Managing Structures Affected by Delayed Ettringite Formation and Alkali-Silica Reaction

by Dr. David Rothstein, DRP, a Twining Company

Delayed ettringite formation (DEF) and alkali-silica reaction (ASR) are durability mechanisms that can lead to cracking that reduces the service life of concrete structures. An overview of these mechanisms was provided in the Summer 2018 issue of *ASPIRE*®. This article will discuss how to manage structures with ASR and DEF, with an emphasis on ASR because it is far more common than DEF.

Investigating Damage

The first step in managing ASR or DEF is to identify whether a structure has been damaged. Investigations are done visually on site, using petrographic techniques, and with other laboratory methods.

Field Investigations

The starting point for all investigations is on-site visual inspection of the structure and documentation of deterioration such as cracks, deformations, displacements, joint deterioration, pop-outs, efflorescence, and discoloration of surfaces.[1] Although map or pattern cracking is a classic indicator of internal expansion, the presence of reinforcement and prestressing (pretensioning or post-tensioning) forces can influence cracking patterns, making them more linear and aligned. The concrete should be sampled for petrographic examination, and the samples should represent a suite of different conditions ranging from cracked to intact. Other samples may be collected to test compressive strength, splitting tensile strength, and other engineering properties that may be of interest for evaluating performance.

Petrographic Investigations

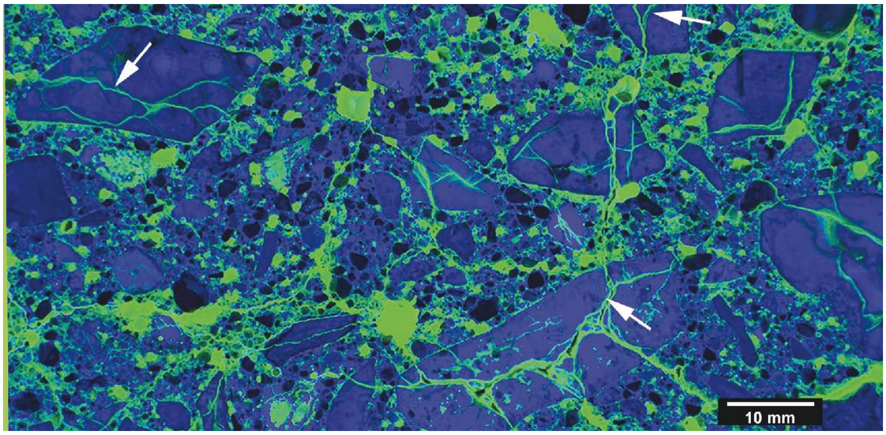
When damage is observed in the field, petrographic examination is used to determine whether there is evidence of internal expansion. An experienced petrographer can determine if internal expansion from ASR is occurring and whether it is linked to macroscopic cracking. In many structures, cracks observed in the field are from early-age mechanisms such as drying shrinkage rather than ASR. Early-age cracks tend to cut orthogonally to exposed surfaces and to cut around aggregate particles. They also lack secondary deposits. In contrast, cracks caused by DEF or ASR contain significant deposits of ettringite or ASR gel, respectively. When internal expansion progresses to the point of visible cracking, a petrographer will see microcracks filled with gel or ettringite that coalesce and feed into macroscopic cracks.

Petrographers can categorize the severity of ASR qualitatively or quantitatively. In qualitative rankings, severe ASR is indicated by clear evidence of macroscopic cracking; moderate ASR by the presence of associated microcracks; and minor ASR by the presence of gel without cracks or microcracks. Quantitative methods include the Damage Rating Index (DRI), which assigns numerical "scores" to indicate the degree of damage.[2] There is no standardized threshold score to indicate a particular level of damage, but the DRI can nevertheless be a useful tool to compare different parts of a structure or assess the same parts of a structure at different times.

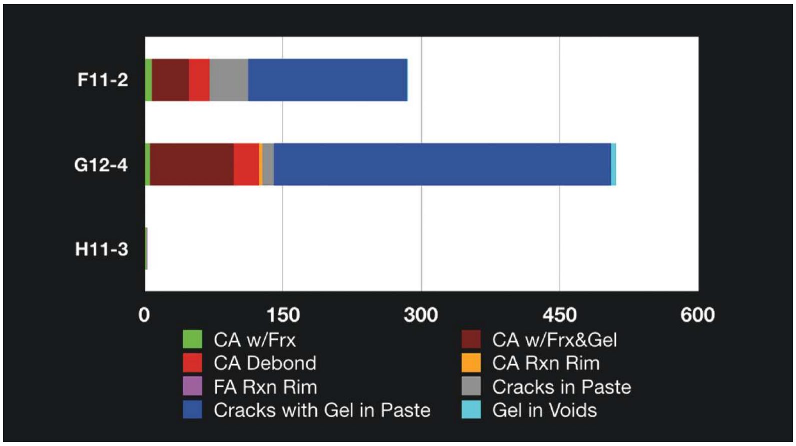
Other Laboratory Investigations

Determining the chemical composition of the gel may help investigators understand whether the ASR is at an early or late stage.[3] Other laboratory tests can help determine the likelihood that ASR will cause continued expansion. For example, residual expansion tests can be used to monitor cores for length change

Photograph of map cracking on concrete pavement affected by alkali-silica reaction. All Photos and Figures: Dr. David Rothstein.



Ultraviolet light photograph of polished slab from a concrete core affected by alkali-silica reaction. The core was impregnated with a fluorescent epoxy. The yellow-green areas are filled with the epoxy. The white arrows indicate examples of cracks.



Summary diagram of Damage Rating Index (DRI) results, showing how the method documents variations in the amount of damage. The bar chart summarizes the amount of distress associated with different indicators of distress associated with alkali-silica reaction (ASR). An entire bar represents a total DRI score, with higher numbers indicating more damage. The different colors within a bar indicate the different forms of damage that contribute to the total score. F11-2 and G12-4 show extensive damage, primarily associated with cracks with gel in the paste, and H11-3 shows essentially no damage. Abbreviations are as follows: CA, coarse aggregate; FA, fine aggregate; Frx, fracture; Rxn, reaction.

under controlled conditions.[4] Measuring the water-soluble alkali content of the concrete can show whether alkali in the system is sufficient to sustain ASR. Remember that in cases where concrete is exposed to deicing salts, the alkali content of the concrete can increase over time because of the ingress of the salts.[5]

Managing the Structure

Once ASR is identified as a concern, the appropriate approach to manage it depends on the severity of the ASR and the potential for future expansion. The first option is to simply monitor the structure by conducting field inspections at regular intervals. Crack index maps and strain gauges can be used to determine if cracks are growing. Also, additional cores can be extracted to be examined petrographically (DRI works well for this) and compared to cores evaluated previously.

If remediation is needed, several approaches are available. The most viable strategy for slowing or stopping the progression of ASR is to cut off the water that feeds it. Studies have shown that an internal relative humidity (RH) of 80% to 85% is essential to sustain ASR in concrete.[6] Often, the first step in keeping concrete elements below this RH threshold involves repairing or modifying drainage systems to redirect water flows away from and out of structures. Waterproofing membranes, filling cracks and construction joints with appropriate materials, and applying sealers or other surface treatments may be adequate. Coatings that permit water vapor to escape are preferred because they will facilitate the drying of the structure. In some cases, sealers that do not allow the structure to breathe can make ASR worse because they trap moisture entering from untreated surfaces. Topical applications of lithium-based compounds have been used with mixed results to arrest the progression of ASR. A major concern with such materials is the depth of penetration, which may be negligible in some cases.

Other measures to prolong the serviceability of structures affected by ASR may include structural repairs such as external post-tensioning, use of carbon- or glass-fiber wraps, or other methods to provide physical restraint. In cases where there is significant damage, cutting expansion joints or removing areas around damaged joints may reduce stress. However, such measures are only temporary, and they do not mitigate future expansion.

Conclusion

The diagnosis of ASR or DEF in a structure does not necessarily mean that immediate removal, replacement, or even repair is required. It is essential to conduct careful field and petrographic investigations of the structure to obtain an understanding of the severity of the problem. In most cases, it is prudent to implement field-based programs to monitor and evaluate the behavior of the structure over time. Preventing the ingress of water remains the most effective method to mitigate ASR in structures. In cases where damage is significant, structural repairs may be necessary. In all cases, experienced engineers, petrographers, and contractors should be engaged to ensure that the proper strategies and methods for this work are deployed.

References

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Dr. David Rothstein is the president and principal petrographer of DRP, a Twining Company, in Boulder, Colo.