

Concrete in Practice

What, why & how?



CIP 43 — Alkali Aggregate Reactions (AAR)

WHAT is Alkali Aggregate Reactivity?

AAR results in deleterious expansive cracking of concrete occurring at later ages after construction. While mostly inert, some concrete aggregates, can react in the highly alkaline environment in concrete resulting in internal expansion that causes deleterious cracking. Alkalis include sodium and potassium that are minor constituents in portland cement but can be from other concrete ingredients or from external sources. Expansion due to AAR is a slow process and results in visible deterioration 10 to 15 years after the concrete structure has been built. In rare cases deterioration at earlier ages may be observed.

Two forms of alkali aggregate reactions are recognized:

Alkali carbonate reactions (ACR) occur with dolomitic limestone aggregate of a specific mineralogy and microstructure. Sources of these aggregates is relatively rare. ACR is typically a more aggressive reaction and occurs earlier in the life of the structure.

Alkali silica reactions (ASR) occur with certain forms of silica (SiO_2) minerals in aggregates that react in a high alkaline (pH) medium in concrete creating an expansive gel. The gel expands by absorbing moisture that causes the expansion of concrete and subsequent damage. Three conditions are required for deleterious ASR to occur:

1. reactive forms of silica in aggregate,
2. high alkali pore solution (pH) in concrete, and
3. presence of moisture.

WHY is AAR a Concern?

Deterioration to concrete structures due to AAR does not generally result in catastrophic failures. Where dimensional stability is important, such as in dams, the expansions can impact the functioning of the structure. In most cases, synergy with other deterioration processes like cycles of freezing and thawing and corrosion of reinforcement exacerbates the rate of deterioration of concrete structures. ASR in concrete pavements and transportation infrastructure can result in spalling of cracked sections. Moisture, additional alkalis from deicing salts, and traffic loading accelerate the process.

HOW is the Potential for AAR Determined?

Aggregates with a distinct mineralogy of dolomite crystals embedded in a clay matrix cause ACR. A qualified petrographer can identify this. Quarries in North America where these aggregates occur are known and their use in hydraulic cement concrete is avoided. Test methods for



ASR Cracking and Expansion in Sidewalk

determining potential for ACR include a rock cylinder expansion test, ASTM C586 and an expansion test of concrete prisms, ASTM C1105.

Cases of ASR have been noted in most areas in North America. Existing signs of ASR in concrete structures in a region is the most definitive way of establishing that the problem exists. A petrographic evaluation of an aggregate source, ASTM C295, can identify potentially reactive silica minerals in aggregates but will not definitively establish whether an ASR problem will occur when the aggregate is used in concrete.

The more reliable test method that has been correlated to actual deterioration in field structures or field-exposed test specimens is an expansion test using concrete prisms, ASTM C1293. This test requires a one-year period and may not be conducive to project schedules if not conducted ahead of time. Aggregates are considered to be potentially reactive when the expansion exceeds 0.04% at 12 months.

A more common test is an accelerated mortar bar expansion test, ASTM C1260. This test provides a result in about 2 weeks. Aggregates are considered potentially reactive when the expansion exceeds 0.20% (ASTM C33). Many agencies, however, use an expansion criterion of 0.10% at 14 days. ASTM C1260 is an aggressive test and aggregates that do not cause deleterious ASR reactions in the field are often characterized as reactive by the test. It is recommended that ASTM C1260 results should be supplemented with other information in determining the potential reactivity of an aggregate source.

Other test methods, like the quick chemical test, ASTM C289 and a longer term mortar bar expansion test, ASTM C227 are not considered to be reliable.

The Appendix of ASTM C33, *Specification for Concrete Aggregates*, provides guidance on AAR test methods, criteria and mitigation methods.

HOW is AAR Avoided?

There are no recommended methods of preventing deleterious expansion when the available aggregate source has been verified to be ACR reactive. The only recourse is to use an alternative source of aggregate.

For deleterious ASR expansion to occur the three factors discussed before are required: alkalis, reactive silica and exposure to moisture. Concrete that remains dry inside buildings and not in contact with soil will typically not need preventive measures. In other situations various strategies can be used to avoid damage due to ASR.

One option is to avoid the use of aggregate sources that are determined to be reactive. This may not be feasible because alternative non-reactive aggregates may not be economically available or data may not exist as to their potential performance.

Another option is the use of a low alkali cement, typically characterized as one with $\text{Na}_2\text{O}_{\text{eq}}$ less than 0.60%. Low alkali cement, however, is not available in many regions. Alternatively, limiting the total alkali content in concrete is often considered a better option. Only the alkali from portland cement is considered. The total alkali content in concrete is determined by multiplying the cement content by the alkali content. Concrete alkali content is typically limited to a 5.0 lb/yd³ (3.0 kg/m³) or lower for more critical structures, like in concrete dams. With this option — low alkali cement or low concrete alkali content — it should be recognized that alkali concentrations can build up in concrete during service conditions from exposure to external sources like deicing chemicals and sea water, or from migration of alkalis within concrete due to drying.

The more accepted option to mitigate deleterious ASR is to incorporate a supplementary cementitious materials (SCM) in concrete. SCM include fly ash, natural pozzolan, slag cement, or silica fume. SCMs bind alkalis in the hydration products and prevents the deleterious expansion from occurring. One exception is fly ashes that have calcium oxide contents greater than 20%, typically characterized as Class C fly ash. Class C fly ashes typically need higher dosage levels to mitigate the reaction.

The quantity of SCM required will depend on the reactivity of the aggregate, the alkali loading in the concrete, the type of SCM and the exposure of the concrete to external sources of alkalis. In many regions historically established SCM contents required to mitigate ASR are used and work well. Alternatively, the effectiveness of an SCM can be evaluated by testing. The SCM contents evaluated should cover a range typical of those proposed for construction. The more common test methods are ASTM C441, ASTM C1293, and ASTM C1567. These test methods accelerate the reaction either by using highly reactive artificial aggregates, elevating

the alkali loading in the test mixture, exposure to highly alkaline solutions, use of elevated temperature, or some combination thereof. The concrete prism test, ASTM C1293 is performed for a 2-year period at which point the expansion should be less than 0.04%. This tends to be too long for typical project submittals. More commonly SCMs are evaluated using ASTM C1567 with a 14-day expansion criterion of 0.10%. Research supports that these methods provide a conservative estimate of the quantity of SCM needed to mitigate ASR in concrete. Regardless of the process used to establish the minimum SCM content required, the impact on other project requirements for concrete must be considered. These include, but are not limited to setting time, bleeding characteristics, workability, and early and later age strength development.

Chemical admixtures, primarily lithium nitrate, have been shown to be effective to mitigate deleterious ASR. Manufacturer recommendations should be sought to establish effective dosage levels for specific concrete mixtures. The Corps of Engineers method CRD-C 662 is referenced to evaluate the effectiveness of the lithium admixture dosage. In some cases, combinations of these options such as the use of SCM and lithium admixtures have proven successful.

Because test methods accelerate the reaction, none evaluate potential for deleterious ASR of the actual composition of concrete mixtures proposed for projects. No test evaluates the effectiveness of the alkali content of portland cement. Test methods evaluate single aggregate sources. When the fine and coarse aggregates are determined to be reactive, the dosage of SCM that mitigates the more reactive aggregate should be used.

AASHTO PP65 provides a step by step method for evaluating aggregates and a prescriptive and performance-based methodology to minimize the potential for damage in field concrete. The methodology requires consideration of the risk level for the occurrence of ASR in structure to establish preventative measures.

References

1. ACI 221.1R, 2008, Report on Alkali-Aggregate Reactivity, ACI Manual of Concrete Practice, ACI, Farmington Hills, MI, www.concrete.org
 2. Guide and Guide Specification for Concrete subject to Alkali Silica Reaction, Portland Cement Association, Skokie, IL, IS413.02 and IS417.07 www.cement.org.
 3. ASTM Standards referenced, *Annual Book of ASTM Standards*, Volume 4.02, ASTM International, West Conshohocken, Pennsylvania, www.astm.org
 4. AASHTO PP 65-10 Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction, AASHTO, Washington DC, www.aashto.org
 5. Resources on ASR from Federal Highway Administration—www.fhwa.dot.gov/pavement/concrete/asr/resources
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