

## Using Advanced Lithium Technology to Combat ASR in Concrete

BY NICHOLAS ADAMS AND DAVID B. STOKES

**A**lkali-silica reaction (ASR) can cause premature deterioration of concrete highways, runways, bridges, parking lots, garages, and other structures. The expense to repair and replace this deteriorated concrete is borne by governments, port authorities, private and public property owners, and ultimately consumers, through taxation and the cost of goods.

Various highway and transportation organizations, including a large number of local agencies involved with bridges, highways and aviation facilities, have joined with concrete producers and additive suppliers to study ASR and explore remedies for it. One U.S. study noted that 23 Air Force, three Army, and six Navy and Marine Corps airfields have identified and reported ASR problems. This condition however, is not limited to North America; it is a worldwide problem. This article looks at the underlying causes of ASR and offers the reader some viable solutions to consider.

### WHAT IS ASR?

ASR is one type of alkali-aggregate reaction (AAR). Alkali-carbonate reaction (ACR) is also a subset of AAR, but is far less common than ASR, and is not discussed in this article. ASR occurs between the alkalis produced from the hydration of portland cement and certain siliceous rocks or minerals in the aggregates used in concrete production. The siliceous rocks or minerals include opal, chert, chalcedony, tridymite, cristobalite, strained quartz, and others. Deterioration and expansion

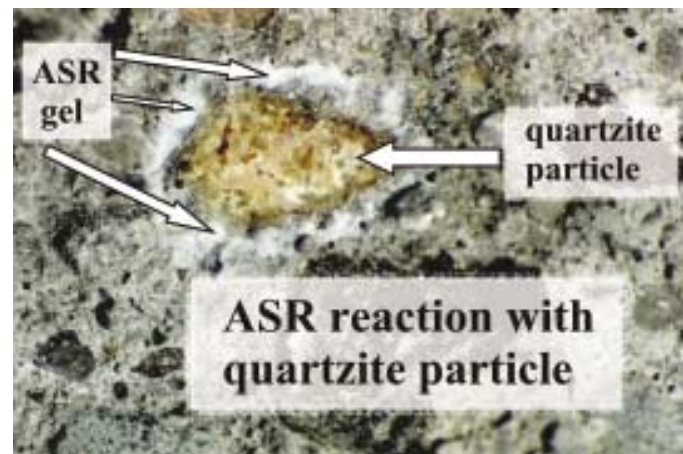


Fig. 1: Petrographic analysis shows silica from quartzite aggregate reacting with surrounding alkalis in the paste to form a rim of silica gel

due to ASR is a two-step process. First, silica in the aggregate reacts with alkalis from the hydrated cement, forming a silica gel (Fig. 1). Second, the gel absorbs water and swells, causing expansive pressures sufficient to crack the concrete.

Left untreated, ASR can continue to cause further expansion and cracking, leaving the affected concrete vulnerable to additional deterioration, such as corrosion of reinforcing steel (Fig. 2), freezing and thawing damage, and sulfate attack. Hence, detection, prevention, and mitigation of ASR is a critical concern when designing a structure for long-term durability.



Fig. 2: As ASR progresses, the cracked concrete allows other distress mechanisms to occur, including corrosion of reinforcing steel

ASR is often apparent five to 15 years after placement, and is often misdiagnosed because several factors contribute to its development within concrete. These factors include:

- Reactive aggregates;
- High alkali cement;
- External alkali sources;
- Marine environments;
- Weather conditions—(freezing and thawing/wetting and drying cycles);
- Corrosion causing agents such as deicing salts; and
- Traffic loading.

ASR appears most often as “Y-shaped” cracks that join to create a map-cracking pattern (Fig. 3). The crack pattern, however, is also related to stress distribution as affected by restraint. Cracks caused by ASR expansion tend to align parallel to the direction of maximum restraint. In a pavement, for instance, the prominent cracks are in a longitudinal direction. Spalling and popouts may also be signs of ASR.

### DETECTING POTENTIAL OR PRESENT ASR

Several tests and procedures have been developed to identify potentially reactive aggregates.

### ASTM C 295 – Standard Guide for Petrographic Examination of Aggregates for Concrete

When performed by a skilled petrographer knowledgeable about concrete, this method can be very reliable in identifying the mineralogical phases that are susceptible to ASR. The examination can't predict if potentially reactive materials will produce harmful expansions.



Fig. 3: Physical distress mechanisms of ASR include “Y-shaped” cracks as shown here

### ASTM C 227 – Standard Test Method for Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

This method can fail to show a material to be reactive, even though the material has proven to be reactive in field use.

### ASTM C 1260 – Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

This method will correctly identify most aggregates that have a potential for reaction, if low enough expansion limits are used. This test method has indicated potential reactivity for some aggregates in the laboratory although the aggregates have no history of deleterious reaction in the field. This may simply indicate that the aggregates were not used in a situation that would lead to deleterious reaction.

### ASTM C 1293 – Standard Test Method to Determine Length Change of Concrete Due to Alkali-Silica Reaction

Considered by many to be the most trustworthy test for reactivity, this test unfortunately requires one year to yield meaningful results. It may give false negatives, particularly for fine aggregates that have shown deleterious reactions in the field.

### ASTM C 856 – Standard Practice for Petrographic Examination of Hardened Concrete

Perhaps the best possible proof of an aggregate's potential for reactivity is direct evidence of ASR in the

field, which is evaluated by this method. A negative result here however could only indicate that there was no deleterious reaction in the particular concrete studied—not that it wouldn't react under different circumstances. In other words—proof positive of reactivity is possible with this method, but not proof negative.

### **ASTM C 441 – Standard Test Method for Effectiveness of Mineral Admixtures or Ground-Granulated Blast-Furnace Slag in Preventing Expansion of Concrete Due to the Alkali-Silica Reaction**

While not a test method for aggregates, this method evaluates the effect of mineral admixtures on expansions of mortars made with Pyrex glass as aggregate. The behavior with actual aggregates could be considerably different.

### **METHODS TO PREVENT OR ARREST ASR**

One way to avoid ASR is simply to use a non-reactive aggregate. However, this becomes a matter of geography, geology, and cost. Many aggregates are reactive and the cost to acquire non-reactive aggregate is a factor in two ways. First, because sources of non-reactive aggregates are diminishing, they have become an expensive commodity. Second, the cost to transport aggregate from a distance greater than 50 miles begins to add significant costs.

Reducing cement alkalis is another possible solution to ASR. However, it too has several major drawbacks. Low-alkali cements are becoming more difficult to manufacture and increasingly expensive to acquire. The processes used to reduce alkalis increase energy consumption for cement manufacturing and result in the production of environmental waste.

In most cases, the amount of alkali-reduction is not sufficient to mitigate highly reactive aggregates. In addition, using low-alkali cement is less effective in the presence of alkaline soils and deicing salts, which add to the total amount of alkalis present in the finished concrete structure. Alkalis can also be supplied by chemical and mineral admixtures, and even the aggregates themselves. In addition, wetting and drying the concrete tends to concentrate alkalis, as do electrochemical methods of corrosion protection, such as cathodic protection.

### **POZZOLANS AND MINERAL ADMIXTURES**

Pozzolans and mineral admixtures have been used to mitigate ASR with varying degrees of success. Some of the most widely used pozzolans include:

- Class F fly ash;
- Class C fly ash;
- Ground-granulated blast-furnace slags (GGBFS);
- Silica fume; and
- Natural pozzolans.

With the exception of natural pozzolans, these mineral admixtures or cementitious materials are all by-products of other industries. The amount of each needed for ASR mitigation varies according to its source, the type of aggregate, the type of pozzolan, the amount of alkalis, the environmental and service conditions for the intended concrete, the geometry of the structure, and the tolerable risk level from ASR damage that can be borne by the structure.

Studies indicate that a low volume of about 15% of Class F fly ash can actually worsen the ASR problem, especially when the fly ash contains more than 5% calcium oxide (CaO). Replacing 25 to 30% (by mass) of the portland cement with Class F fly ash was found to mitigate ASR in concrete, according to a 1996 California Department of Transportation study.

The State of New Mexico has some of the most reactive aggregates in the U.S. A 1998 study concluded that 25 to 27% Class F fly ash replacement was sufficient for most of the aggregates studied. Class C fly ash and blends of Class F and C fly ash did not provide enough expansion reduction.

ACI developed a guide on the use of GGBFS in concrete in 1995 (ACI 233R). The guide indicates that a minimum of 40% cement replacement with GGBFS is needed to mitigate ASR. But the use of slags may result in lower initial concrete strength, particularly in cold weather. Replacements with Grade 120 slag result in lower concrete strengths in the first 3 days, but greater strengths after 7 days. Substituting Grade 100 slag gives lower strengths in the first 21 days, and greater strengths after that. Grade 80 slag tends to produce lower strengths at all ages.

### **LITHIUM-BASED ADDITIVES**

Lithium-based admixtures or treatments of hardened concrete are promising alternatives to conventional methods for preventing or mitigating ASR. The FMC Corp., and many other interested agencies and researchers, have conducted tests on concrete containing lithium compounds for more than five decades. As a result of extensive research on the subject, the Strategic Highway Research Program (SHRP) places lithium compounds on the "short list" of recommended preventatives and remedies for ASR (Report C343).

## Special Products & Practice Spotlight



Fig. 4: Lithium-based products may be sprayed on the surface of ASR-affected concrete to further mitigate distress

In addition, several national and local specifications now include lithium technologies as a tool for combating ASR.

Based on the findings of SHRP research, lithium-based admixtures have been optimized to provide a range of products, custom-tailored to specific applications. In general, lithium admixtures offer the following benefits:

- Permit the use of local, cost-effective aggregates;
- Increase the life span of concrete structures;
- Lithium nitrate and glass-based admixtures, a new form of admixture, are engineered to be safe, easy to handle, and environmentally benign; and
- Lithium nitrate and glass-based admixtures have no significant effect on other concrete properties.

While lithium admixtures can carry the whole burden of mitigating ASR, their best use is obtained by combining the positive effects of pozzolans with the chemistries of lithium to economically manufacture concrete that is ASR resistant with enhanced durability due to pozzolans.

### HOW LITHIUM WORKS TO CONTROL ASR

Evidence indicates that lithium forms an alkali-silica gel that is non-expansive. Lithium silicates are less water-soluble and do not absorb or bind water to the degree that sodium or potassium silicates do. While the reaction of lithium with the ASR reaction product appears irreversible, there should be sufficient lithium present in the pore solution to protect against future attack by any alkalies remaining in the concrete mixture.

### Mitigating further expansion

Treating ASR afflicted concrete can be a viable and cost-effective option to extend the life of existing concrete structures. There are two primary concerns when

addressing ASR in hardened concrete:

- Mitigating further expansion from ASR; and
- Repairing the damage already caused by ASR.

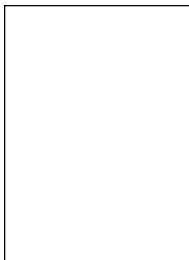
Reduction of expansion early in the process of ASR will lengthen the life of the structure and extend the time before repairs or replacement becomes necessary. By using a lithium-based treatment product, further ASR expansion can be significantly decreased, extending a structure's life. The treatment product can be applied by topical ponding or spraying (Fig. 4), pressure injection, vacuum impregnation or electrical injection. If ASR is left without mitigation, expansion will continue and traditional-method repairs will fail. In fact, traditional repairs—those without a lithium treatment—may actually enhance ASR distress in hardened concrete by supplying a fresh source of alkalies.

Once a lithium-based mitigation solution has been applied, patching and repairs can be done using traditional concrete technologies. Best results are obtained when the cementitious systems used in the repair also incorporate a compatible lithium admixture.

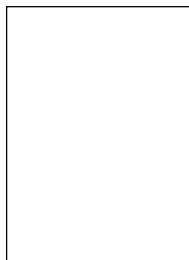
—FMC/Euclid Co. Alliance

For more information:

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