Can Shotcrete be Affected by Alkali Silica Reaction?

By Mark Lukkarila, F.ACI

The American Concrete Institute (ACI) defines alkali-silica reaction (ASR) in ACI CT-23: ACI Concrete Terminology as "the reaction between the alkalies (sodium and potassium) in portland cement and certain siliceous rocks or minerals, such as opaline chert, strained quartz, and acidic volcanic glass, present in some aggregates."

Outward signs of ASR include pattern cracking (either longitudinal or map-type depending on restraint in the structure), closed or spalled joints, displacement, or popouts. The product of ASR is a gel that has a strong affinity for moisture and will increase in volume when it absorbs moisture, causing expansive pressures that will crack the concrete. The amount of expansion is also dependent on the ASR gel chemistry. There are three requirements for ASR to cause damage:

- A reactive form of silica
- The availability of alkali (contributed by cement, external alkali source, or some aggregates)
- Sufficient moisture. Moisture not only provides for expansion of the gel but also sustains the chemical reaction

If any one of these are missing, ASR will not occur. Cracks initiated by ASR mainly affect serviceability and may promote other modes of deterioration such as freeze-thaw damage. For instance, a concrete pool shell experiencing deleterious expansion due to ASR will likely leak over time.

Petrographic examination of concrete samples conducted in accordance with ASTM C856, Standard Practice for Petrographic Examination, will reveal evidence confirming that the concrete is experiencing ASR. Evidence from a petrographic examination, together with a thin section examination, would include fractured aggregates that disrupt the paste, gel plugs within the reactive aggregate at the interface between the reactive aggregates and the paste, copious quantities of gel exuding into cracks and into voids, and gel-soaked paste directly adjacent to the reactive aggregates. Reaction rims may also be present but must not be confused with weathering rinds, which can be common in natural gravel deposits.

Scanning electron microscopy (SEM) is a very useful tool when looking at concrete that has experienced some form of distress. A SEM uses an electron beam instead of light to produce an image. When the electron beam hits the sample, x-rays as well as primary backscatter and secondary electrons are ejected from the sample. Detectors collect the x-rays along with backscatter and secondary electrons to produce an image. Backscatter electron images display contrast produced by different elements. Energy dispersive spectroscopy (EDS) identifies the different elements present and determines quantities of individual elements. With respect to ASR, scanning electron microscopy with EDS provides a more detailed view of the gel microstructure and, more importantly, its composition.

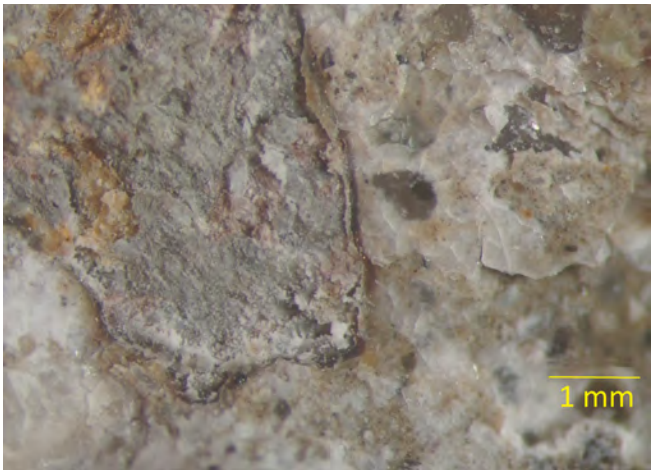

Fig. 1: Photomicrograph of a fresh fracture surface showing a reacted volcanic aggregate with rim development and ASR gel adjacent to the particle.

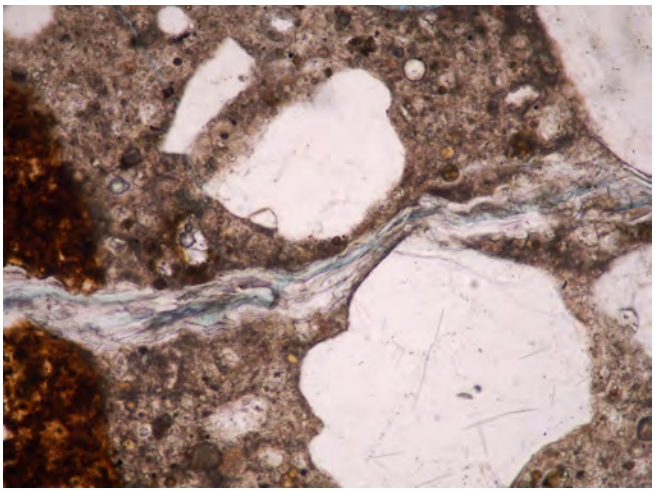

Fig. 2: Thin section photomicrograph of alkali-silica reaction of a glassy volcanic rock (on the left) with copious quantities of ASR gel completely filling the fracture that propagates through the paste.

There are several ways of reducing the impact of ASR. ASTM C1778, Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete, provides guidance on identifying the potential for ASR such as the evaluation of field history of an aggregate source. Additional guidance on evaluation of ASR potential is found in ASTM C295, Standard Guide for Petrographic Examination of Aggregates for Concrete; ASTM C1260, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method); and ASTM C1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction. ASTM C1778 also provides guidance on how to prevent ASR, such as ASTM 1567, Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method); ASTM C1293 run for 2 years to show mitigation of different combinations of cementitious materials and aggregates. One preventative measure would be to use an aggregate source that does not contain alkali-reactive rock types. However, this could be cost prohibitive because such aggregate sources would likely need to be shipped in from another geographic region. The more popular approach would be to use supplementary cementitious materials (SCMs). Testing, as outlined in ASTM C1778, should be conducted to identify the level of SCMs needed to mitigate ASR expansions.

Now let's look at ACI's definition of shotcrete. Shotcrete is defined in ACI CT-23: ACI Concrete Terminology as "concrete placed by a high-velocity pneumatic projection from a nozzle." This definition shows that shotcrete is simply a placement method of concrete. Therefore, concrete placed pneumatically at high velocity, or shotcrete, is susceptible to the same concrete deterioration mechanisms as form-and-pour concrete. This includes, but is not limited to, alkali-aggregate reaction (ASR and alkali-carbonate reaction), sulfate attack, and freeze-thaw distress.

ASR damages the internal microstructure of concrete. Microphotographs of concrete sections provide visual evidence of the impact of ASR. Below are several microphotographs of ASR in various concrete materials.

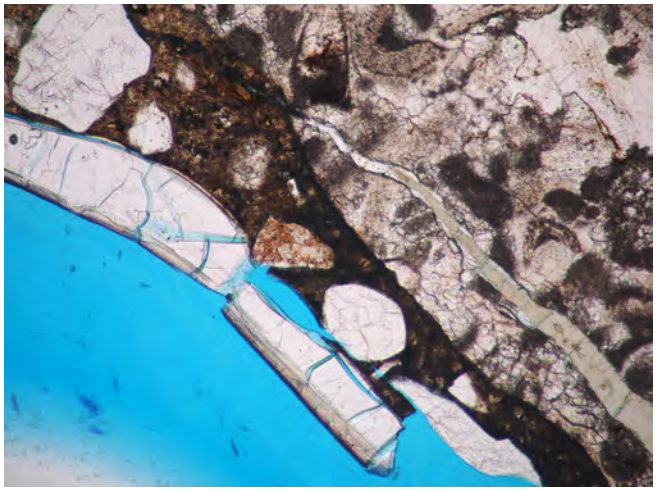

Fig. 3: Thin section photomicrograph of ASR gel lining an air void and filling a fracture within a siliceous limestone coarse aggregate particle.

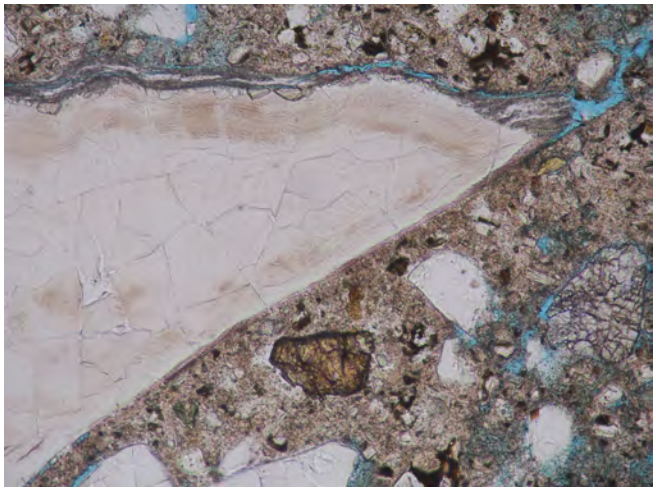

Fig. 4: Thin section photomicrograph of an ASR in a chalcedonic chert.

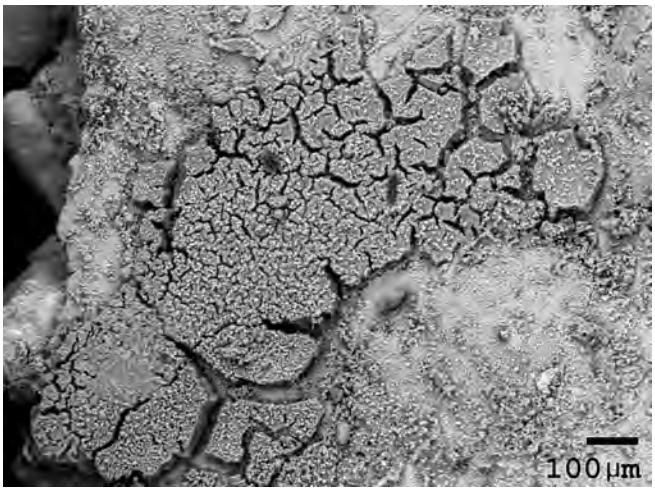

Fig. 5: Scanning electron image of ASR gel in an exposed fracture.

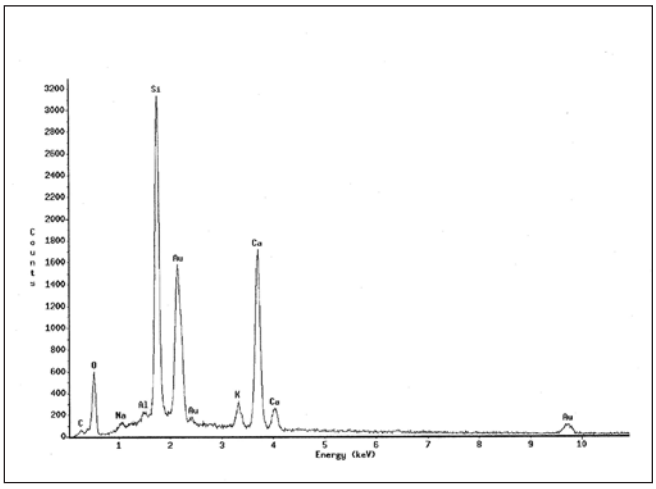

Fig. 6: Energy dispersive spectroscopy spectrum of the ASR gel shown in Fig. 5.

There are many potential causes for concrete deterioration. Often, there is more than a single factor contributing to deterioration. Internal concrete damage due to ASR has been widespread, affecting concrete in pools, tanks, and even nuclear storage casks. Conferring with a ready-mix supplier before casting concrete, and asking about ASR aggregate testing, is always recommended. Beton Consulting Engineers LLC can help identify the causes of distress and provide solutions to prevent distress for future projects.

Mark Lukkarila, *of Beton Consulting Engineers LLC, has worked as a Petrographer and Materials Scientist for over 35 years. Mark has performed petrographic examinations of concrete, aggregates, and masonry, as well as petrographic examination of historic mortars and concrete. During his career in the consulting, manufacturing, and research arenas, he also served as Research Laboratory Manager and Technical Services Director in the cement industry, as well as Technical Services Manager in the masonry industry. While in the cement industry, Mark became adept at interpreting process conditions using clinker microscopy and has gained extensive knowledge of cementitious systems, cement, and hydration chemistry. Mark's practical experience and knowledge in manufacturing, as well as performance of concrete, is the reason that he is a respected forensic investigator. Mark also has extensive experience with new product development and troubleshooting product performance, as well as process-related issues.*

Mark received a Bachelor's degree in Earth Science from the University of Minnesota Duluth. Mark is a Fellow of the American Concrete Institute (ACI). He is very active in ACI and is the current Chair of Committee 225 Hydraulic Cements, and 524 Plastering. Mark is also the Past-Chair of 221, Aggregates and Committees E701, Materials for Concrete Construction. He also serves as Secretary of ACI Committees 221, Aggregates and 225, Hydraulic Cements. He is a member of Committees 710, ACI University Programs, 240, Pozzolans, 506, Shotcrete, 524, Plastering, C621 Cement Testing Certification, and an Associate Member of 201, Durability. He is also a member of ASTM and is a voting member of C01, Cement, as well as, C12, Mortars and Grouts for Unit Masonry, and he served as the Chair of Subcommittee C09.46, Shotcrete and was the past Task Group Chair of C294/295, Aggregate Petrography.

Mark is an approved educator and examiner for ACI's shotcrete certification program. He also is ACI certified as an Aggregate Testing Technician – Level 1, Concrete Strength Testing Technician, and Concrete Field Technician-Grade 1. Mark was also an instructor for MnDOT's AggregatProduction certification classes.