



TECHNICAL NOTE

TECH NOTE NO: 27
TITLE: Alkali Silica Reaction in Concrete
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DATE/REV: 12/21/06

Introduction

In order to provide long service life for Portland cement concrete pavements, it is important to select materials that assure durability. Aggregates are generally selected based on physical characteristics such as grading, particle shape, hardness, density, and cleanliness. However, attention must also be paid to chemical and mineral composition because not all aggregate components are stable in concrete. A key chemical reaction between hydrating cement and aggregate is the alkali silica reaction. It produces expansion and cracking and leads to reduction in strength and early failure of the concrete.

Features of Reaction

Alkali-silica reaction (ASR) is a chemical reaction between alkali ions (Na^+ and K^+) and hydroxide ions (OH^-) in the concrete pore solution, generally derived from the portland cement, and silica (SiO_2), generally occurring in the aggregate. The reaction produces a hydrous alkali-silica gel. Formation of the gel alone does not cause cracking, rather cracking occurs when the gel adsorbs water and swells. The swelling causes expansion. It often results in pressures greater than the concrete can withstand and so produces cracks in the concrete.

Reactive aggregates, which can exist anywhere in the country, contain non-crystalline or poorly crystalline silica. The classical example is silica glass, often found in volcanic rocks such as rhyolite. Other examples are opal and chalcedony, often found in such sedimentary rocks such as chert, flint, and shale, and sometimes as minor constituents in otherwise innocuous rocks like limestone. A third example is quartz that has been crystallographically strained, often found in metamorphic rocks like gneiss, schist, graywacke, and quartzite.

A complicating feature of ASR is that the reaction is often quite slow, such that expansion and cracking are not observed for many years. Therefore, the reaction must be accelerated in laboratory tests.

An interesting feature of ASR is that expansion, which depends on the amount of reactive silica in the aggregate, usually shows a maximum value at some intermediate proportion of the reactive silica. At low levels of reactive silica increasing the amount increases the expansion, but at some amount the expansion peaks, and at high levels of reactive silica increasing the amount decreases the expansion. This is termed a pessimum effect, because expansion is greatest, or pessimum, at this intermediate proportion of reactive silica. For some reactive constituents (e.g., opal) the pessimum occurs at a very low proportion, perhaps only a few per cent, and decreases sharply at higher levels. For other reactive constituents (e.g., chert) the pessimum occurs at around 50% and decreases only gradually at higher levels. Glass does not usually show a pessimum, expansion increases even up to 100% glass.

A similar feature is observed with particle size of the reactive aggregate. Large sized particles (say, centimeters in diameter) are slow to react and produce little expansion, at least at early ages. Crushing the same material to sand size (millimeters in diameter) speeds up the reaction and produces more expansion at early ages. Grinding the same material to a powder (micrometers in diameter) fundamentally changes the chemical reaction, producing calcium silicate hydrate (a normal hydration product of portland cement), which has little tendency to adsorb water and swell, instead of alkali silica gel, so expansion is reduced. Materials that are reactive as sands are pozzolanic as powders.

Aggregate reactivity depends directly on the alkalinity (typically expressed as pH) of the solution in the concrete pores. This alkalinity generally primarily reflects the level of water-soluble alkalis (sodium and potassium) in the concrete. As noted previously, these alkalis are typically derived from the Portland cement.

Recognizing Reactive Aggregate

In order to prevent this damage, it is essential to recognize aggregates that have the potential to react in this manner. A simple way to prevent damage due to ASR is to recognize and avoid reactive aggregate. The American Society for Testing and Materials (ASTM) has approved developed several standard test methods to evaluate aggregates. Some of the test procedures are quick (1 day to 2 weeks), while one is quite long (1 year). The more important methods are discussed here.

The most rapid method is the ASTM Standard Test Method for Potential alkali-Silica Reactivity of Aggregates (Chemical Method) (C 289). Aggregates in the form of sands are mixed with concentrated (1 N) sodium hydroxide solution and stored at 1 day at 80°C for 1 day. The mixture is filtered and the solution is analyzed chemically for concentration of silica and hydroxide ion. Depending on the concentration of these species, the aggregate is considered to be deleteriously reactive, potentially reactive, or innocuous. Innocuous aggregates show either little or no reduction in alkalinity or a very high reduction in alkalinity accompanied by little silica dissolution. This test is generally recognized to provide erroneous conclusions with some aggregates, and research is underway at the University of Illinois to find modifications that improve its reliability.

Probably most widely used is the ASTM Standard Test Method for Potential alkali Reactivity of Aggregates (Mortar Bar Method) (C 1260). This method is used to test combinations of aggregate and cement. Aggregates in the form of sands are used to

prepare mortar bars. The bars are stored in a concentrated (1 N) sodium hydroxide solution at 80°C for two weeks and removed for measurement of length changes using a dial gauge designed for this purpose. Expansion less than 0.10% is generally considered to be innocuous, expansion between 0.10% and 0.20% is potentially innocuous, and expansion greater than 0.30% is potentially deleterious.

A concrete test, ASTM Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction (C 1293), is often used to verify results of the rapid tests. Concrete prisms are stored in a humid environment at 37.8°C for one year and removed for measurement of length changes using a dial gauge. Expansion less than 0.04% is generally considered to be innocuous and any greater expansion is potentially deleterious.

Mitigation

If reactive aggregate is to be used in concrete without damage due to ASR, it is necessary either to limit the alkali level in the concrete or to use admixtures that mitigate the expansion. Use of a low-alkali cement (<0.6% total alkali) is often sufficient to prevent damage. If a low-alkali cement is not available in the market area or if additional mitigation is desired, then it is necessary to use chemical or mineral admixtures. Potential admixtures must be tested to determine their effectiveness and dosage.

Mineral admixtures are known to be effective ways to mitigate ASR expansion. These materials include fly ash; ground, granulated, blast-furnace slag; metakaolin; and silica fume.

Fly ash is categorized as either Class F or C, according to its SiO₂ content (Class C is also higher in CaO and Class F is lower). Class F fly ash is better at mitigating ASR, and Class C fly ash may even adversely affect the reaction. Fly ash mitigates ASR mainly by producing calcium silicate hydrate that complexes alkali in the pore solution and thereby reduces the pH. Silica fume mitigates ASR in much the same way.

Slag mitigates ASR by creating calcium aluminosilicate hydrate that both reduces diffusion of alkali and water to aggregate reaction sites and complexes alkali in the pore solution as noted above. Metakaolin mitigates ASR in much the same way.

The use of a chemical admixture containing lithium is also considered to be a promising way to mitigate ASR expansion. The most common admixture is lithium nitrate. It can be added to new concrete or applied to existing concrete. With addition of lithium, ASR gel forms but is not deleteriously expansive. The mechanism by which lithium-based admixtures prevent expansion is not well understood.

As noted previously, potential admixtures must be tested to determine their effectiveness at reducing expansion and to assess the required admixture dosage. A new standard test method has been developed to test for mitigation by mineral admixtures in combination with aggregate and cement, Standard Test Method for Determining the Potential alkali-Silica Reactivity of Combinations of Cementitious materials and Aggregates (Accelerated Mortar-Bar Method) (C 1567). This test procedure is the same as C 1260, described previously for testing aggregate. When using C 1567, the combination of mineral admixture, aggregate, and cement must yield an expansion less than 0.10% in order for the admixture to be used as an effective mitigation.

There is currently no standard test or specification for lithium-based admixtures.

Illinois Specifications

Recent developments have led more states departments of transportation to initiate ASR specifications for concrete pavements. Since ASR is such a complicated chemical reaction, testing must be done for each aggregate and admixture combination for every project due to material variance. One can not just state that putting fly ash in the concrete will mitigate ASR, it is necessary to test combinations of fly ash and aggregate to see if the combination is innocuous. Natural sands can be blended with manufactured sands in accordance with grading specifications and the blend tested to determine whether the resulting sand is innocuous. Coarse aggregates must also be tested and can be crushed to be tested in mortar.

The state of Illinois Department of Transportation (IDOT) does not currently have a specification for ASR, but has developed a special provision for use on specific projects that may eventually become a specification for the entire state. The IDOT Bureau of Materials continues to hold discussions of the IDOT ASR plan.

The special provision was developed for the I-74 project near Peoria, which exhibits evidence of ASR affected concrete. It is currently being used only in projects across the state with 40-year design lives. Generally IDOT has concluded that ASR is less likely in the Chicago area because the materials available to that market are less reactive, but acknowledges that ASR it must be considered when designing durable pavement.

As an example, District 1 is using a concrete mix on the Dan Ryan project that contains GGBFS instead of fly ash. This is because there are few Class F fly ashes available in the Chicago market and GGBFS is readily available.

The special provision uses ASTM C 1260 for testing aggregates. It divides fine aggregates into three categories: expansion less than 0.10%, expansion between 0.10% and 0.20%, and expansion between 0.20% and 0.30%. It divides coarse aggregate into two categories: expansion is less than 0.10% and expansion greater than 0.10% but less than 0.20%. No mitigation is required for aggregate whose expansion is less than 0.10%. Mitigation is required for aggregates whose expansion is greater than 0.10%. Aggregate may not be used whose expansion is greater than 0.30%. Mitigating procedures must be shown by ASTM C 1567 to produce expansion less than 0.10%.

IDOT is developing a list of approved fine aggregate sources similar to their Freeze Thaw Rating list for coarse aggregates. When completed, this list will be published on the IDOT web site (<http://dot.state.il.us/materials/research/materialslist.html>).