

Can Chemistry Solve a Serious Distress Problem That Has Plagued the Concrete Industry for 80 Years?

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The formation of alkali-silica reaction (ASR) gels in concrete structures (**Fig. 1**) is a sometimes serious, and often expensive to remedy, distress mechanism that has plagued the concrete industry since it was first discovered in France more than 80 years ago and in the United States in 1940.¹ The gels are formed by the reaction of alkalis in the cement with silica in certain aggregates. The gels can expand as they absorb moisture and exert sufficient force to crack the concrete. This often results in the costly replacement of concrete structures.

Many aggregates do not form ASR gels. For those that do, some aggregates form gels rapidly, with the gels appearing within the first few years of service life. Other aggregates react much more slowly, and it might take many years for the distress to manifest itself. In either case where the gels form, the result may be the very expensive replacement of the structure (for more information about ASR, see the Perspective in the Summer 2018 issue and the Safety & Serviceability article in the Spring 2019 issue of *ASPIRE*[®]).

The chemistry laboratory at the Turner-Fairbank Highway Research Center (TFHRC) has been studying the chemistry of ASR gels for more than 10 years. The research has shown that the chemical structure of ASR gels varies and has a marked influence on the expansion rate.²⁻⁴ This research has

Figure 1. Cracking in a concrete bridge pier caused by alkali-silica reaction. Photo: FHWA.



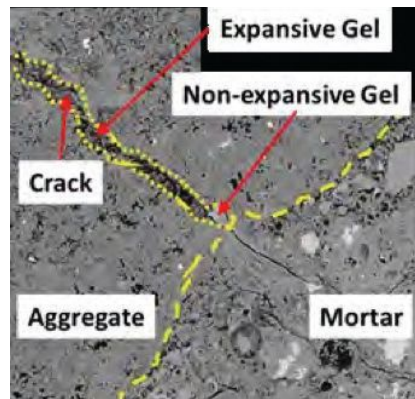
also shown, for the first time, that aluminum plays an important role in the expansion of these gels.

Figure 2 shows a scanning electron microscope image of a concrete section with an aggregate particle cracked by ASR. The ASR gel that has developed inside the aggregate is high in alkali content and is expansive. As the gel expands, it forces the crack in the aggregate to widen; ultimately this will crack the concrete. As the gel moves from the aggregate into the cement paste, it absorbs calcium and changes to a calcium-rich gel, which is not expansive.

A reliable method to accurately determine the likelihood that an aggregate will form expansive ASR gels has eluded the industry since the first test methods were put forward in 1947. Almost all the test methods—and there have been many variations over the years—rely on measuring the physical expansion of prepared mortar or concrete specimens immersed in sodium hydroxide solution at 85°C. The most commonly used tests are ASTM C1260,⁵ which is rapid (taking only 16 days), and the more accurate ASTM C1293⁶ method (**Fig. 3**), which takes one year. A newer test, AASHTO T 380,⁷ is under evaluation by the industry. It too measures physical expansion of specimens.

The Turner-Fairbank ASR Susceptibility Test, T-FAST, is a test method being developed at the

Figure 2. Scanning electron microscope image of concrete containing alkali-silica reaction gel. Photo: FHWA.



TFHRC chemistry laboratory that does not require the preparation of mortar or concrete samples, unlike the existing ASTM tests.⁸ All that is needed is 5 grams of crushed aggregate (**Fig. 4**), which is 1000 times less than the aggregate needed for ASTM C1293. The test is carried out in a 50-mL test tube made of polytetrafluoroethylene, which is placed in an oven at 55°C for 21 days (**Fig. 5**). A typical laboratory oven can contain up to 300 of these test tubes.

At the end of the test period, the contents of the tube are filtered and the filtrate analyzed for silicon, calcium, and aluminum. The analysis is used to calculate the reactivity index (RI), which is the concentration of silicon divided by the

Figure 3. A 3 × 3 × 11.25-in. concrete specimen for an ASTM C1293 test. Photo: FHWA.





Figure 4. Five grams of crushed aggregate for T-FAST. Photo: FHWA.



Figure 5. A 50-mL polytetrafluoroethylene (PTFE) test tube is placed in an oven at 55°C for 21 days to determine the reactivity index of the test aggregate in the T-FAST test. Figure: FHWA.

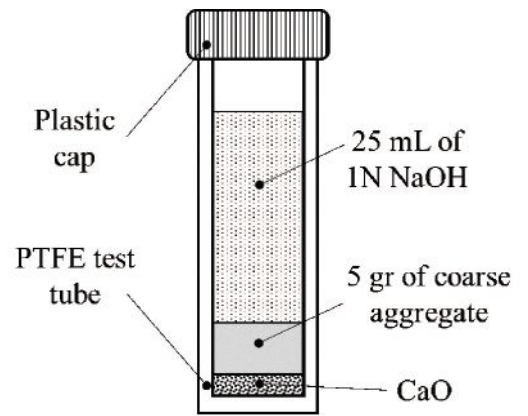


Table 1. Comparison of Test Data with Block Farm Data

Test	Agreement with Block Farm Data
ASTM C1260	68%
ASTM C1293	71%
AASHTO T 380	75%
T-FAST	88%
T-FAST (adjusted for effect of fine aggregate)	100%

Sources: Table created by FHWA with data from Ideker, J. H., A. F. Bentivegna, K. J. Folliard, and M. C. Juenger. 2012. "Do Current Laboratory Test Methods Accurately Predict Alkali-Silica Reactivity?" *ACI Materials Journal* 109 (4): 395–402, and Thomas, M. D., K. J. Folliard, B. Fournier, T. Drimalas, and S. I. Garber. 2013. *Methods for Preventing ASR in New Construction: Results of Field Exposure Sites*. FHWA-HIF-14-004. Washington, DC: Federal Highway Administration.

concentration of calcium plus aluminum in the filtrate. If the RI is greater than 0.45, then the aggregate is likely to form a gel.

The most reliable way of determining the alkali-silica reactivity of an aggregate is either by field experience, or by constructing farms of concrete blocks that are exposed to weather for a period of years (Fig. 6). The physical dimensions of the blocks are periodically measured to determine expansions.

Table 1 shows the correlation of current test methods with block farm results. T-FAST shows 88% agreement with block farm data. In addition to showing the importance of aluminum, the re-

search at TFHRC shows the effect of fine aggregate on the formation of ASR gels. The fine aggregate used in the current tests is very often chosen because it is known to be nonreactive. However, it was found that the fine aggregate, while being nonreactive, can sometimes leach alkalis into the system, distorting the test results. If the effect of the fine aggregate is compensated for in T-FAST, there is 100% agreement with block farm data.

This research on ASR is still a work in progress, so references have not yet been published.⁸ The next step is mitigation. If only reactive aggregates are available, how can they be used? Finally, the icing on the cake will be a method to evaluate not just the aggregate but the job-specif-

Figure 6. Block farm of concrete specimens. The physical dimensions of the blocks are periodically measured to determine expansions. Photo: Massachusetts Department of Transportation.



ic concrete mixture, so that everything that will be in the concrete is accounted for in the test.

References

1. Stanton, T. E. 1940. "Expansion of Concrete through Reaction between Cement and Aggregate." *Proceedings of the American Society of Civil Engineers* (ASCE) 66(10): 1781–1811.
2. Leemann, A., G. Le Saout, F. Winnefeld, D. Rentsch, and B. Lothenbach. 2011. "Alkali-Silica Reaction: The Influence of Calcium on Silica Dissolution and the Formation of Reaction Products." *Journal of the American Ceramic Society* 94(4): 1243–1249.
3. Vayghan, A. G., F. Rajabipour, and J. L. Rosenberger. 2016. "Composition-Rheology Relationships in Alkali-Silica Reaction Gels and the Impact on the Gel's Deleterious Behavior." *Cement and Concrete Research* 83: 45–56.
4. Rajabipour, F., E. Giannini, C. Dunant, J. H. Ideker, and M. D. Thomas. 2015. "Alkali-Silica Reaction: Current Understanding of the Reaction Mechanisms and the Knowledge Gaps." *Cement and Concrete Research* 76: 130–146.
5. ASTM International. 2014. *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*. ASTM C1260-14. West Conshohocken, PA: ASTM International.
6. ASTM International. 2020. *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction*. ASTM C1293-20a. West Conshohocken, PA: ASTM International.
7. American Association of State Highway and Transportation Officials (AASHTO). 2019. *Standard Method of Test for Potential Alkali Reactivity of Aggregates and Effectiveness of ASR Mitigation Measures (Miniature Concrete Prism Test, MCPT)*. AASHTO T 380. Washington, DC: AASHTO.
8. Munoz, J. F., C. Balachandran, and T. S. Arnold. Forthcoming. "New Chemical Reactivity Index to Assess Alkali Silica Reactivity." *ASCE Journal of Materials in Civil Engineering*. 