ALKALI-SILICA REACTIVITY - A HIGHWAY PERSPECTIVE

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This paper provides an overview of research on alkali-silica reactivity (ASR) in highway concrete being performed for the U.S. Strategic Highway Research Program (SHRP). Research to-date has shown interesting results on the effects of chemical species (chloride, sulfate and lithium ions) and physical processes (drying and steam curing) on ASR. Criteria for a rapid aggregate reactivity test were determined. Moisture levels in field concrete were found to be sufficiently high to sustain ASR even in warm and dry climates. Fly ashes showed significant differences in their ability to prevent ASR.

INTRODUCTION

Alkali-silica reactivity (ASR) is a serious cause of deterioration of concrete in pavements, bridges and other highway structures in the United States, resulting in costly and time-consuming repair and reconstruction. Despite much research and significant advances in our understanding of this phenomenon, the problem still persists. Perhaps there are two aspects to the problem: either a satisfactory solution is still not available, or the available knowledge, while adequate, is not being properly utilized and implemented.

The Concrete Program of the Strategic Highway Research Program (SHRP) is addressing both aspects of the problem through its project, Eliminating or Minimizing Alkali-Silica Reactivity. This 5-year study considers a number of issues regarding ASR that, from the highway community's viewpoint, still need a satisfactory resolution. There is a need to develop reliable test methods and specifications for concrete-making materials to avoid ASR. The environmental conditions favorable for this reaction also need to be established. Pozzolanic materials (fly ash, slag, silica fume, etc.) have often been effective in preventing ASR, but tests to qualify such materials for successful mitigation are questionable, and even lead to conflicting interpretations. To permit better definition of pozzolanic characteristics and requirements for preventing expansive ASR, test procedures need to be refined or developed. In addition to making new concrete structures free from ASR, the possibility of eliminating or controlling ASR in existing highway concrete also should be explored. Extending the service life of highway concrete has very significant economic implications.

The SHRP research consists of three tasks:

1. Background Studies
2. Avoiding ASR in New Concrete
3. Mitigating ASR in Existing Concrete

BACKGROUND STUDIES

The background studies consisted of a review of literature on ASR, a survey of highway pavements and structures for ASR-related distress, and a few mechanistic studies on the effects of certain chemical and physical factors on ASR, selected because of their practical implications

Literature Review

An extensive literature search and review on the subject of ASR was carried out under this task which resulted in the compilation of an annotated bibliography and a synthesis of our current knowledge on ASR. The bibliography contains over 1300 citations covering pertinent literature on the phenomenon of ASR since it was first reported about 50 years ago. The synthesis, entitled, Alkali-Silica Reactivity - An Overview of Research, discusses recent advances in the chemistry and physics of ASR, and also points out areas where we still need to learn more about this phenomenon.

Mechanistic Studies

This task investigated the role of certain chemical and physical factors in promoting or retarding ASR in concrete. Specifically, these studies sought to understand how lithium, chloride and sulfate ions affected the mechanism and products of the reaction. The effects of drying and steam curing also were included because of their practical relevance.

Lithium Ions

Lithium salts have been shown to significantly inhibit ASR in concrete (1). SHRP studies showed that lithium hydroxide was particularly effective in preventing expansion due to ASR. While the mechanism of this inhibition is not clear, it appears that lithium is taken up by the ASR gel product along with sodium and potassium, and that the lithium-containing gel is relatively non-expansive. If the gel incorporates lithium in amounts sufficiently high as compared to sodium and potassium, the expansion is supressed. Additional work is needed to confirm this conclusion, and to establish the long-term effectiveness of lithium ions in inhibiting ASR.

Chloride Ions

Chloride ions from deicing salts were found to exacerbate ASR in concrete. Increased concrete expansion due to ASR in sodium chloride solution has been reported previously (2). SHRP research showed that the additional expansion (and damage) in concrete exposed to chloride solutions might result from secondary ettringite formation. In some instances, deposits of Friedel's salt were detected which also might have contributed to the expansion. The observed effect of chloride ions on ASR is of rather serious concern because of the widespread use of chloride-containing deicing salts on roads and bridges in winter in many regions of the United States.

Sulfate Ions

There is evidence of a rather significant interrelationship between sulfate ions and ASR in concrete (3,4). SHRP studies on the effect of soluble sulfates on ASR showed that when the sulfate ions remained in solution over long periods of time, the uptake of alkali ions by the ASR products was facilitated. Reasons for the observed effect need to be clarified.

Drying

Analyses of pore solutions extracted from pavement core mortars and cement pastes indicated that drying temporarily immobilized alkali ions in concrete presumably by incorporating them into the hydrated cement. Further work showed that the phenomenon was not entirely irreversible. Also, it does not appear to be a practical option in the field where ground water is continually available to the highway structure, particularly, the pavement.

Steam Curing

The effect of steam curing on ASR has been reported recently (5). This could be a cause of some concern because steam cured concrete is often used in highway structures, such as prestressed bridge beams, etc. SHRP studies showed that the heating cycle during steam curing apparently affected the formation and decomposition of ettringite. Analysis of the hydration products showed that some sulfate remained unaccounted for, which was believed to have reacted with the ASR gel. Analysis of the pore solution showed a significant reduction in the hydroxyl ion concentration -- a condition not favorable for ASR. However, this appeared to be offset by the more favorable condition of high temperatures during steam curing with the net result of increased reaction rate and consequent expansion. Data on expansion of mortar bars, made with reactive aggregates, also showed increased expansion with increased temperature of steam curing.

Field Survey

An extensive survey of pavements and bridge structures was carried out to determine the extent of ASR, and its dependence on the climatic conditions across the United States. The survey showed that the ASR was rather more widespread in United States than had been believed generally. Based on this survey, a field guide, entitled, Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures, was prepared to provide guidance on identifying ASR in highway pavements and bridge structures using actual examples. The illustrations show that the nature of ASR-related distress and cracking depends on the type and configuration of the structure. The handbook also describes a simple and rapid chemical test developed recently for the detection of ASR in concrete based on the fluorescence of the ASR gel product when treated with uranyl acetate solution (6,7).

Moisture Conditions

The field survey also collected data on moisture and humidity conditions of highway concrete to determine any correlation with ASR-related expansion. Results indicated that relative humidity values higher than 80% (corrected to 21°-24° C) were required to sustain ASR. Field measurements revealed that most of the concrete in pavements and other highway structures was sufficiently damp to sustain ASR, even in desert climates. For example, relative humidity values higher than 80% were measured just 2 inches below the top surface in most of the pavement even in summer in the Southern California desert. Bridge decks and columns also were found to be sufficiently damp to support ASR on a seasonal basis. Presumably, the residual mixing water in concrete as well as external sources of moisture contribute to the moisture conditions needed for ASR to continue.

AVOIDING ASR IN NEW CONCRETE

The objective of this task was to develop a reliable test for screening out reactive aggregates, and prepare guidelines on permissible combinations of cementitious materials, aggregates and environmental factors to avoid distress in concrete due to ASR.

Rapid Aggregate Reactivity Test

From an evaluation of the various tests proposed for identifying reactive aggregates, a method similar to that developed in South Africa (8) was found to be most promising. It appears capable of identifying even slow-reacting aggregates in about 14 days. The test involves monitoring of expansion of mortar bars, immersed in 1 normal sodium hydroxide solution and maintained at a temperature of 80° C, for up to 14 days. Based on field service records of highway concrete structures, a failure criterion of 0.08 to 0.1% expansion may be established eventually by this method. In other words, aggregates that have reacted deleteriously in highway concrete structures show an expansion of at least 0.08 to 0.1% in this test.

The above test also is being explored to determine the maximum cement alkali content at which the specimen will not exceed the failure criterion. This is being done by monitoring the specimen expansion at various sodium hydroxide concentrations for specified periods of time. This information may be helpful in specifying the maximum permissible cement alkali content that would be safe for use with potentially reactive aggregates.

A variation of the above test is being used to develop a rapid procedure for estimating the residual ASR potential of field concrete for expansion. This approach may have significant practical implications because, if it can be established that the concrete has become too deficient in alkalies to sustain ASR while the cracks associated with ASR are only barely perceptible, no mitigation or rehabilitation work may be necessary.

Pozzolans and Mineral Admixtures

Pozzolans (fly ash, silica fume, slag, etc.) are generally effective in inhibiting ASR-related expansion in concrete. However, current ASTM test procedures and criteria for evaluating pozzolans for their effectiveness are open to question and need a reappraisal. A modified ASTM C-227 procedure is being explored for this purpose in which the specimens are stored at 60° and 80° C. Test results for a number of fly ashes showed significant differences in expansion, both with respect to the source and quantity of fly ash used.

MITIGATING ASR IN EXISTING CONCRETE

This task was aimed at minimizing expansion or deterioration in existing highway concrete due to ASR. Two approaches may be taken to achieve this objective: either interfere with the mechanism of ASR, or minimize its effects (volume change and cracking).

Chemical Inhibitors

Presently two types of chemical treatments have been utilized mainly to mitigate ASR-related distress in highway concrete: high-molecular weight methacrylate treatment to pavements, and silane application to pavements and bridges. These materials appear to improve the concrete integrity by penetrating and filling the cracks and bonding the concrete. Based on field performance, the above treatments can be recommended presently on high-traffic pavements.

Lithium hydroxide also appears to be effective in inhibiting ASR-related expansion in old in-service concrete. However, it must penetrate through the concrete in order to be effective which presents a major practical limitation. Use of electric current to drive lithium ions into concrete may work for bridge decks but may not be feasible for pavements where any steel, if present at all, would be located only near the mid-depth level. Perhaps lithium salt solution can be made to penetrate ASR-induced cracks by flooding the wearing surface, provided the cracking is not too severe. Artificial drying just prior to application may facilitate penetration of the solution. A pavement section showing ASR-related distress was treated recently with lithium hydroxide solution in the state of Nevada. Long-term monitoring will determine the effectiveness of this treatment.

A number of other chemical agents (crown ethers, cryptands, amines, etc.) also were investigated for their ASR inhibiting effectiveness, based on their ability to complex with sodium and potassium ions. However, this approach did not prove to be economically feasible. Also, the long-term effectiveness and the environmental effects of these materials remained uncertain.

Physical Restraint

Physical restraint to movement in a concrete structure should help prevent, or at least control, cracking and expansion. Triaxial confinement of ASR-affected concrete demonstrated that stresses up to about 1.7 to 2.0 MPa (250 to 300 psi) can develop in concrete made from typical paving mixes. Above this stress level, the expansion due to ASR appears to be balanced by the creep of the concrete, with the net result of practically no volume change. Proper restraint may, therefore, provide a means of preventing expansion. The feasibility of this approach, however, will depend on the configurations of the concrete structure and the restraining system.

A laboratory experiment with a "miniature pavement" is currently underway to determine the feasibility of this approach. A number of small test sections constructed with several reactive and non-reactive aggregates, and maintained at various humidity and temperature conditions, are being monitored for volume change (expansion and shrinkage) and cracking while under known applied compression. Preliminary results show a noticeable reduction in expansion due to ASR, although the effect does not appear to be uniform over the entire thickness of the test section.

CONCLUDING REMARKS

SHRP research on ASR has contributed to an increased awareness of the problem in the highway community in the United States. This research focuses on some selected technical and educational issues critically important for the durability of highway concrete. The approach is, by design, pragmatic with a goal to develop new, or improve upon the existing, technology to eliminate or control ASR in highway concrete. The practical products of this research will be implemented by the state highway agencies as soon as they are validated after field evaluation. Some initial steps toward implementation already have been taken in the form of workshops and training sessions for state highway agencies.

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