-silicate gel which can imbibe moisture, if available, causing the gel to swell and develop pressures. Such pressures cause internal expansion in the concrete leading to conspicuous "map" cracking in surface areas, longitudinal cracks in the structural members, pop-outs and bulging in concrete, buckling of metallic embedments and malfunctioning of appurtenant machineries on the concrete structures. In a similar manner, certain carbonate rocks can, by their reaction with alkalis, produce expansion that results in deterioration of concrete.

While the damage to concrete due to alkali-carbonate reaction is believed to be essentially confined to certain locations in North America and the Middle East, damages due to ASR are more well known. Apart from reactive aggregates and cements having relatively high alkali content, presence of moisture is necessary for the deleterious reaction. ASR was first documented in 1940 in case of a concrete dam in USA and since then many other concrete dams and hydraulic structures are known to have suffered damages from it. Distress to concrete structures due to alkali-aggregate reaction has been reported from many parts of the world, like UK, New Zealand, Germany, Iceland, Denmark, Turkey and the Middle East. Recently, National Council for Cement and Building Materials (NCB) diagnosed two cases of severe cracking and distress to concrete dams in India due to

*Reprint

such alkali-aggregate reaction which incidentally are the first reported cases of this type in the country. Distress to a concrete dam in neighbouring Pakistan has also been recently reported.

This Technology Digest (Part I) describes the types of reactive rocks in concrete aggregates which are believed to be responsible for such alkali aggregate reaction and the diagnostic methods available. Part II of the Technology Digest will cover possible approaches to prevent such deleterious reaction, with particular reference to the Indian sub-continent.

REACTIVE ROCK TYPES

The reactive substances in naturally occurring rocks which give rise to ASR are metastable silica minerals and volcanic glasses. These are generally identified as opal, chalcedony, certain forms of quartz which are microcrystalline to cryptocrystalline, or crystalline but intensely fractured, "strained", and/or inclusion-filled, cristobalite and tridymite, beekite, rhyolitic, dacitic, latitic, or andesitic glass or cryptocrystalline devitrification products, etc. Accordingly, the most important deleteriously alkali reactive rocks are opaline cherts, chalcedonic cherts, quartzose cherts, siliceous limestones, siliceous dolomites, rhyolites and tuffs, dacites and tuffs, andesites and tuffs, siliceous shales, phyllites, opaline concretions, fractured, strained and inclusion-filled quartz and quartzites, flint, tridymite, sandstones, etc.

Another class of reactions involves complex rock types having as active components various layer—lattice and other silicate minerals. These include graywackes, phyllites, siltstones, argillites, arenites, schist, granite, granite-granodiorite gneisses, charnokites, and others. Shales and gneiss aggregates with co-existence of ferromagnesia micas, quartz and alkali feldspaths close to albite are also reported to give rise to ASR. It is now recognised that in rocks containing medium or coarse grained quartz, the reactivity is due to defect in the quartz lattice. The presence of such "strained" quartz showing undulose extinction is capable of bringing about deleterious ASR, albeit at a much slower rate. Cases of ASR in concrete dams in India and Pakistan have been caused by the presence of such strained quartz in aggregates.

In all such cases the amount of deleterious constituents need not be very high; presence of 1% or more is sufficient to cause harmful reactions. Such deleterious ASR when caused due to presence of strained quartz may take considerably larger periods of service life (10 to 20 years or more) to become evident, and a number of rock types in the Indian sub-continent may contain strained quartz. From these considerations, the problem of alkali-aggregate reaction in concrete merits urgent attention.

DIAGNOSTIC METHODS

Two types of diagnostic methods are considered: one relating to selection of aggregates before a concrete construction is taken up, and the second relating to diagnosis of causes of distress in a concrete structure while in service. In the first category, there are a number of laboratory methods including petrography, rapid chemical test, dimensional change tests on mortar bars, concrete prisms and rock cylinders; these are covered in the national specifications, like ASTM and Indian Standards. By and large, these tests have proved useful in detecting potentially deleterious reactive aggregates, although certain instances showing their limitations have also been reported. Previous service records of aggregates from a particular location usefully supplement the information gathered from such laboratory tests.

While detection of potential alkali-reactivity of aggregates containing cryptocrystalline silica minerals is somewhat straightforward, eg, by rapid chemical test or mortar-bar test, those due to presence of strained quartz pose some problem. In such cases rapid chemical test may not detect the reactivity, and that threshold values for mortar-bar tests may have to be somewhat lowered. Comprehensive investigation at NCB has led to methods for characterisation of such reactive aggregates containing strained quartz, through comparison with the established test procedures as well as use of infra-red spectroscopy and scanning electron microscopy (Fig 1) with the energy dispersive analysis of X-rays. These methods are being applied in case of concrete dams to be constructed in future.

In so far as detection of ASR as a cause of distress to concrete

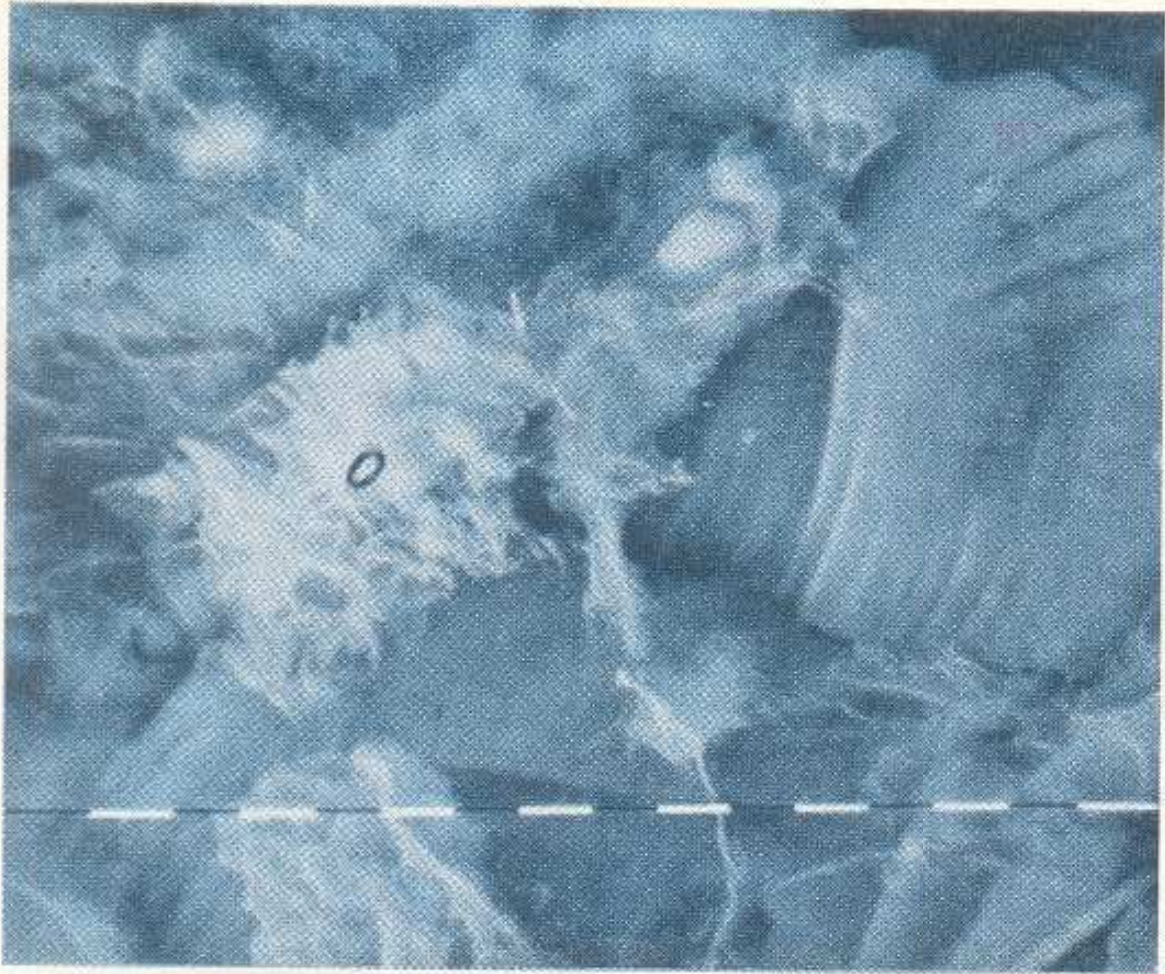


Fig 1 Scanning Electron Micrograph of an aggregate treated in KOH

structures in service is concerned, occurrence of ASR is characterised by:

a) Presence of gel as a most abundant and conspicuous deposit in voids and cracks inside the concrete (Fig 2) and sometimes as exuding out of it. This gel has been described as "white and porcelain-like in texture, or usually translucent and bluish white or dull opaque white, rubbery to powdery to brittle", etc;

b) Presence of aggregate alteration borders along with dark reaction rims (Fig 3) and dark borders visible under low magnification; and

c) Presence of ramifying cracks about an aggregate particle and internal cracks in the aggregate, which tend to become narrow and terminate in the border described in (b).



Fig 2 Gel formation on the aggregate



Fig 3 Dark reaction rims on aggregate

The expansive gels have been described as $\text{SiO}_2 \cdot \text{Na}_2\text{O} \cdot \text{K}_2\text{O} \cdot \text{CaO} \cdot \text{H}_2\text{O}$. Within this broad range, details of chemical composition of alkali-silica gels have been reported by many investigators. Depending upon the presence or absence of lime (CaO), the gels can be classified as 'true' alkali-silica gels, lime-alkali-silica gels and lime-alkali-silica gels of high lime content. There is possibly an interaction of the alkali-silica gel with the cement paste by which the gel picks up calcium, and completely lime-free alkali-silica gel may not be encountered. Presence of MgO , SO_3 and chloride-ions in the reaction products has also been reported.

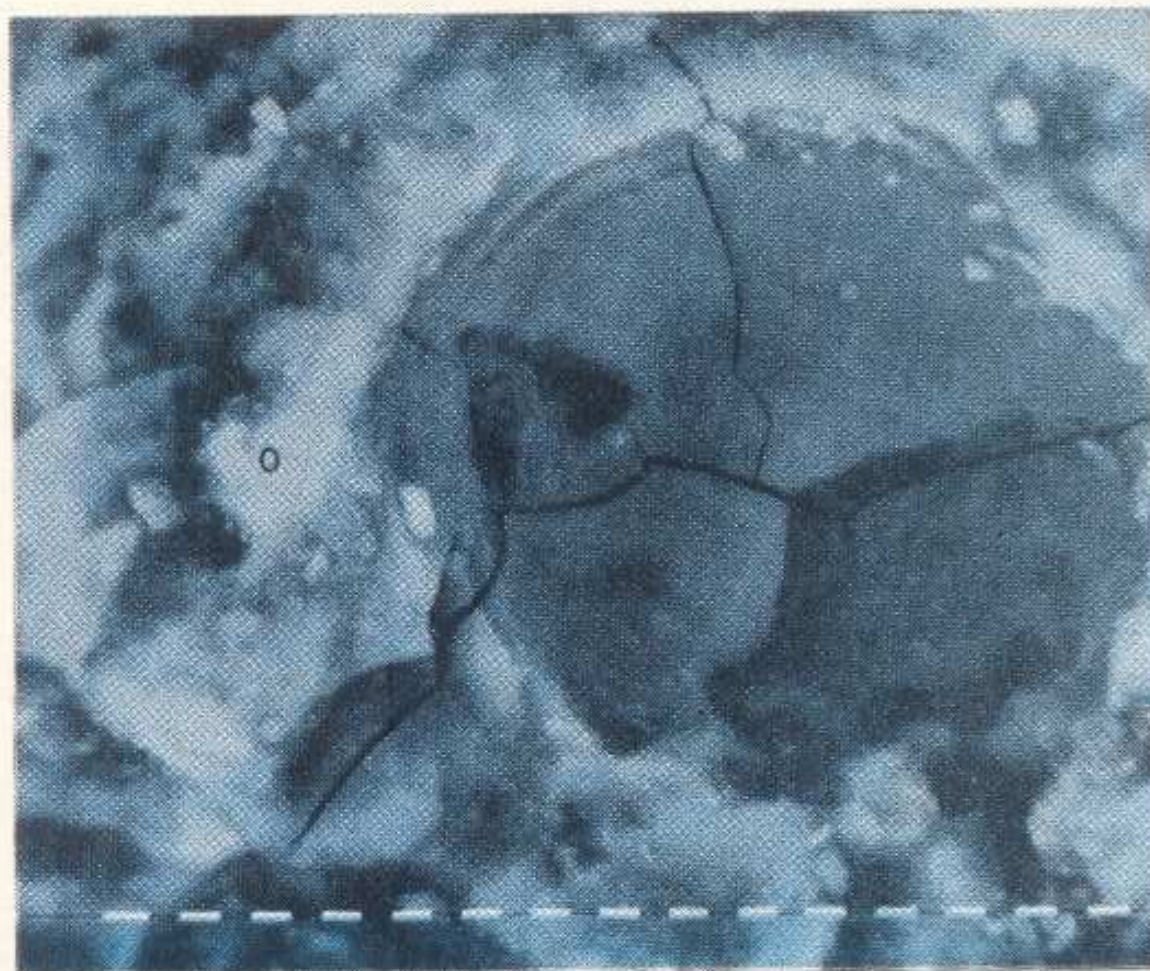


Fig 4 Scanning Electron Micrograph of gel formation around a cavity occupied by an aggregate and microcracks on the mortar phase

Among the methods employed to detect the presence of ASR in in-situ concrete structures are optical microscopy, chemical analysis including flame photometry, infra-red spectroscopy, X-ray diffraction, electron microscopy (Fig 4) and others. Rapid chemical test for detection of ASR as per ASTM-C-289 or IS : 2368 on selective aggregates extracted from the concrete has also reported. Generally some or the other of these techniques have been used in investigations of ASR by various agencies. However, NCB is uniquely equipped with all the above diagnostic facilities.

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