

ALKALI SILICA REACTION IN CONCRETE

INTRODUCTION

The purpose of this Technical Note is to increase the understanding about the potential deterioration of concrete structures due to the internal chemical process known as alkali aggregate reaction. Alkali aggregate reaction occurs in a number of forms, the most common in Australia being that of alkali silica reaction (ASR). ASR can cause expansion and subsequent cracking of concrete, thus compromising its durability by exposing the concrete to the easier ingress of aggressive agents such as moisture, carbon dioxide, oxygen, other gases, and salt solutions which lead to premature corrosion of the steel reinforcement^(1,2,3,4). ASR also has important implications in the management of bridge assets and other concrete structures. There are several methods commonly used to prevent or minimise the risk of ASR (Fig. 1).

WHAT IS ALKALI SILICA REACTION (ASR)?

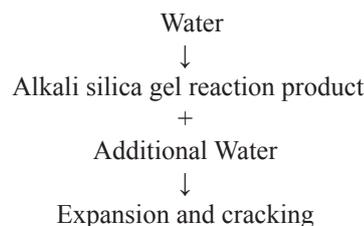
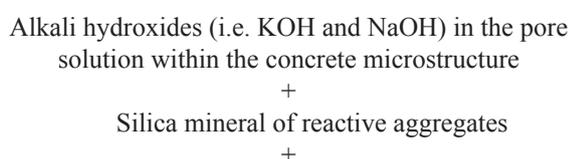
ASR is a disruptive chemical reaction within the concrete matrix. The reaction, in susceptible aggregates and in the presence of moisture, is between the alkali hydroxides (sodium and potassium) and free or unstable, volatile silica minerals. It produces an expansive sodium or potassium rich (alkali) silica gel which has the ability to absorb further amounts of moisture and expand. When this expansive gel completely fills the pore system within the concrete it exerts excessive tensile stresses^(1,2,3,4). The result is severe cracking of the concrete.

For deleterious ASR to occur in a structure:

- the concrete must contain aggregate with a high proportion of reactive silica;
- the concrete pore solution must have a sufficiently high alkali hydroxide content; and
- there must be sufficient moisture, typically >75% internal relative humidity.

The absence of any one of these inhibits the reaction.

The alkali silica reaction can be summarised as follows:



SOURCES OF ALKALI AND MOISTURE

The alkali hydroxides are mainly derived from the cement as they are present in its raw materials. Other possible sources include chemical admixtures, supplementary cementitious materials, SCMs (i.e. fly ash, slag, silica fume), water and alkali released from some aggregates. Ground water, sea spray and sea water can also supply alkali. Mixing water in excess of that required to hydrate the cement can be retained as moisture within the pore system. More moisture can become available from rain and runoff, condensation, seasonal increases in humidity, leaking joints and inadequate drainage scuppers. Structures in moist environments, with surfaces immersed in water or exposed to regular cycles of wetting and drying, are particularly vulnerable.

TYPES OF POTENTIALLY REACTIVE ROCKS

Rocks must contain free or unstable fine-grained silica such as glass, quartz and quartz derivatives to be potentially reactive to alkalis. Potentially reactive aggregates include some originating from basalt, rhyolite, dacite and andesite, hornfels, granite and quartzite. Potentially reactive sedimentary aggregates include those originating from river gravel and sandstone.

VISIBLE SIGNS OF DAMAGE

The visible signs of ASR damage are characterised by a network of cracks known as map cracking (Fig. 2). Cracking can be directional, influenced by the direction of the largest applied stresses, such as in the case of prestressed concrete components. This may also be the case where significant amounts of steel reinforcement are present in a concrete component, as cracking tends to be more prominent in the direction parallel to the steel reinforcement (Fig. 2). Other visible signs of damage include damp patches, usually at crack junctions, and discolouration due to the calcium rich alkali-silica gel which migrates to the surface of the concrete (Fig. 2). A greater awareness of ASR and its

potential damage to concrete in recent years has made it easier to identify the problem. Previously, ASR induced cracking may have been attributed to other factors such as drying and plastic shrinkage, surface crazing or structural movements or loadings. Shrinkage cracks and surface crazing normally develop early in the life of the structure (i.e. within hours, or days/weeks after casting the concrete and certainly within the first year), whereas ASR induced cracking may appear after about 5 to 8 years, with further deterioration taking place in subsequent years.

DURABILITY CONSIDERATIONS

The main deleterious consequences of ASR are essentially related to potentially significant reductions in compressive strength (up to 25%), tensile strength (up to 50%), flexural strength, elastic modulus (up to 60%) and bond strength of the steel reinforcement. Not much evidence exists of significant reductions in structural capacity. The issue of greatest concern is the long term durability of concrete structures due to the network of cracks which substantially increase the permeability to aggressive agents. This can further accelerate deterioration mechanisms such as carbonation, chloride attack and corrosion of the steel reinforcement. Very porous and low strength concrete may be less susceptible to ASR induced damage as the gel products will tend to fill the porous microstructure first before they start cracking the concrete.

TESTING FOR POTENTIAL ALKALI REACTIVITY OF AGGREGATES

The assessment of concrete aggregates for potential alkali reactivity can be undertaken using a number of laboratory test procedures.

- a) **Petrographic examination:** an optical examination and analysis of the aggregate. This is undertaken to identify the types of minerals present and any suspect mineral phases. This is done using test method ASTM C295⁽⁵⁾.
- b) **VicRoads accelerated mortar bar test method RC 376.03⁽⁶⁾.** Mortar bars are stored in caustic soda solution at 80°C and expansion is monitored for the required period. The test is rapid and provides results in about 3 to 4 weeks. The average expansion should not exceed 0.1% at 21 days.
- c) **VicRoads concrete prism test method RC 376.04⁽⁷⁾.** This test is considered to be less severe on the test samples and can be used to evaluate the aggregate performance over a 12 month period. The concrete prism test is appropriate when a longer period of time is available. Concrete prisms are produced using the actual concrete aggregates, with a minimum cement and alkali content, and are stored in sealed containers at 100% relative humidity and 38°C. The length of the prisms is measured at prescribed intervals for the 12 month period. Average expansion exceeding 0.03% at one year is considered deleterious. Section 610⁽⁸⁾ states that aggregates classified as reactive by the

concrete prism test method in a concrete mix design, should not be used in that particular concrete mix design. In addition it states that alternative aggregates and/or alternative concrete mix designs should be used provided they comply with the requirements of the specification.

MINIMISING THE RISK OF ASR

There are several methods commonly used to prevent or minimise the risk of ASR. These include:

- where practical use of non-reactive aggregates,
- use of low alkali cement (i.e. less than 0.6% alkali expressed as Na²O equivalent);
- limit the total alkali content (from all sources) within the concrete mix to less than 2.8kg/m³;
- incorporate lithium salts in the concrete mix to produce a non-expansive gel product in contrast to the alkali. However, more field performance data using this method is required; and
- use of Supplementary Cementitious Materials (SCMs).

The use of SCMs as cement replacements has proven to be very effective in reducing the negative effects of ASR. SCMs reduce the availability of alkalis for expansion reactions and make the concrete more water tight. Depending on the type of aggregate and magnitude of potential reactivity the effective cement replacement levels are:

- fly ash 10% to 30%;
- slag 40% to 65%; and
- silica fume 5% to 15%

Fig. 1 demonstrates the effectiveness of fly ash in reducing ASR induced expansions.

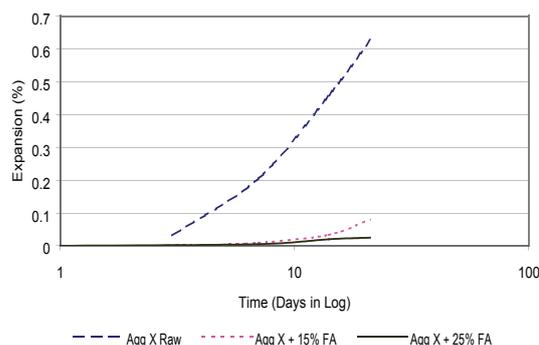


Fig. 1: Comparative Mortar Bar Expansion Results of Aggregate X with and without Fly Ash.

VICROADS SPECIFICATION REQUIREMENTS

VicRoads Concrete Specification Section 610 requires that a petrographic examination of aggregates be undertaken in accordance with ASTM C295. This is to characterise the aggregate source and to determine the presence of potentially reactive silica minerals. The specification also requires that the potential alkali silica reactivity of the coarse and fine aggregates shall be determined using either the accelerated mortar bar or the concrete prism test methods in accordance

with VicRoads test methods. For the accelerated mortar bar test, the average expansion should not exceed 0.1% at 21 days. Where potentially reactive aggregates are used, the total alkali content within the concrete mix must not exceed 2.8 kg/m³ and SCMs must be used and retested to ensure that expansion does not exceed 0.1% at 21 days. As an alternative, for a longer term evaluation of aggregates using the less aggressive concrete prism test method, the average expansion at 12 months is to be less than 0.03%, and reactive aggregates are not to be used.

MANAGEMENT OF AFFECTED STRUCTURES

ASR affected structures should be inspected on a regular basis by experienced personnel. Monitoring of cracks should be undertaken using suitable measuring devices. Concrete cores are extracted from structures and subjected to petrographic analysis by viewing thin sections with a petrographic microscope. Alternatively, a more detailed examination of polished sections of concrete can be done by scanning electron microscopy (SEM). An assessment is made of the existing and predicted level of ASR expansion to enable determination of the timing and type of remedial options. Remedial measures to prevent moisture ingress may include:

- the injection of cracks with flexible epoxy or elastomeric chemical grouts;
- the application of flexible epoxy, elastomeric acrylic or cementitious coatings; and
- silane impregnations where appropriate.

In more severe cases concrete encasement or even propping and strutting may be required.

At present there is little precedent for extensive repairs for this type of problem which will probably become increasingly evident as bridges and other concrete structures age. Bearing in mind however, that cracking and subsequent deterioration occurs in the presence of water, cracks greater than 0.3 mm in width should be chased out and filled (injected) with a suitable flexible epoxy resin to prevent further ingress of water (Fig. 2 and Fig. 3). In atmospheric or splash zones the structure should subsequently be coated with a pore-lining penetrant such as pure silane to dry it out (or in combination with acrylic top coats), a flexible urethane or epoxy coating or a suitable cementitious coating. Where cracks are less than 0.3 mm, an application with a pure silane, crack bridging or crack filling epoxy, urethane or flexible acrylic coating may be sufficient. In tidal or submerged zones flexible epoxy or urethane coatings, or polymer modified cementitious coatings may be the most appropriate. Re-application of these coatings will be required at regular intervals (in the order of 10 to 20 years depending on the type of coating and exposure conditions) until the problem is effectively controlled.

It should be noted that the repair of concrete cracks is covered by Section 687⁽⁹⁾ and the coating of concrete by Section 686⁽¹⁰⁾ and Technical Note No. 16 of this series.

Technical Note No. 38 of this series also covers cracks in concrete.

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8. *VicRoads Standard Specification Section 610 (2005), "Structural Concrete".*
9. *VicRoads Standard Specification Section 687 (2002), "Repair of Concrete Cracks".*
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Fig. 2. Cracking due to alkali aggregate reactivity and related dampness (L), Crack Injection and Application of Flexible Epoxy Coating for ASR Repairs (R)



Fig. 3. Crack Injection with Epoxy Resin for significant ASR Repairs (L), Verification of depth of penetration of epoxy injection

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