The presence of Alkali-Silica Reaction in concrete structures and damaged caused under this reaction

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ABSTRACT

The concrete structures during the life exploitations are under the severe conditions. In this way the different behavior of structures will be basic on the conditions. In this paper we will present one of the important parameter, Alkali-Silica Reaction, and the damage under this parameter in concrete components and in concrete structures. In most concrete, aggregates are more or less chemically inert. However, some aggregates react with the alkali hydroxides in concrete, causing expansion and cracking over a period of many years. This alkali-aggregate reaction has two forms: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). The failure to fallow precautions may result in progressive degradation, demanding expensive repair and improvement of concrete construction to preserve the prescribed function.

In this state-of-the-art report we will present the concept of ASR, factors involved in ASR and the means that are available to control it. Although there is extensive knowledge about the mechanisms of the reaction, the components of the aggregate that can react harmfully and precautions to be taken to avoid resulting distress, gaps still exist in common knowledge for ASR. This is partly true with respect to the applicability of test methods to identify the potential for reactivity, methods to repair affected concrete and, means to control the consequences of the reactions in existing structures.

Keywords: Concrete, aggregate, ASR; AAR; structure damages, etc.

INTRODUCTION

Aggregates such a constituent material can react with alkali hydroxides in concrete. The reactivity is potentially harmful only when it develops significant expansion [1]. Alkali-silica reaction has been recognized as a potential source of distress in concrete since the late 1930[s][2]. This alkali-aggregate reactivity (AAR) has two forms: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR, sometimes called alkali-carbonate rock reaction, or ACRR). ASR is of more concern than ACR because the occurrence of aggregates containing reactive silica minerals is more common. Therefore this article's main interest is in ASR. Alkali-reactive carbonate aggregates have a specific composition that is not very common. Alkali-silica reactivity has been recognized as a potential source of distress in concrete since the half of twentieth century. There are a number of reasons for ASR such as (1) most aggregates are chemically stable in hydraulic-cement concrete; (2) aggregates with good service records are abundant in many areas; (3) the concrete in service is dry enough to inhibit

ASR; (4) The use of certain pozzolans or slags controls ASR; (5) In many concrete mixtures, the alkali content of the concrete is low enough to control harmful ASR; (6) Some forms of ASR do not produce significant deleterious expansion.

To reduce ASR potential requires understanding the ASR mechanism; properly using tests to identify potentially reactive aggregates; and, if needed, taking steps to minimize the potential for expansion and related cracking.

1. ALKALI-SILICA REACTION

1.1   The Problem of ASR

For quality concrete is a carefully selected composition of materials which, when properly manufactured, mixed proportion , concreting, compaction, finished and cured will have sufficient strength and durability in accordance with the desired application. Although presences of alkalis in cement is important to the concrete's strength development, they can under certain circumstances, principally and directly contributory to degradation and loss of durability.

The most evident manifestations of deleterious ASR in a concrete structure are concrete cracking, displacement of structural members due to internal expansion of the concrete, and putouts. However, these features should not be used as the only indicators in the diagnosis of ASR in a concrete structure. Cracking in concrete is essentially the result of the presence of excessive tensile stress within the concrete, which can be caused by external forces such as load, or by development of a differential volume change within the concrete. Early contraction, too large thermal gradients during curing of the concrete, corrosion of embedded reinforcement, freezing and thawing, and internal and external sulfate attack are some of the mechanisms that also can lead to the formation of cracks in concrete. Diagnosing ASR-related cracking requires the additional identification of ASR reaction product in the concrete and, most importantly, requires positive indications that this product has led to the generation of tensile stresses sufficiently large that the tensile strength of the concrete was exceeded.

The worldwide costs of ASR degradation are extremely high. Regional manifestations of these costs are seen in: remedial repairs in already deteriorating structures; new construction where costs are impacted dramatically in use in imported, low-alkali cement and imported non-reactive aggregates and in the more intangible impact on structure life cycle and overall owner and user utility.

1.2   Alkali-Silica Reactivity mechanisms

The alkali-silica reaction forms a gel that swells as it draws water from the encompassing cement paste. Reaction products from ASR have a great chemical attraction with for moisture. In absorbing water, these gels can induce pressure, expansion, and cracking of the aggregate and surrounding paste. The reaction can be summarized as a two-step process: (1) Alkali plus reactive silica gel produces reaction product; (2) Gel reaction product plus moisture exposes expansion. "Gel reaction product" is the name given to the alkali silica gel formed in the first part of the two-step process. The presence of gel doesn't always coincide with distress, and thus, gel presence does not necessarily indicate destructive ASR. For alkali-silica reaction to occur, three conditions must be present: (1) reactive silica in the aggregate; (2) high-alkali (pH) pore solution; (3) sufficient moisture.

Reactive silica in the aggregate: Reactivity is a function of the type and form of constituents comprising the aggregate. Silica minerals in aggregates are generally stable if crystalline and generally reactive if amorphous, but there are exceptions. The constituent minerals of an

aggregate are incurred from a petrographic analysis [2]. The following list of rock types contains critical amounts of potentially reactive forms of silica: chert and flint containing chalcedony; acidic and intermediate volcanic rocks, such as rhyolite, dacite, latite, and andesite, and the associated porphyries and tuffs; sandstone etc.

High-alkali-content pore solution: In solution alkali hydroxides will react with reactive forms of silica in aggregate. As the aggregate reactivity increases, gel reaction products can be formed with lesser concentrations of alkali. That is why use of low-alkali cements alone may not be sufficient to control ASR with highly reactive aggregates containing minerals such as opal. As the pH, or alkalinity, of the pore solution increases, potential for the alkali-silica reaction increases. At higher concentrations of alkali hydroxides, even the more stable forms of silica are exposed to attack. If the alkali concentration is great enough, the alkali hydroxides break stronger silicon bonds found in less reactive aggregates to form the gel reaction product. This explains why aggregates thought to be nonreactive sometimes exhibit ASR. Repeated cycles of wetting and drying can create high localized concentrations of alkalies.

Sufficient moisture: Moisture allows migration of alkali ions to reaction sites and the resulting gel absorbs moisture, leading to expansion. For this reason, destructive ASR does not develop in concretes that are dry in service. Research has shown that expansive ASR can occur in concrete having humidity above 80% [3].

Wetting and drying: Dry exposures decrease potential for expansive cracking due to alkali-silica reactivity.

Temperature: Structures in warmer exposures are more susceptible to ASR than those in colder exposures because the ASR rate usually increases with increasing temperature.

2. VISUAL SYMPTOMS OF EXPANSIVE ASR

Destructive ASR expansion does not occur without reaction products. Previously proposed procedures for diagnosing ASR can be summarized as follows: (1) site inspection and testing, (2) sampling, (3) laboratory investigation, (4) evaluation, and (5) risk assessment of future reaction. Visual observation of the structure is a main step of this testing method.

Expansion: Typical indicators of ASR presence are map cracking, and in advanced cases, closed joints, spalled concrete surfaces, or relative displacements of different portions of a structure (see Fig. 4a).

Figure 1. a) Expansion, b) Cracking, c) Popouts

Cracking: Concrete deleteriously affected by expansive ASR is characterized by a network of cracks (see Fig. 4b). A visual inspection should note the location, length, width, apparent depth, and continuity of cracks, and whether the cracks go through or around the aggregate.

Pop outs: A pop out is caused by a fragment breaking out of the surface of the concrete, leaving a hole that may vary in size, but is usually 25 to 50 mm wide. (see Fig. 4c). A popout caused by expansive ASR is formed to deliver pressure created by gel just beneath the concrete surface. Locating gel at the site of a popout is a strong indication of ASR. The presence of ASR-induced popouts is not necessarily an indication of ASR distress. Popouts can also be caused without ASR by freezing and thawing of low density porous aggregate at or near the concrete surface.

Color Change (Discoloration): Surface discoloration is common in association with map cracking. Darkened or blotchy areas are often associated with ASR. Areas along cracks may be bleached, pinkish, or brownish in color, extending several millimeters (tenths of an inch) from the crack.

2.1. PREVENTING MEASURES

ASR and the subsequent expansion of concrete occur only when the following conditions are present (as documented by [5,6,7]):
1. Concrete is sufficiently humid, in service.
2. Concrete contains aggregates with siliceous constituents that are alkali-silica reactive.
3. A source of sufficient alkalies that is, sodium and potassium, is available that can: 1) raise the pH of the pore fluid by allowing more hydroxyl ions to remain in solution and 2) React with the dissolved silica to form alkali silica gel.

Strategies to prevent ASR expansion focus on controlling one or more of the three preceding conditions, that is:
1. Control the available humidity.
2. Control the type and amount of potentially reactive siliceous constituents in the aggregate, or in the concrete.
3. Lower the pH of the concrete pore fluid to decrease the solubility of the silica in it. This is done by lowering the amount of available Na_2O_e, since this will lower the pH.

2.1.1 Limiting moisture: Water in the concrete pores transports the alkali and hydroxyl ions to sites of reactive aggregates. Keeping concrete dry will reduce the potential for ASR gel to swell and cause distress. As a practical matter, this is possible only for interior concrete in buildings, or above-ground concrete in dry climates. Concrete with a low permeability will reduce ion mobility and delay the reaction [8]. Applying a coating or sealant to the concrete surface may be a viable option to reduce expansion if the concrete is not in contact with moist subgrade or other moisture source [8]. Sealants will limit the ingress of moisture and minimize swelling of ASR gel.

2.1.2. Aggregate selection: Not all aggregates are susceptible to deleterious ASR, and the problem is often reduced to choosing right one. However, avoiding ones that contain reactive elements is not an economical option. If an aggregate has potential for causing ASR distress, several beneficiation strategies could be employed [6]:
1. Decreasing the reactive silica concentration by blending reactive and non-reactive constituents may be useful.
2. Selective quarrying, although in many cases difficult to accomplish in the field, can be employed to avoid strata of rock that are identified as potentially reactive.
3. Heavy media separation or rising-current classification has been used successfully in cases where reactive material has a low density.
4. Washing and scrubbing will remove some of the reactive coatings, and possibly some of the reactive fines if this operation follows final crushing.
5. Chemical treatment of aggregate may reduce its potential for reactivity.

2.1.3. Minimizing alkalies: The commonly employed procedure to minimize the potential for deleterious ASR deterioration is to control the alkali content of concrete ingredients in order to reduce the hydroxyl ion concentration (and therefore the pH) of the concrete pore solution. Mixing water (particularly if sea or brackish water is used), some chemical admixtures (containing sodium), perhaps some sodium or potassium feldspar in aggregates, and aggregates dredged from brackish marine environments can contribute alkalies.

2.1.4. Cement selection: Studies have shown that alkalinity of the pore solution of cement pastes is related to the alkali content of the portland cement [9] and the water-cement ratio. Cements with higher alkali contents produce higher expansions with the same aggregate in mortar-bar or concrete prism tests. The alkali content of cement primarily depends on the nature of the available raw materials, and therefore the availability of low-alkali cements may be limited in some regions.

2.1.5. Finely divided materials other than portland cement: More recent research has confirmed that the use of ground granulated blast-furnace slag and pozzolanic materials like raw or calcined natural pozzolans, fly ash, rice husk ash, silica fume, and metakaolin are effective in minimizing the potential for excessive expansion of concrete due to ASR [5,8]
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2.1.6. Chemical admixtures: [10] proposed the use of lithium salts to prevent excessive expansion due to ASR. The status of more recent research developments on admixtures for ASR has been reviewed [7]. Lithium salts appear to be the most promising admixtures, although still somewhat expensive

3.   IDENTIFICATION OF POTENTIALLY REACTIVE AGGREGATE

Field performance history is the best method of evaluating the susceptibility of an aggregate to ASR. Verification can be accomplished for existing sources through inspection of concrete structures, 10 years old or older.

3.1.   Common tests to evaluate potential alkali-silica reactivity of aggregate

Several tests are commonly used (often in combination) to evaluate whether an aggregate or cement-aggregate combination is potentially deleteriously alkali-reactive.

3.2.   **Petrographic examination of aggregate:** Mineral composition is a good indicator of potential aggregate reactivity. Petrographic examination should be used as a screening method for aggregates. It gives quick results to help predict possible aggregate reactivity but can't give quantitative information about the aggregate's actual behavior in concrete. A petrographic evaluation of an aggregate sample, by an experienced petrographer, will identify potentially reactive minerals in an aggregate sample.

3.3.Mortar-bar expansion test: One of the most commonly used tests to determine whether a cement-aggregate combination is potentially alkali-silica reactive is the mortar-bar expansion test, described in ASTM C 227. The test involves molding mortar bars containing either the fine aggregate or the coarse aggregate in question and either a job cement or a reference cement of known alkali level. The mortar is placed in metal molds to fabricate a set of four mortar bars. After hardening, the four mortar bars are demolded and measured for initial length in a comparator meeting the requirements of ASTM C 490. The specimens are placed over water in containers, and the containers are sealed to maintain 100 percent relative humidity. The containers are stored at 38$^{\text{o}}$C to accelerate the effects of alkali-silica reaction.

An average length change (for the four mortar bars) greater than 0.05 percent at three months and greater than 0.10 percent at six months test age is considered by ASTM C 33 to be excessive and indicative of potentially deleterious ASR. This test is considered an accurate indicator of a highly-reactive siliceous aggregate's potential for deleterious reactivity with alkalies in concrete [11].
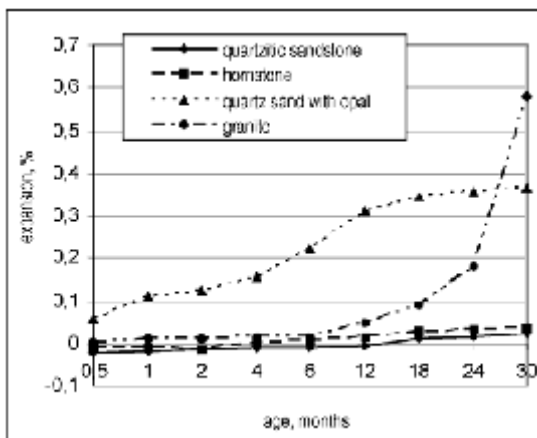

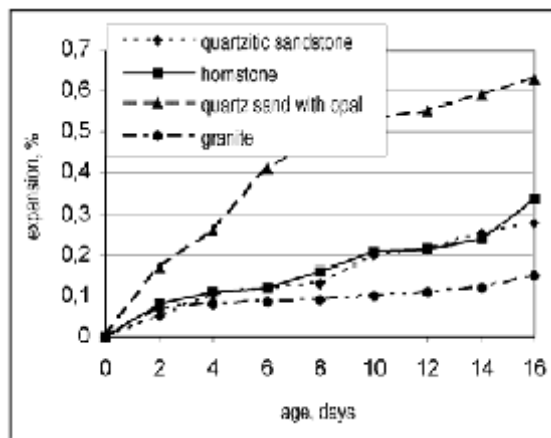Figure 2. Expansion of mortar bars (ASTM C 227 method)

Figure 3. Expansion of mortar bars (ASTM C 1260 test)

3.4.Accelerated mortar-bar expansion test: There have been recent modifications and improvements to mortar-bar expansion tests that are currently in use, such as ASTM C 1260 which is based on previously presented ASTM C 227. Although test specimen preparations are the same, in improved one the mortar bars are stored in a 1 Normal NaOH solution and maintained at a temperature of 80°C to accelerate the alkali-silica reaction. Comparator readings are taken over a period of 14 days. On the 16th day after casting, if the average expansion is less than or equal to 0.10 percent, the cement-aggregate combination is considered non-reactive. If the average expansion is greater than 0.10 percent but below 0.20 percent, the aggregate may be slowly reactive and additional confirmatory tests should be performed. If average expansion exceeds 0.20 percent, the aggregate is considered deleteriously reactive. In general, the accelerated mortar-bar test is quick, reliable, and can characterize the potential reactivity of slowly as well as rapidly reactive rock types.

3.5.Quick chemical method: The ASTM C 289 quick chemical method determines the potential ASR of an aggregate. For this method, a representative sample of the aggregate in question is crushed to pass a 300-um sieve and be retained on a 150-um sieve. The crushed material is immersed in a hot (80 ± 1.0 ^{o}C) 1N NaOH solution and is sealed for 24 hours. After 24 hours, the solution is filtered and measured for dissolved silica (Sc) and a reduction of the original hydroxide ion concentration (Rc) due to the reaction. The quantity of dissolved silica and reduction in alkalinity are plotted on a graph presented in ASTM C 289. The graph basically divides plotted points, and hence aggregates, into three categories: aggregates considered innocuous, aggregates considered potentially reactive, and aggregates considered deleterious.

3.6.Concrete prism test: The concrete prism test is similar to the mortar bar expansion test, except that it uses concrete prisms rather than mortar bars, and alkali is added to the fresh concrete mixture to reach a certain level within the concrete. The prism test has been adopted as ASTM C 1293. A cement content of 420($\pm$)10 kg/m^{3} is used for the test procedure, with a w/c (water-cement) ratio ranging from 0.42 to 0.45. Sodium hydroxide is added to the mixture water to reach an alkali level 1.25 percent Na_2O_e by mass of cement. Once demolded, the

specimens are stored in a sealed container with a water reservoir in the bottom. The container is kept at 38°C. The length of time (a year or more) to obtain definitive results for this test method will reduce its use in cases where results are required quickly. A modification of the quick chemical test developed in France is reported to permit distinguishing between those aggregates that behave normally and those that exhibit the pessimum effect in the mortar-bar test [12]. However, evaluation of this proposed modified quick chemical test has been limited.
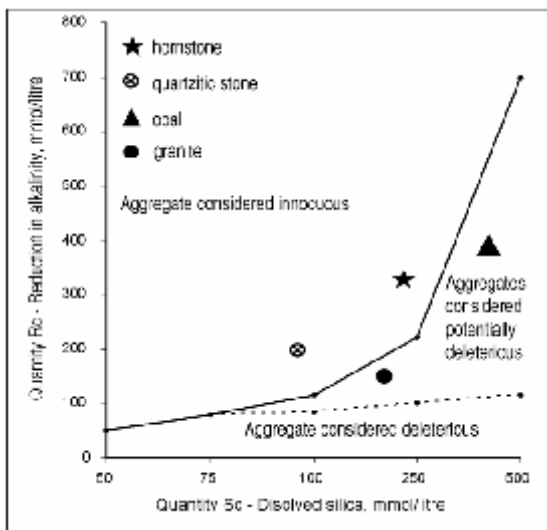

Figure 4. Illustration of division between innocuous and potentially deleterious aggregates on the basis of reduction in alkalinity test (ASTM C 289).
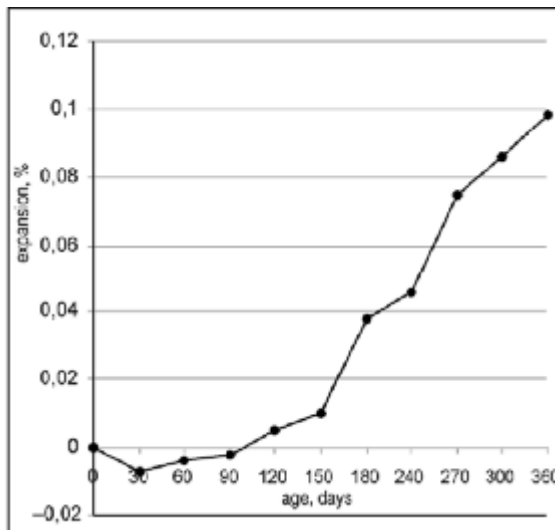

Figure 5. Expansion of concrete prism with quartzite sandstone in the ASTM C 1293 test.

3.7.Less common tests to evaluate potential alkali-silica reactivity of aggregates: Several standardized and non-standardized test methods are available to evaluate potential ASR of aggregates for instance: (1) Potential volume change of cement-aggregate combinations; (2) (3) Concrete cube test; (4) Autoclave mortar bar test; (5) Nordtest accelerated alkali-silica reactivity test; (6) Gel pat test.

4.   REPAIR METHODS AND MATERIALS

Distress in a structure or pavement that has been affected by AAR may be classified as structural or non-structural in nature. Structural distress may be manifested in excessive loss of concrete strength, distortion of structural members, or loss of structural continuity due to cracking. Repair may be possible by removal and replacement of any deteriorated concrete, epoxy resin injection of cracks, and application of a moisture-repellent coating. Non-structural distress in concrete damaged by ASR and ACR is mostly of cosmetic nature. Repair may include removal and replacement of only severely damaged concrete and application of a protective moisture-repellent coating. Wider cracks will require sealing with epoxy before coating. Some success in maintaining good surface appearance has been achieved with latex-modified cement-based coatings.

CONCLUSION

The greatest researchers in this field are form countries affected by this phenomenon as America, Australia, New Zealand, Europe, where also tests and methods for determining the reactive components, preventive measures, methods for the detection of constructions affected by ASR and main prior knowledge has been developed. From all the data and analysis presented in this paper we can conclude:

- that one of the initial factors for ASR to appear is humidity, which reacts with alkalis in cements and silica in aggregate.
- Risk of ASR to appear is evident and more frequent if aggregate is reactive; as long as the cement is controlled during the manufacturing process.
- Important factor in our circumstances can be waste water or water containing alkalis above allowed limits.
- At important structures exposed to different atmospheric conditions such as airports, dams, bridges, is important to make tests on ASR.

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