

Alkali- Silica Reaction (ASR)

The alkali–silica reaction (ASR), more commonly known as "concrete cancer", is a swelling reaction that occurs over time in concrete between the highly alkaline cement paste and the reactive non-crystalline (amorphous) silica found in many common aggregates, given sufficient moisture. 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- silica reaction as shown in Fig.1.

Alkali Silica Reaction Damage in Bridge



Figure 1. Alkali- Silica Reaction

Mechanism of Reaction

Alkali-silica reaction is one of the most recognized deleterious phenomena in concrete. Various types of silica present in aggregates react with the hydroxyl ions present in the pore solution in concrete. The silica, now in solution, reacts with the sodium (Na^+) and potassium (K^+) alkalis to form a volumetrically unstable alkali silica gel. Water absorbed by the gel can be water not used in the hydration reaction of the cement, free water from rain, snowmelt, rivers, water condensed from air moisture.

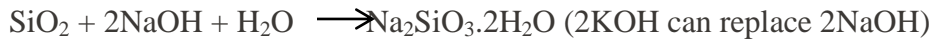
The reaction is followed by expansion / swelling of the aggregate particles due to the formation of alkali-silicate gel that absorbs water and tends to increase in volume. Since the gel is confined by

the cement paste, it builds up pressure causing expansion, due to which multidirectional cracking (map cracking) appears on surface of concrete

Adverse effect of ASR

In general, the reaction can be viewed as a two-step process:

Step 1: Silica+alkali \longrightarrow alkali-silica gel (sodium silicate)



Step 2: Gel reaction product + water \longrightarrow expansion since the gel is restrained by the surrounding mortar; an internal pressure is generated by the swelling. Once that pressure is larger than the tensile strength of the concrete, cracks occur leading to additional water migration or absorption and additional gel swelling.

Mechanism of concrete deterioration

The mechanism of ASR causing the deterioration of concrete can thus be described in four steps as follows:

1. The very basic solution (NaOH / KOH) attacks the siliceous aggregates (silicic acid dissolution at high pH), converting the poorly crystallized or amorphous silica to a soluble but very viscous alkali silicate gel (N-S-H, K-S-H).
2. The consumption of NaOH / KOH by the dissolution reaction of amorphous silica decreases the pH of the pore water of the hardened cement paste. This allows the dissolution of $\text{Ca}(\text{OH})_2$ (portandite) and increases the concentration of Ca^{2+} ions into the cement pore water. Calcium ions then react with the soluble sodium silicate gel to convert it into solid calcium silicate hydrates (C-S-H). The C-S-H forms a continuous poorly permeable coating at the external surface of the aggregate.
3. The penetrated alkaline solution (NaOH / KOH) converts the remaining siliceous minerals into bulky soluble alkali silicate gel. The resulting expansive pressure increases in the core of the aggregate.
4. The accumulated pressure cracks the aggregate and the surrounding cement paste when the pressure exceeds the tolerance of the aggregate.

Structural effects of ASR

The cracking caused by ASR can have several negative impacts on concrete, including:

1. Expansion: The swelling nature of ASR gel increases the chance of expansion in concrete elements.
2. Compressive strength: The effect of ASR on compressive strength can be minor for low expansion levels, to relatively higher degrees at larger expansion.
3. Tensile strength / Flexural capacity: Researches show that ASR cracking can significantly reduce the tensile strength of concrete; therefore reducing the flexural capacity of beams. Some research on bridge structures indicate about 85% loss of capacity as a result of ASR.
4. Modulus of elasticity/UPV: The effect of ASR on elastic properties of concrete and ultrasound pulse velocity (UPV) is very similar to tensile capacity. The modulus of elasticity is shown to be more sensitive to ASR than pulse velocity.
5. Fatigue: ASR reduces the load bearing capacity and the fatigue life of concrete.
6. Shear strength: ASR enhances the shear capacity of reinforced concrete with and without shear reinforcement.

Mitigation

ASR can be mitigated in new concrete by several complementary approaches:

1. Limit the alkali metal content of the cement. Many standards impose limits on the "Equivalent Na_2O " content of cement.
2. Limit the reactive silica content of the aggregate. Certain volcanic rocks are particularly susceptible to ASR because they contain volcanic glass (obsidian) and should not be used as aggregate. The use of calcium carbonate aggregates is sometimes envisaged as an ultimate solution to avoid any problem. However, while it may be considered as a necessary condition, it is not a sufficient one. In principle, limestone (CaCO_3) is not expected to contain a high level of silica, but it actually depends on its purity.
3. Add very fine siliceous materials to neutralize the excessive alkalinity of cement with silicic acid by deliberately provoking a controlled pozzolanic reaction at the early stage

of the cement setting. Convenient pozzolanic materials to add to the mix may be, e.g., pozzolan, silica fume, fly ash, or metakaolin. These react preferentially with the cement alkalis without formation of an expansive pressure, because siliceous minerals in fine particles convert to alkali silicate and then to calcium silicate without formation of semipermeable reaction rims.

4. Another method to reduce the ASR is to limit the external alkalis that come in contact with the system.
5. By limiting the contact of underground or meteoritic water infiltrations with the concrete structure (water tight membrane, roofing, sufficient water drainage ...).

Curative treatment

There are no curative treatments in general for ASR affected structures. Repair in damaged sections is possible, but the reaction will continue. In some cases, when a sufficient drying of thin components (walls, slabs) of a structure is possible, and is followed by the installation of a watertight membrane, the evolution of the reaction can be slow down, and sometimes stopped, because the lack of water to continue to fuel the reaction. Indeed, water plays a triple role in the alkali-silica reaction: solvent for the reaction taking place, transport medium for the dissolved species reacting, and finally also reagent consumed by the reaction itself.

Identification of alkali-silica reaction

Gel may be present in cracks and within aggregate particles. The best technique for the identification of ASR is the examination of concrete in thin section, using a petrographic microscope. Alternatively, polished sections of concrete can be examined by scanning electron microscopy (SEM); this has the advantage that the gel can be analyzed using X-ray microanalysis in order to confirm the identification beyond any doubt as shown in Fig.2.



Figure 2 Concrete thin-section, viewed with a petrographic microscope, showing a chert aggregate particle (at the right of the image) from which alkali-silica gel has extruded into adjacent cracks.

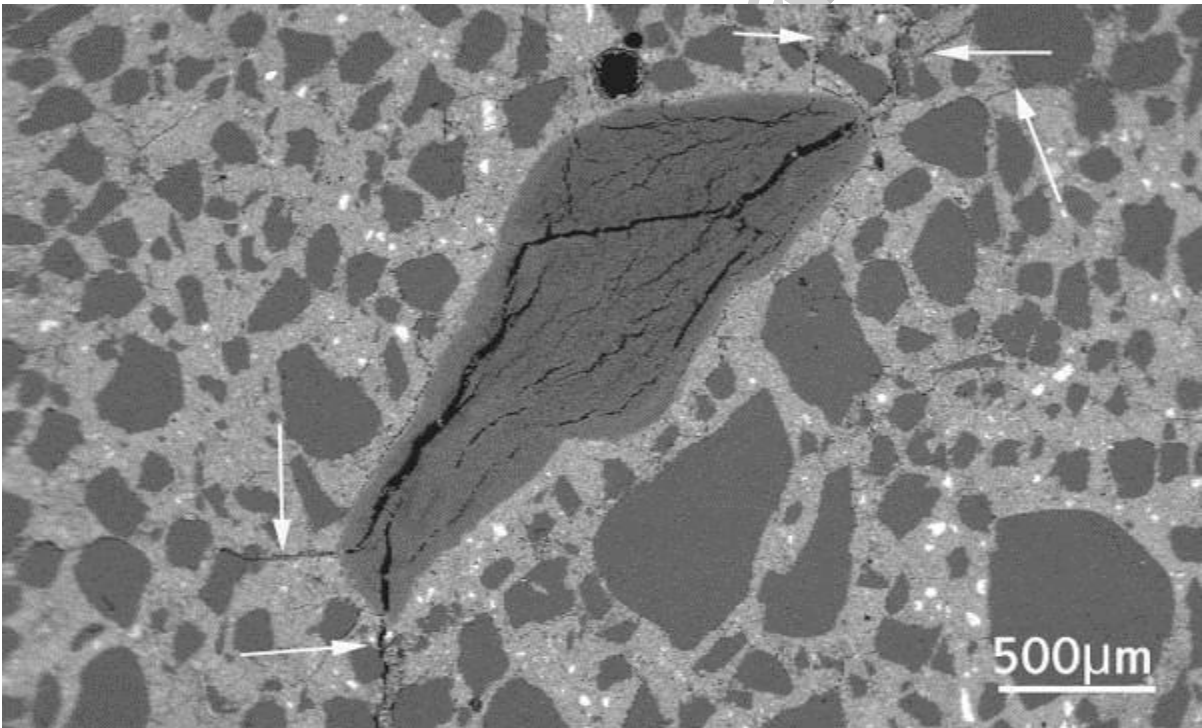


Figure 3 Polished section of concrete, scanning electron microscope image: chert aggregate particle with internal cracks due to ASR extending from the aggregate into the nearby concrete (arrowed).

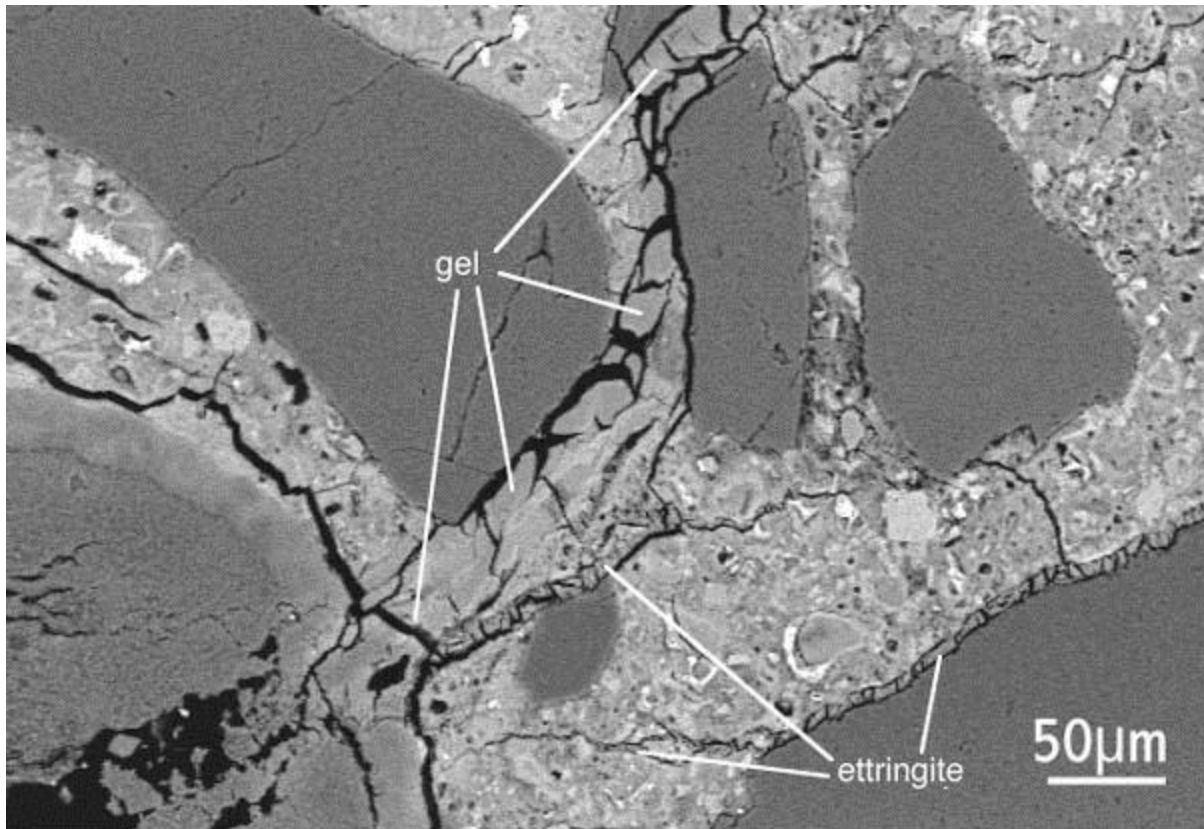


Figure 4 Detail of chert particle in previous image, showing alkali-silica gel extruded into cracks within the concrete. Ettringite is also present within some cracks.

The conditions required for ASR to occur are:

- A sufficiently high alkali content of the cement (or alkali from other sources)
- A reactive aggregate, such as chert
- Water - ASR will not occur if there is no available water in the concrete, since alkali-silica gel formation requires water.