

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. exposure of concrete to 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, 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

ACR is caused by aggregates with a distinct mineralogy of dolomite crystals embedded in a clay matrix. 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 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 deterioration in field structures is an expansion test using concrete prisms, ASTM C1293. This test requires a one-year period and may not be conducive to project schedule if aggregate has not been previously tested. Aggregates are potentially reactive if the expansion exceeds 0.04% at 12 months.

The accelerated mortar bar expansion test, ASTM C1260 and AASHTO T 303, provides a result in about 2 weeks and is more common. Aggregates are potentially reactive when the expansion exceeds 0.10%. This test method is aggressive and can characterize aggregates that are non-reactive as potentially reactive. A few aggregate types that are reactive test to be non-reactive. ASTM C1260 results should be supplemented with field service, petrographic evaluation, or an ASTM C1293 test result in determining the potential reactivity of a source.

AASHTO T 380 is a miniature concrete prism test that provides results in a shorter timeframe than ASTM C1293 using different expansion criteria.

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

AASHTO R 80 and ASTM C1778 provide guidance on determining the potential reactivity of aggregates.

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. These aggregate should not be used in concrete.

Three conditions, discussed earlier, are required for deleterious cracking due to ASR. Concrete that will be dry in service and not in contact with soil will typically not need preventive measures.

Prohibiting a potentially reactive aggregate from use in concrete is typically not a prudent approach because alternative non-reactive aggregates may not be economically available in the region.

The potential for deleterious ASR can be minimized by limiting the total alkali content in concrete. Only the alkali from portland cement is considered in this determination. This is accomplished by using a cement with a lower alkali content and/or reducing the cement content in the mixture. 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 where damage affects service conditions and repair is expensive. Alkali concentration can increase in concrete from exposure to external sources like deicing chemicals and sea water, or from migration of alkalis within concrete due to drying. A low alkali cement does not minimize the risk for ASR if cement content is high.

The common option to mitigate deleterious ASR is to incorporate supplementary cementitious materials (SCM) in concrete. SCM include fly ash, natural pozzolans, slag cement, or silica fume. SCMs bind alkalis in the hydration products and prevents the deleterious expansion from occurring. However, fly ash with calcium oxide contents greater than 18%, typically characterized as Class C fly ash are generally not effective for mitigation but some are effective if used at higher dosage levels.

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. In many regions historically established SCM contents required to mitigate ASR are used and work well. Alternatively, the effectiveness of an SCM and the quantity needed can be evaluated by testing. The SCM contents evaluated should cover a range that would be typical for most concrete used in structures. The more common evaluation methods include ASTM C1293 and ASTM C1567. These test methods accelerate the reaction by 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 equal to or less than 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 rate of strength gain.

Chemical admixtures, primarily lithium nitrate, have been shown to be effective to mitigate deleterious ASR. Suppliers of these admixtures provide guidance on establishing 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. Lithium admixtures are used only if other methods of mitigation are not effective or available locally. Combinations of options such as the use of SCM and lithium admixtures have proven successful.

Because test methods accelerate the reaction, none evaluate the potential for deleterious ASR of the actual composition of concrete mixtures proposed for projects. No test method evaluates the effectiveness of the alkali content of portland cement or of concrete. 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 R 80 and ASTM C1778 provide 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 the structure to establish preventative measures.

ACI 318 requires the designer to address AAR for structural members assigned to Exposure Classes W1 and W2 (in contact with water). ACI 301 specification includes the following options (summarized) for AAR:

- Aggregates tested for potential ACR should not be used
- Use non reactive aggregate - ASTM C1293 < 0.04%
- For reactive aggregate:
 - * ASTM C1567 expansion ≤ 0.10%
 - * Max limit on concrete alkali at 4 lb/yd³ or 3 lb/yd³, depending on the C1293 expansion (reactivity level)

References

1. ACI 221.1R, ACI 201.2R, ACI 301, ACI 318, American Concrete Institute, Farmington Hills, MI, www.concrete.org
2. ASTM Standards referenced, *Annual Book of ASTM Standards*, Volume 04.02, ASTM International, West Conshohocken, Pennsylvania, www.astm.org
3. AASHTO R 80, AASHTO T 303, AASHTO T 380, AASHTO, Washington DC, www.aashto.org
4. Resources on ASR from Federal Highway Administration—www.fhwa.dot.gov/pavement/concrete/asr/resources

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66 Canal Center Plaza, Ste. 250, Alexandria VA 22314 • www.nrmca.org

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