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Classification of alkali–silica reaction damage using acoustic emission: A proof-of-concept study

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HIGHLIGHTS

- Acoustic emission (AE) was used to monitor alkali–silica reaction (ASR) damage in concrete specimens.
- The rate of AE activity showed a good correlation to the rate of expansion from ASR damage.
- ASR damage was assessed using petrographic examination and related to AE parameters.
- An AE based chart was developed to classify ASR damage.

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ABSTRACT

Alkali–silica reaction (ASR) is a concrete degradation mechanism that generates internal cracks in concrete material as a result of volumetric expansion. This mechanism is currently affecting many structures throughout the United States, especially in Texas and the Pacific Northwest. In this study, an accelerated ASR test was implemented at the University of South Carolina Structures and Materials Laboratory on twelve specimens with dimensions of 3 × 3 × 11.25 in. (76 × 76 × 286 mm). The specimens were cast using reactive aggregate and mortar with a high alkali content and placed in a controlled environment with high humidity and temperature to accelerate the reaction, while being continuously monitored with acoustic emission. Length change measurements and petrographic examination were conducted periodically to serve as benchmarks for ASR damage detection. Micro-cracking associated with ASR damage was detected by AE and the rate of AE activity was correlated to the rate of ASR damage. An AE based Intensity Analysis chart that enables ASR damage classification in correlation with petrographic analysis was developed.

1. Introduction

Concrete degradation is one of the crucial issues that face infrastructure owners and the civil engineering community. The heterogeneous nature and low tensile strength of concrete make it susceptible to cracking induced by service loads in addition to material degradation through various mechanisms including corrosion of reinforcement, sulfate attack, alkali–aggregate reaction (AAR), freeze–thaw cycling, leaching, radiation, elevated temperatures, salt crystallization, and microbiological attack [1]. Degradation of concrete often affects the safety and serviceability of structures which leads to economic losses and, in some cases, catastrophic failures and fatalities. This has raised the need for advanced monitoring techniques to determine the current structural state of the concrete members and to assist in the evaluation of repairs.

This study focuses on alkali–silica reaction (ASR) degradation, which is currently affecting many structures across the United States [2]. This degradation mechanism has gained more attention since the presence of ASR induced cracks in the Seabrook Nuclear Power Plant [3]. Fig. 1 shows a map of states with ASR degradation and a photograph of ASR cracks in a highway bridge. ASR degradation is affected by material selection of the concrete matrix and initiates when certain types of reactive siliceous aggregates are combined with cement paste having high alkali content. The ASR

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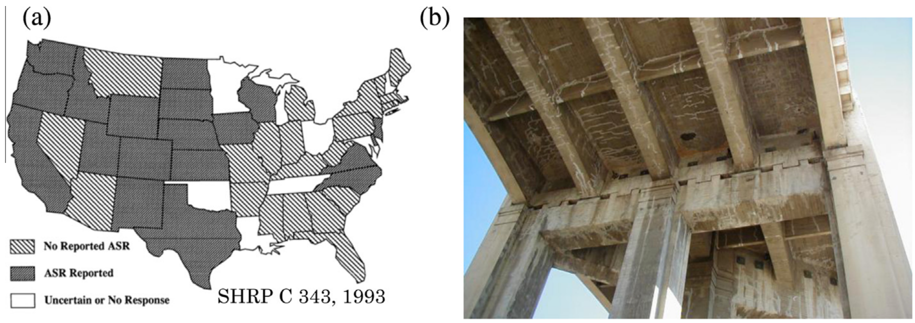

Fig. 1. (a) Map of states with ASR degradation [2], and (b) example of ASR induced cracks.

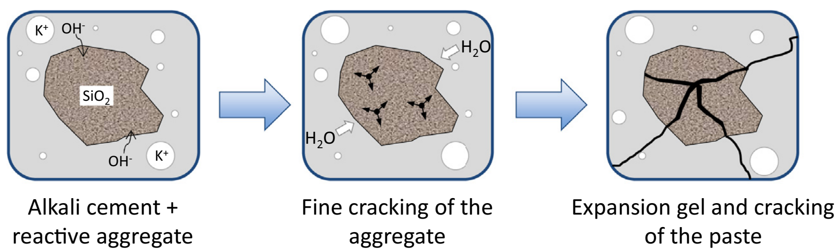

Fig. 2. Mechanism of ASR damage in concrete [www.journal.hep.com.cn].

mechanism requires as little as 80-percent relative humidity to occur and only permits a few mitigation techniques once the structure is in-service [4]. The reaction product is a gelatinous material that swells when moisture is absorbed and can cause expansion and cracking [5]. Fig. 2 shows a schematic of the mechanism of ASR damage in concrete.

Currently ASR damage in field structures is evaluated through length change measurements, visual inspection of cracks, and/or concrete coring with subsequent petrographic examination [6]. Length change measurements can be inconsistent given the high precision required (in the micro-range) and their susceptibility to temperature changes. On the other hand, visual inspection is subjective and only detects damage after visual signs are apparent while the petrographic examination is a local, qualitative, and destructive method which may not be allowed in some structures, such as nuclear power plants. In addition, all the above methods, with exception to length change, are used for periodic inspection and are not suitable for continuous monitoring. Therefore, there is a need for a nondestructive evaluation/structural health monitoring (NDE/SHM) method to enable detection and monitoring of ASR degradation.

Acoustic emission (AE) is a promising method for health monitoring of concrete structures which gained more attention in the last decade. AE is defined as transient stress waves produced by a sudden release of energy, such as crack formation or growth [7,8]. The high sensitivity of the sensors, in the kHz range, enables it to detect cracks long before they are visible [9,10]. This research effort is motivated by recent studies that show the ability of the method to detect other concrete degradation mechanisms, particular corrosion and cracking in reinforced and prestressed concrete specimens [11–17]. It is noted that a previous study investigated the use of AE to detect ASR damage in cylindrical specimens [18]. The results of this study showed that AE can detect early cracking associated with ASR; however, the rate of AE activity plateaued at the end of the test.

The study described herein examines the ability of AE to detect and classify ASR degradation. To achieve meaningful data within a reasonable period of time (one year), the laboratory test was intentionally accelerated in general conformance with ASTM C1293 [19]. The test environment was carefully controlled to minimize variability and to maintain conformance with ASTM C1293. The specimens were continuously monitored using AE and two benchmark measurements for ASR degradation were used: discrete length change measurements to measure longitudinal expansion and petrographic examination (resulting in a damage rating index). The results of this study demonstrate the ability of AE to detect and assess the rate of ASR induced degradation in concrete structures.

2. Research significance

ASR degradation is currently affecting many structures in the United States including highway bridges and nuclear power plants (Fig. 1). The excessive cracking associated with this degradation mechanism results in serviceability concerns which require repair or complete replacement of the affected structure. This study demonstrates the ability of AE, as a non-invasive SHM method, to detect and assess the extent of ASR damage. An algorithm for ASR damage classification was also developed, which can help infrastructure owners evaluate the current condition of the structure and assess the effectiveness of repairs.

3. Experimental program

3.1. Tests specimens

An accelerated ASR test was designed to degrade the specimens in a reasonable time. The test program included twelve conditioned specimens and three control specimens (cast using nonreactive aggregate during an earlier study), all having dimensions $3 \times 3 \times 11.25$ in. ($76 \times 76 \times 286$ mm) similar to ASTM C1293 [19]. An alkalinity concentration of 5% $Na_2O_{(eq)}$ was used in the concrete mix of the ASR specimens, as opposed to the specified concentration of 1.25% in ASTM C1293. A highly reactive aggregate (Knife River) from Cheyenne, Wyoming was used in the ASR specimens. Tables 1 and 2 shows the ASTM C1293 specifications and the concrete mix design used to cast the ASR specimens with a water/cement ratio of 0.48. The conditioned specimens were cast using two identical batches (six specimens per batch). The control specimens were cast with ordinary Portland cement and innocuous aggregates.