HPC Bridge Views

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FHWA Alkali-Silica Reactivity Development and Deployment Program

M. Myint Lwin, Federal Highway Administration

Alkali-silica reactivity (ASR) is a deleterious reaction that can occur in concrete mixtures when alkalis in the cement and other pozzolanic materials react with siliceous aggregates and expand when exposed to moisture. The Federal Highway Administration (FHWA) has initiated an ASR Development and Deployment Program in response to the SAFETEA-LU legislation. A comprehensive program, which is focused on preventing and mitigating ASR, has been developed to address states' needs and provide them with tools to address ASR in bridges, pavements, and other highway structures such as median barriers or retaining walls. This article outlines the various tasks of the ASR Development and Deployment Program.

Task Area 1: Understanding the ASR Mechanism Process for Mitigation

Applied research will be conducted to quantify competing chemical reaction rates between various constituents in the concrete mix and the environment. The goal of this research is to develop a model that can predict a mix design that is resistant to ASR.

The application of lithium by electrochemical techniques.

Task Area 2: Develop Testing and Evaluation Protocol

Protocols have been developed for engineers and transportation practitioners to provide a step-by-step process on the current best practices of ASR prevention and mitigation. The protocols are titled "Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction" and "Diagnosis and Prognosis of Alkali-Silica Reaction (ASR) in Transportation Structures."

Currently available rapid test procedures have varying levels of confidence and most have limitations. Research will be conducted to identify recent worldwide advances in rapid test methods, identify the most viable and effective test methods, determine their limitations, assess the required test period, and refine or modify these methods. If a rapid laboratory test method that is reliable and can predict the long-term performance of a concrete mix design in a short period of time is not available, a new one may need to be developed.

Task Area 3: Selection, Implementation, and Maintenance of Field Application and Demonstration Projects

Funding is available to states through the ASR Development and Deployment Program for projects focused on applying methods and techniques for ASR prevention and mitigation. Technical assistance for the planning, design, and construction of field projects will be provided. Instrumentation of projects for data collection and analysis will also be provided. Data will be collected, appropriate laboratory testing will be performed, data will be analyzed, and conclusions will be developed on the efficacy of the prevention or mitigation strategy. A goal within the program is to begin field trial implementation by the fall of 2008.

In addition, research will focus on controlled laboratory experiments to seek new or emerging technologies that may be viable and cost effective for ASR mitigation. The mitigation of ASR will be different for bridges and pavements and will take into account the various challenges with mitigating ASR in our transportation structures.

Task Area 4: Assist States in Inventorying Existing Structures for ASR

SAFETEA-LU legislation specifically requires that a system for tracking ASR-affected structures be developed. An evaluation of the current practices that states are using to survey and track ASR-affected bridges, pavements, and other highway structures will be performed. A general plan for including ASR indicators in state bridge inspection programs and pavement survey/pavement management systems will be developed. In addition, it is anticipated that an ASR severity rating system will be developed to assist states in prioritizing mitigation techniques, rehabilitation, or reconstruction.

It is important to distinguish between ASR and other deterioration mechanisms so that the appropriate rehabilitation method is implemented. State engineers have raised concerns with the current methods available for the field detection of ASR. Research will be performed to develop a simple reliable non-destructive field test method that can determine the presence of ASR and predict the total expansion and the rate of expansion.

Task Area 5: Deployment and Technology Transfer of Findings

It is extremely important that information is transmitted in a timely and effective manner to state engineers. The development of an ASR Reference Center is underway. This Center will be housed on FHWA's website and will contain valuable resources related to ASR. Some of the resources to be included in this Reference Center are research reports; list of reference documents; list of local, national, and international specifications; links to other ASR related websites; and summaries of past field trials for ASR mitigation.

An ASR newsletter called "Reactive Solutions" has been developed. This quarterly newsletter is designed to provide information to state engineers regarding national activities related to ASR, present an environment in which states can learn from each other, and offer a forum for answering questions related to ASR.

Further Information

You can view past issues of the ASR newsletter at http://www.fhwa.dot.gov/pavement/concrete/asr.cfm where you can also find out more information about FHWA's ASR Development and Deployment Program. If you would like to be added to the distribution list, email asrnewsletter@transtec.us. If you are interested in participation in a field trial or would like additional information on ASR, please contact Gina Ahlstrom at gina.ahlstrom@dot.gov.

(articles continue on next page)

Guide Specification for Concrete Subject to ASR

Beatrix Kerkoff, Consultant to the Portland Cement Association

Three tests used to assess the susceptibility of an aggregate to alkali-silica reaction.

Most aggregates are chemically stable in hydraulic cement concrete without deleterious interaction with other concrete constituent materials. However, this is not the case for aggregates containing certain siliceous minerals that react with soluble alkalies in the concrete, sometimes resulting in detrimental expansion and cracking of concrete structures.

The best way to avoid deleterious alkali-aggregate reactions is to take appropriate precautions before concrete is placed. Reducing the potential for alkali-silica reaction (ASR) requires (1) understanding the ASR mechanism; (2) properly using tests to identify potentially reactive aggregates; and, if needed, (3) taking steps to minimize the potential for expansion and related cracking.

Because different geographic regions have different needs and available materials, the Portland Cement Association has developed a Guide Specification for concrete subject to alkali-silica reactions.

Testing the Aggregates

The Guide Specification provides for a combination of three separate laboratory tests to assess the susceptibility of an aggregate to ASR. The tests may be done in any order; however, petrographic examination (ASTM C295) and the mortar-bar test (ASTM C1260) would generally be performed simultaneously, while the concrete prism test (ASTM C1293) is performed later, if needed.

The aggregate is examined petrographically to identify and quantify the constituents, with maximum limits set for the various minerals that are potentially reactive. In the mortar-bar test, a 14-day expansion exceeding 0.10% indicates that the aggregate is potentially reactive. If either of these tests indicates the aggregate is potentially reactive, it may be further evaluated by the concrete prism test, with a one-year expansion limit of 0.04%.

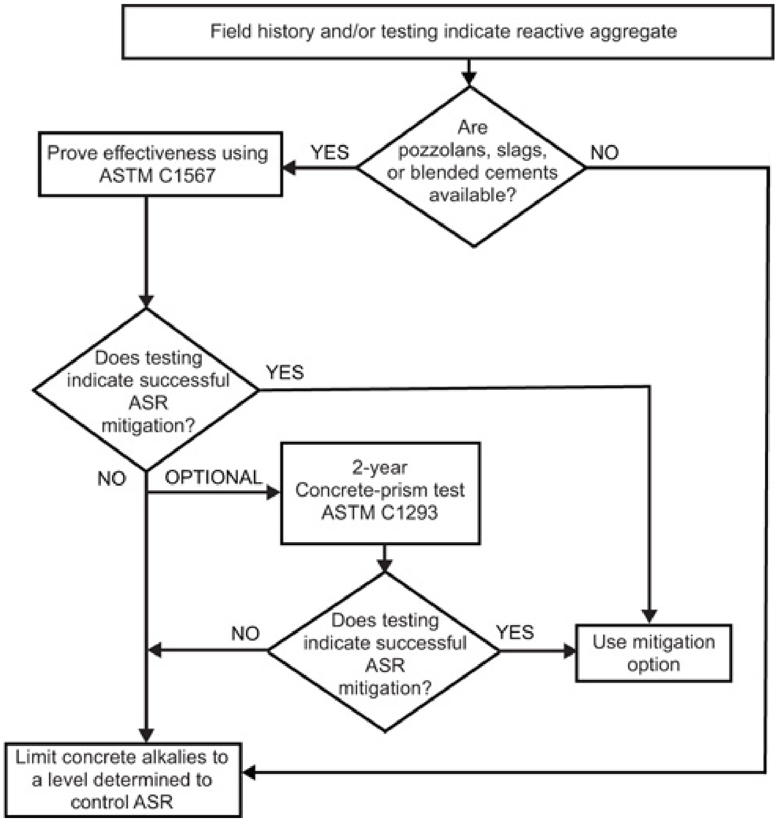
Materials and Methods to Inhibit ASR

Most concrete is not affected by ASR and special requirements are not needed. However, if historical experience or the aggregate tests mentioned above demonstrate that ASR is a potential concern, then concrete mixtures must be specifically designed to mitigate ASR.

A variety of materials can be used to control ASR. Supplementary cementitious materials (SCMs) such as fly ash, slag cement, or silica fume can be included as a concrete ingredient added at batching, as a component of a blended hydraulic cement, or both. Blended hydraulic cements should conform to ASTM C595 (AASHTO M 240) or ASTM C1157. SCMs added directly to concrete are governed by ASTM C618 or AASHTO M 295 for fly ash and natural pozzolans; ASTM C989 or AASHTO M 302 for slag cement; and ASTM C1240 or AASHTO M 307 for silica fume. Specifiers can invoke the optional physical and chemical ASR requirements in these standards; however limits on expansion are typically not applicable for a particular project as the tests do not use job aggregates, and the limits may be more restrictive than are necessary or achievable.

Using locally available materials in appropriate amounts is generally the most efficient solution to mitigate ASR.

When pozzolans, slag cements, or blended cements are used to control ASR expansion, their effectiveness should be determined using the following flowchart.



The accelerated mortar-bar test (ASTM C1567) can be used to evaluate combinations of cementitious materials and aggregates. A mortar-bar expansion at 14 days of less than or equal to 0.10% is considered acceptable to control ASR for a particular job aggregate. Combinations of actual cementitious materials and aggregates that do not meet this limit can be further evaluated by the concrete prism test.

Combinations of materials that exhibit a concrete prism expansion greater than 0.04% at 2 years are considered potentially reactive. Combinations of cementitious materials and aggregate exhibiting expansions less than 0.04% and demonstrating no prior evidence of reactivity in the field are considered nonreactive.

Where possible, different amounts of pozzolan or slag cement should be tested to determine the optimum dosage. Some materials exhibit a "pessimum" effect: dosages that are too low may actually result in higher ASR-related expansions than if no pozzolan or slag cement is used.

The flow chart above shows the sequence of checking the suitability of blended cements or supplementary cementitious materials to mitigate ASR. For the entire guide specification process to determine if potential aggregate reactivity exists and to select materials to control ASR, click here.

If pozzolans, slag cements, and/or blended cements are not available, or if testing or other engineering concerns preclude their use, portland cement and other concrete ingredients can be selected to limit the concrete's alkali content based on the reactivity level of the aggregate, or based on proven field performance with the potentially reactive aggregate (Farny and Kerkhoff 2007). For service conditions more severe than experienced in the past, such as increased exposure to external alkalies or increased concrete alkali content, relying on proven field performance may not be a valid option. Another solution is the use of chemical inhibitors, such as lithium compounds. The degree to which lithium compounds suppress expansive ASR depends on aggregate reactivity and concrete alkali content. The Federal Highway Administration has published guidance on testing, specifying, and using lithium compounds in new concrete construction (Thomas et al. 2007).

Further Information

Farny, James A. and Kerkhoff, B., "Diagnosis and Control of Alkali-Aggregate Reactions in Concrete," IS413, Portland Cement Association, 2007, 26 pp.

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Thomas, M. D. A., Fournier, B., Folliard, K., Shehata, M., Ideker, J., and Rogers, C., "Performance Limits for Evaluating Supplementary Cementing Materials Using the Accelerated Mortar Bar Test," R&D Serial No. 2892, Portland Cement Association, Skokie, Illinois, USA, 2005, 22 pp.

Editor's Note

A summary of the different tests for ASR is given in HPC Bridge Views, Issue No. 36, November/December 2004.

ASR Prevention in Texas

Brian D. Merrill, Texas Department of Transportation

Crack induced in a prestressed concrete beam by alkali-silica reaction.

For some states, alkali-silica reaction (ASR) in concrete has become just as big a concern as corrosion of reinforcing steel. Such is the case in Texas, where reinforcing steel corrosion mainly affects the far northern part of the state and along the coastline.

ASR is the result of the reaction between alkalies in the cement and certain siliceous aggregates. This reaction can result in excessive expansion and cracking of concrete exposed to moisture. Cracking of structures suffering from ASR is usually observed within 10 years of construction. For excessive expansion of concrete due to ASR to occur, four requirements must be met: the aggregate must be sufficiently reactive; the pH of the pore fluid must be high (high alkalinity); the amount of reaction product formed (ASR gel) must be large; and there must be sufficient water available in the concrete.

The Texas Department of Transportation (TxDOT) revised its structural concrete specifications in 1999 in an attempt to prevent ASR in new concrete by (1) limiting the total alkali contribution to the concrete mix; (2) using supplementary cementitious materials (SCMs) such as Class F fly ash, ground granulated blast-furnace slag (GGBFS), and silica fume; (3) using blended Type IP or IS cements; or (4) performance testing using ASTM C1260 or ASTM C441.

At the same time, TxDOT launched a massive ASR research project to study the issue. One of the studies was Project 0-4085, "Preventing Premature Concrete Deterioration due to ASR/DEF in New Concrete" conducted at the University of Texas' Center for Transportation Research. This project used extensive laboratory testing along with a large exposure site to evaluate the effectiveness of various ASR mitigation methods. TxDOT used the results to confirm and expand the 1999 specifications to prevent ASR.

TxDOT's current ASR specifications for structural concrete are largely prescriptive due to the high volume of concrete usage (> 60 million yd^3 in 2006) and the time it takes to run tests on more than 150 commonly used aggregate sources. All aggregates are treated as if they are potentially reactive unless we have test data confirming otherwise. The following eight mix design options were developed with industry input to provide maximum flexibility:

Option 1. Replace 20 to 35% of the cement with Class F fly ash.

Option 2. Replace 35 to 50% of the cement with GGBFS or MFFA. MFFA is Class F fly ash modified to improve early strength gain and setting properties.

Option 3. Replace 35 to 50% of the cement with a combination of Class F fly ash (35% max), GGBFS, MFFA, UFFA, metakaolin, or silica fume (10% max). UFFA is ultra-fine fly ash.

Option 4. Use Type IP or Type IS cement. Up to 10% of a Type IP or IS cement may be replaced with Class F fly ash, GGBFS, or silica fume.

Option 5. Replace 35 to 50% of the cement with a combination of Class C fly ash (35% max) and at least 6% of silica fume (10% max), UFFA, or metakaolin.

Option 6. Use lithium nitrate admixture at a minimum dosage of 0.55 gal. (30% solution) per pound of alkalies.

Option 7. Use straight cement if the total alkali contribution from the cement in the concrete does not exceed 4.00 lb/yd3 of concrete.

Option 8. Performance Testing. Test both coarse and fine aggregates separately in accordance with ASTM C1567 and certify that expansion for each aggregate does not exceed 0.10%.

Also, TxDOT generally uses prescriptive specifications when specifying HPC to keep construction costs down. Performance specifications for concrete in Texas have tended to increase bid prices because the high volume of concrete consumption introduces some level of risk to the contractors that the concrete may not meet the performance requirements. We have done enough testing of HPC mixes that we are comfortable prescribing mix designs that will meet our needs. TxDOT's HPC specifications limit the mix design options that can be used to Options 1 through 5 (no testing required) and Option 8, if the permeability is less than 1500 coulombs at 56 days when tested in accordance with AASHTO T 277.

HPC mixes as specified by TxDOT have been shown through testing to mitigate ASR in two ways. The first is physical mitigation because the permeability of the concrete is much lower meaning less moisture can penetrate the concrete to form ASR gel. The second is chemical mitigation. SCMs react with calcium hydroxide and this reaction lowers the alkalinity of the concrete and ties up free calcium ions needed to form ASR gel.

Further Information

For further information on TxDOT's ASR efforts, please contact Brian D. Merrill at 512-416-2232

Virginia's Approach to ASR

D. Stephen Lane, Virginia Transportation Research Council

Alkali-silica reaction (ASR) was first reported to have occurred in Virginia in 1941, when Kammer and Carlson revisited the cause of expansion and cracking in a dam attributed a decade earlier to an unidentified cement-aggregate interaction (Lane, 1993). In the late 1950s and mid 1960s, occurrences were noted in pavements of the Pentagon network and the R. E. Lee Bridge in Richmond constructed in the mid 1930s (Lane, 1993). The reactive constituent in the aggregates was microcrystalline or strained quartz, which is more slowly reactive than other reactive constituents such as opal, chalcedony, or volcanic glass. Despite these early identified occurrences, ASR was not considered to be a significant concern in Virginia until much later, in part because the focus of early work on ASR revolved around the rapidly reacting materials.

In the late 1980s, a stretch of interstate pavement placed in the Charlottesville, VA, area in the early 1970s was replaced because of significant cracking caused by ASR. Other stretches, less severely affected, were ultimately overlaid by the mid 1990s. Two coarse aggregates, a metabasalt and a granitic gneiss were involved, both containing microcrystalline and/or strained quartz as the reactive component. This coincided with a growing regional and international recognition of the potentially deleterious nature of aggregates containing varieties of quartz as the reactive constituent, greatly extending the areas where problems might be encountered. In 1989, the National Ready Mixed Concrete Association and the National Aggregates Association organized the Mid-Atlantic technical committee, composed of industry representatives; state Departments of Transportation of Maryland, North Carolina, Delaware, Pennsylvania, and Virginia; Federal Highway Administration; and the local mass transportation agency to serve as a working group to study the problem and develop solutions.

While the 1980s was a period of reawakening regarding the impact of ASR, it was also a period when the use of pozzolans and slag cement experienced great growth in the United States concrete industry. The Virginia Department of Transportation (VDOT) had revised its concrete specifications to allow the use of fly ash and slag cement in 1984 and 1985, respectively. Although economic considerations were the primary driving forces at this point, numerous studies had demonstrated the beneficial attributes that these materials could provide with respect to mitigation of both ASR and chloride-induced corrosion.

In 1990, VDOT launched a study to determine the extent of its ASR problem and to develop measures to prevent further problems. It quickly became clear that the local availability of Class F fly ash and slag cement provided an economical solution to both the ASR and chloride-induced corrosion problems, without any real downside. In 1991, VDOT revised its concrete specification to require 15% replacement plus 5% addition of Class F fly ash or 25 to 50% slag cement unless Type II cement with an alkali content less than 0.40% Na2O equivalent = Na2O + 0.658K2O was used.

The outcome of the initial study supported the interim specification because potentially reactive aggregates were in widespread use and test methods capable of clearly distinguishing between non-deleterious and deleteriously reactive aggregates were not available. Also, it seemed that the primary purpose behind identifying non-deleterious aggregates was to avoid having to use fly ash or slag cement in the concrete, which would be less economical and leave it more susceptible to chloride-induced corrosion because of concrete permeability.

A follow-up study (Lane and Ozyildirim, 1995) focused on determining the amounts of pozzolans or slag cement needed to prevent deleterious reactivity using a standard reactive material (borosilicate glass). The work showed that the amount of a given mitigating material needed was a function of the alkali content of the portland cement with which it was used. Based on this study, VDOT revised its concrete specification to a sliding scale of minimum replacement of portland cement with Class F fly ash, slag cement, or silica fume as a function of the cement alkali content as shown the above table.

VDOT ASR Mititgation Requirements - 1995 Revision

Cementitious Material*	Maximum Cement Alkali Content %
Cement	0.45
Cement with Minimum 15% Class F Fly Ash	0.60
Cement with Minimum 20% Class F Fly Ash	0.68
Cement with Minimum 25% Class F Fly Ash	0.75
Cement with Minimum 30% Class F Fly Ash	0.83
Cement with Minimum 25% Slag Cement	0.60
Cement with Minimum 35% Slag Cement	0.90
Cement with Minimum 50% Slag Cement	1.00
Cement with Minimum 3% Silica Fume	0.60
Cement with Minimum 7% Silica Fume	0.90
Cement with Minimum 10% Silica Fume	1.00

*Replacement of portland cement by mass

The above table lists the minimum percentages of fly ash, slag cement, or silica fume to be used depending on the cement alkali content.

A subsequent study (Lane and Ozyildirim, 1999) was then conducted to verify the findings by testing concretes produced with a reactive aggregate used in Virginia construction. This study included other durability factors in addition to ASR and recommended adjustments to the earlier specification with the intent of providing adequate mitigation of both ASR and chloride-induced corrosion.

The belowtable lists the minimum percentage of cement replacement using fly ash, slag cement, or silica fume for portland cement alkali contents less than or equal to 0.75% and greater than 0.75%.

The use of pozzolans or slag cement has served VDOT well over the years in preventing significant early damage resulting from ASR. Assuring compliance has been straightforward, relying primarily on mill certifications of the cementitious materials. It has allowed VDOT to avoid the much more difficult and larger task of developing and maintaining a program of testing aggregates for ASR potential, which would impose much greater management and manpower demands.

While the ideal is to avoid ASR-related damage and the specifications in place for over kljlkjlkjjlkjfifteen years appear

VDOT Recommendation to Provide ASR Mitigation and Low Permeability Concrete

Portland Cement Alkali Content, %	≤ 0.75	> 0.75
Class F Fly Ash, * %	20	25
Slag Cement, * %	40	50
Silica Fume, * %	7	10

***Minimum percentage cement replacement by mass**

to be accomplishing that (Lane, 2006), structures built earlier may require periodic repair or rehabilitation. VDOT has overlaid damaged bridge decks with latex-modified concrete since 1970, polymer mortar since the early 1980s, or silica fume concrete (now low-permeability with pozzolans or slag cement) since the early 1990s. These systems have served as primary maintenance and rehabilitation tools. A number of these decks were undoubtedly damaged by ASR but the cause(s) never clearly defined. VDOT has had excellent success with these overlay systems in extending bridge deck service life.

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Further information

For further information on VDOT's approach, please contact the author at 434-293-1953 or stephen.lane@vdot.virginia.gov.