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Concrete Cancer & It's Remedies

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Abstract

Cancer is a term which we don't want to come across in our daily life, same is in case of concrete. Cancer in humans starts out as a concealed disease. When the symptoms begin to appear and we come to know about it, by that time the cancer has been already present and causing the deterioration internally. There is another analogy common between human cancer and concrete cancer that is, if detected at an initial stage and treated early, the chances of damage can be lessened. Concrete cancer is popularly known as Alkali Silica Reaction. This article provides an overview of alkali-silica reactivity (ASR) in concrete. Alkali-silica reaction is one of the most recognized deleterious phenomenon in concrete that results in excessive expansion, cracks, loss in mechanical properties and serviceability problems. In this article we have tried to explain the background, chemistry behind ASR, factors affecting ASR, and symptoms of ASR & treatment technologies.

Key Words: Alkali silica reactivity, concrete, cancer, air entrainment, petrographic analysis, cracking.

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INTRODUCTION

Concrete is the most widely-used construction material in the world. It was only due to rapid growth in world population and successive urbanization during the 20th and 21st centuries, which lead to the demand of new construction work. This inturn catalyzed the number of investigations throughout the world on cement based concrete and its characteristics so as to improve the strength and qualities of materials used in construction. Concrete consists of particles of aggregate, water, and a binding agent (cement and other cementitious materials). The reactions between aggregates and binding agents are extremely complex. Many natural aggregates contain a quantity of amorphous silica and carbonate, which both reacts with the alkalis (Na and K) of the mixture, this interaction is widely known as the alkali aggregate reaction (AAR). AAR is subdivided based on the type of mineral involved. The alkali-silica reaction (ASR) is one of the most common causes of internal concrete degradation. This chemical reaction occurs between the amorphous silica contained inside the aggregates, and the alkalis of the cement pore solution. During the reaction hydrophilic silica gel forms, which starts swelling as it absorbs water. This induces internal stresses in the concrete, which in turn cause macroscopic expansion and cracking. Due to its deleterious effects on the mechanical properties of concrete, the ASR is more commonly known as concrete cancer. The speed of the chemical degradation process of ASR is slow and, thus, the consequences in an affected structure often become visible only after many service years. The long term durability, serviceability, and the safety of the structures can be damaged by the alkali-silica reaction. A large number of researches have been conducted to investigate both the fundamental and practical aspects of ASR. It was because, many concrete structures in US built from the late 1920's to the early 1940's failed due to overall cracking throughout the structures. The destruction manifested at the concrete surface as extensive map cracking, surface pop-outs, spalling and gel exudation. From that time, it has been a subject of intense research.

There are many existing concrete structures throughout the world that are affected by ASR, to varying degrees. These structures include buildings, foundations, dams, harbor works, airport runways, other major civil works, and all forms of transportation infrastructure including pavements, bridges, tunnels, and associated structures such as sidewalks, curbs, barrier walls, and retaining walls. Thus it is very important that the management of ASR affected concrete structures should be done after proper diagnosis, prognosis and subsequent mitigation.

CHEMISTRY BEHIND ASR

The chemical reaction of ASR is a multi-stage process. The process starts with the reactive silica on the surface area of the aggregate in a high alkaline (high pH) solution. The hydroxyl ions (OH-) attack the stronger siloxane bridge (Si-O-Si) as it forms a poor crystallized silica network. The silanol bonds replace broken Siloxane bonds as shown in Equations 1 and 2.

The positively charged alkali ions, such as Na+ or K+ balance the negative charge created by the breakdown as shown in Equation 3.

$$Si–O–Si \ + \ OH \ \rightarrow \ Si–OH \ + \ OH–Si \qquad EQ\ 1$$

$$Si–OH \ + OH^{-} \rightarrow \ SiO^{-} + H_2O \qquad EQ\ 2$$

$$Si–O–Si \ + 2NaOH(KOH) \ \rightarrow \ 2\ Si – O - – Na+ (K+) \qquad EQ\ 3$$

The alkali-silica reaction produces two types of component gel non-swelling calcium-alkali silicate-hydrate [C-N(K)-S-H] and swelling alkali-silica-hydrate [N (K)-S-H] gels. When the alkali-silica reaction occurs in concrete, some nonswelling C-N (K)-S-H component are produced. The presence of non-swelling gel does not coincide with distress, and thus, does not necessarily indicate destructive ASR. Only when the both types of ASR gels form the damages due to alkali-silica reactivity only occur. The occurrence of reaction products (swelling gel) is the main diagnostic symptom of ASR. The hydrophilic alkali-silicate gel absorbs water from surroundings and increases in volume. The alkali silica gel starts expanding and exerting force against surrounding concrete. Once the expansionary pressure is larger than the tensile strength of concrete, cracks occur and lead to additional water permeation through migration and gel swelling. Extensive expansion and severe cracking are caused by high-swelling gel. The rate of the expansion depends on the chemical composition and the available alkali content of the cement matrix.

FACTORS AFFECTING ASR

Main components essential for ASR-induced damages in concrete structures are:

- Reactive silica in aggregates
- Sufficient alkalis
- Presence of moisture
- Time

Reactive Forms of Silica in Aggregates: Reactive aggregates exposed to a highly alkaline pore solution tend to break down, which creates silica. Subsequently, the reaction between alkali hydroxides and reactive silica occurs to produce ASR gel in concrete. The probable reactivity of aggregates depends on numerous factors, such as chemical composition, level of crystallinity, and solubility of the silica in alkaline (high-pH) concrete pore solution. Additionally, the aggregate’s internal grain size is inversely correlated to the surface area of the silica accessible for alkali attack. Therefore, fine aggregates are more susceptible to ASR because of their higher surface area. The porosity of the aggregate also increases the rate and ASR reactivity. The extent of ASR-related reactions is proportional to the amount of amorphous silica present in an aggregate. The reactive forms of silica include silica tetrahedron, amorphous silica, and crystalline silica. Their common sources include Shale, Opal, Cristobalite, Cherts, Trodymite, Obsidian, Chalcedony, Cryptocrystalline volcanic rocks.

Sufficient alkalis: The pores in concrete are often filled with a solution containing alkalis (Na+ , K+) and hydroxyl (OH) ions. The amount of alkalis in concrete is expressed by sodium oxide equivalent as the percent of

Na_2O plus 0.658 times the percent of K_2O. An effective way of preventing ASR-induced damages is not only to control cement alkalis, but also the total alkali content of the concrete mixture. Common sources of alkalis in concrete are the Portland cement, deicing agents and sea water. Portland cement contributes the largest amount of alkalis.

Moisture: For the ASR to start off water is an essential requirement because it acts as a transporter for alkali cations and hydroxyl ions. The gel formed during ASR absorbs more moisture which leads to development of pressure on concrete which inturn leads to expansion and cracking. Concrete mixtures involved in highly reactive aggregates and high-alkali cements have exposed little or no expansion in a dry environment. Likewise, the concrete structure with a large amount of local moisture typically results in more expansion. Reducing the permeability of concrete is also a feasible approach to decline the deleterious effects of ASR.

Time: ASR takes years to develop (usually 10 to 20 years of service) but may continue for a long time. But the rate of reaction mainly depends on the amount of reactive silica, aggregate and moisture availability. Cracks appear after variable lengths of time. Concrete swelling may be gradual or may occur suddenly at a later time.

CONSEQUENCES OF ASR

Typical indicators of ASR might be any of the following:

- A network of cracks (Surface Map Cracking)
- Large crack widths
- White rim around aggregates
- Rebar corrosion
- Buckling & spalling
- Relative displacements of different parts of a structure
- Fragments breaking out of the surface of the concrete (pop outs).

Since ASR deterioration is slow, the risk of catastrophic failure is low. However, ASR can cause serviceability problems and can exacerbate other deterioration mechanisms such as those that occur in frost, deicer, or sulphate exposures.

Typical Cracking due to Alkali- Silica Reaction: ASR cracks in reinforced concrete develop in the direction of the main reinforcing bars. Fewer cracks occur in the perpendicular direction because compressive stress is developed in the concrete as a result of restraint from expansion by the reinforcing bar. For the concrete with little/no reinforcement (i.e. at the free end of a beam or abutment, on the surface of a sea defense structures or in a concrete block, etc.), the ASR caused crack pattern is irregular or map-like.

Swelling of the Concrete due to Alkali-Silica Reaction: Alkali-silica reaction result in swelling of the concrete. The amount of swelling or expansion depends on the reactivity of the aggregates, the alkalinity of the cement solution, and the ambient moisture conditions of the structure.

TREATMENT TECHNOLOGIES:

If any one of three requirements is eliminated, ASR can be prevented. In new construction ASR is usually prevented by either selecting a non-reactive aggregate or by controlling the availability of alkali in the concrete through the use of lowalkali cement and/or the use of supplementary cementing materials (such as fly ash, slag, silica fume, or natural pozzolans). Another option for reducing the risk of damaging expansion in new concrete is through the use of lithium compounds, such as lithium nitrate. For existing ASR-affected structures, the first two requirements (sufficient alkali and reactive silica) are already present, and it is only feasible to attempt to control the supply of the third requirement (water) if the reaction is to be slowed or stopped. It may also be possible to introduce lithium into the hardened concrete and change the nature of the reaction. These are the only two remedies that are known to be able to stop or retard the reaction.

Controlling Moisture Availability: A supply of moisture is required for alkali-silica reaction to occur, which in turn causes gel to form with attendant damage due to its swelling. Ambient moisture level need not be continuous; the reaction will proceed every time the humidity rises above the 80 percent level. It is also believed that cycles of wetting and drying can cause a higher rate of damage than continuous exposure to saturated or near saturated conditions and there is some evidence to support this in existing concrete. All exposed concrete, even mixtures containing only small amounts of deleterious materials, should be considered susceptible to ASR. Concrete may only be considered non-susceptible if it can dry so the internal humidity drops below 80 percent, and thereafter is permanently protected from the weather and other sources of moisture, including heavy condensation, capillary moisture, and seepage water.

External Source of Alkalis: There are a number of sources of alkalis which might potentially raise the alkalinity of the pore solution within the concrete matrix. They attack the external faces of the concrete and reinforcement which is particularly vulnerable to these contaminants. It is doubtful that alkalis are absorbed from external sources and cause damage from ASR. However, it is important to recognize the effect of the contaminants so as not to confuse them with ASR. External sources may include sea water and de – icing salt.

Selecting Non – reactive Aggregates: A major consideration for avoiding ASR is in the selection of aggregates. This demands an accurate testing, correctly predicting the ASR reactivity of aggregates. Specific tests may be performed on specific aggregates. An examination of past records on the use of the aggregate can give useful information. However, data collected will only be of value if it relates to the use of the aggregate when combined with cement of similar alkali content and used in concrete with mixture proportions similar to those proposed for the new work. While carrying out the examination of an aggregate it must be remembered that no tests, either singly or in combination, will give a definitive indication of what the aggregate's performance will be in actual practice. Tests and other assessments can only provide the evidence to make an engineering judgment on whether to use the aggregate or not, or whether other precautions need to be taken if the aggregate is used.

Minimizing Alkalis: The most commonly used mitigation method is to control the alkali content in the concrete. Cement is the major source of alkali in concrete. Controlling the alkali content has been proved to decrease the expansions caused by ASR. A proposed limit of 0.60% has been recommended for the alkali content of the cement to be used in concrete to reduce ASR expansions. Low-alkali portland cement is recommended so that total quantity of alkalis in the concrete mixture lies below a specified limit. Mineral admixtures such as fly ash, silica fume, calcined clay should be used as they reduce the deleterious effects on concrete. The replacement of part of the Portland cement with finely ground pozzolanic materials can constitute a valid defense against alkali silica reaction. Natural and artificial pozzolans (fly ash and silica fume) were found to be effective in reducing expansion to an acceptable level due to alkali silica reaction.

Air Entrainment: This technique reduces effects of internal swelling on cracking as it provides room for ASR gel to accommodate.

Lithium compounds to Control ASR in New & Existing Concrete Structures:

Lithium compounds have proven to be effective in both new and post treating hardened concrete that has already expanded from ASR, thereby reducing or eliminating future expansion. The use of lithium compounds has been known to be effective in controlling ASR induced expansion for about 50 years. Commonly produced lithium compounds include Lithium carbonate (Li_2CO_3), lithium hydroxide (LiOH), lithium hydroxide monohydrate ($LiOH{\bullet}H_2O$), lithium chloride (LiCl), lithium fluoride (LiF), Lithium Nitrate ($LiNO_3$) and Lithium Sulphate (Li_2SO_4).

Topical Application: Topical application has been the most common method of applying lithium to ASR-affected concrete (primarily pavements and bridge decks) in recent years. It is quite clear from past topical applications of lithium that the lingering question is whether or not topical treatment of lithium leads to sufficient penetration to reduce ASR-induced damage. The potential for lithium ingress is significantly influenced by the extent of deterioration of the concrete at the time of treatment. Cracking will clearly facilitate ingress of the solution, but, if the deterioration of the concrete has proceeded too far, it may be too late to treat the affected concrete.

Electrochemical Treatment: Electrochemical techniques have been developed to remove chloride ions from reinforced concrete. This involves the application of low voltage DC electric potential to cause the migration of negatively-charged chloride anions away from steel and towards a surface-mounted anode. By making a few modifications to this system, it can be used to deliver positively-charged lithium cations into a structure. Various lithium compounds have been used to date as the electrolyte including lithium nitrate, lithium hydroxide, and lithium borate. Limited testing of bridge decks treated electrochemically have indicated that a significant quantity of lithium is absorbed from the electrolyte during treatment and that depths of penetration of at least 30 mm (1.2 in.) are possible (greater depths were not tested).

Vacuum Impregnation: Originally developed in Europe in the early 1970s, the vacuum injection/impregnation processes have been utilized in North America since the mid-1980s for the in-situ restoration of concrete, stone, and masonry structures. Under negative pressure, appropriately selected repair products and materials (e.g., lithium-based admixtures) can penetrate into the deteriorated system thus filling cracks, interconnected cracks, voids, and even micro cracks. It has been reported that the vacuum processes can actually fill cracks as fine as 5 μm (0.0002 in.) using low-viscosity resins.

INVESTIGATION FOR DIAGNOSIS OF ASR:

A reliable diagnosis can only be made after a detailed examination of the site, the records of materials and methods used in the construction and the subsequent history of the concrete, and examination of samples taken from the concrete in the laboratory. Assessment includes identification and forensic investigation.

Visual Assessment: Done on structures and on core samples. The visual signs to be looked for and studied properly include crack patterns, crack widths and flow of stresses.

Petrographic Assessment: Petrographic examination of cores extracted from the structure under investigation is a critical tool in evaluating and confirming the presence of ASR and its contribution in the damaging process of aging concrete structures. Petrographic assessment includes:

- **Scanning Electron Microscopy**: Damage and composition of reaction products is inspected at microscopic level.
- **Optic Microscopy:** Identification of reaction gel in matrix.

CONCLUSION:

- ASR in concrete is a complex chemical reaction that lowers concrete lifetime & may cause premature failure of structure. So by early detection of ASR, engineers can save millions spent in repair and rehabilitation costs and increase the service life of existing structures.
- There are many good ways to prevent ASR in new constructions.
- Mitigating ASR in existing structures is need of the hour because ASR can open the doors for other deleterious problems in concrete.
- In India much research work needs to be done so to investigate about the structures already affected by ASR. Only 2 case studies are done till date. And it’s really high time that we as engineers need to buckle up our efforts in this field.

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