QUANTITATIVE MONITORING OF ALKALI AGGREGATE REACTIONS USING ACOUSTIC EMISSION

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A significant part of the deterioration of the world's concrete infrastructure, especially highways and bridges is caused by reactions between the cement and the aggregate (AAR). Such reactions are especially troublesome because the reaction often proceeds so slowly that problems do not emerge until years after construction. Furthermore until recently there has not been any reliable test to determine whether a particular aggregate-cement combination was likely to react. However even present tests for AAR potential have at least three problems - they are qualitative rather than quantitative; often time consuming; and often inconclusive. This paper presents an alternative, non-destructive, method, using the acoustic emission technique, which can provide a quantitative estimate of AAR potential within a few days of casting.

INTRODUCTION

Alkali-aggregate reactions may be divided into two types - alkali-silica (ASR) and alkali-carbonate (ACR). Both actions have caused serious damage to many structures although it is often the case that only one type of reaction will occur in a given location. Both actions have also required extensive research work to develop tests for the principal two concern of owners and engineers - namely (a) how to determine whether a given cement-aggregate combination is going to (or is likely to) produce problems; and (b) how to determine if an **existing** structure is (eventually) going to exhibit damage. Researchers have investigated two types of test; chemical and physical. Both types have been adopted by A.S.T.M. The chemical test (A.S.T.M. C289) measures the amount of chemical reaction between the aggregate and a solution of sodium hydroxide by determining the amount of soluble silica released during a 24 hour exposure. The physical test (A.S.T.M. C227) measures the expansion of a mortar bar made from the mix to be examined and compares it with that of a standard mortar after storage in a wet room for at least 14 days. More recently the Strategic Highway Research Program (SHRP) in the USA has produced a chemical test to be applied to the surface of a structure. However this test is used only to determine whether a given source of damage is caused by AAR as opposed to some other damaging mechanism. Furthermore, several States and Provinces in North America are working on their own tests and procedures (e.g. California Dept. of Transportation).

It may be noted that there is, as yet, no test for **concrete**, either in the laboratory or the field.

It is clear that a rapid, non-destructive, and quantitative method for evaluating either the AAR **potential** of a proposed concrete or the **remaining resistance** of an existing concrete would be of great benefit to the profession since resources could then be directed to those structures with the most need with resulting increases in safety and economy. If such a test could be adapted from the laboratory to the field then further economies would result.

The paper presents a method which promises to meet these requirements. First, a brief description of the AE technique and equipment is presented followed by the results of a pilot test program. Finally, the development of a **field** test is briefly discussed.

Acoustic Emission Technique

The AE technique, in essence, consists in listening to a specimen with a very sensitive microphone. With modern equipment the method can detect extremely small amounts of released energy. The technique is often called micro-seismicity. To perform tests one requires (a) sensitive microphones (b) amplifying circuitry (c) a computer to receive, interpret, store, manipulate and feed back the incoming signals, and (d) some expertise in selecting appropriate levels for the settings of the equipment (e.g. frequencies to be sampled, threshold levels). A typical (microphone) voltage vs time plot for a mechanical event within a body is shown in Fig 1, which also shows the several signal characteristics and the statistics which may be extracted from the data.

Acoustic Emission: Pilot Tests

To study AAR in concrete and mortars, four types of concrete were cast. The following aggregates and combinations were used.

1. A local, natural, sand and gravel with a known low potential for AAR. ("Teichert").

2. A sand and gravel from an area known to have a very poor AAR record.("Friant").

3. A ground glass containing a form of silica which is highly reactive with cement. This aggregate is used as a standard in ASTM test C441. ("Glass")

The amounts of materials available permitted only one w/c ratio (0.5) and only one cement to be tested. The cement, of a type commonly used in northern California, had a total alkali content of less than 0.7%. This low alkali content was deliberately chosen so as to be a severe test for the method.

The following combinations were selected for testing.

A. concrete containing glass gravel and glass sand.
B. concrete containing glass gravel and Friant sand
C. mortar containing Friant sand
D. mortar containing Teichert sand.

In this way the actions of two aggregates, one very good and one very poor (from AAR considerations) could be compared with the action of a standardized reactive glass.

Sample Properties

Samples were concrete blocks 6 ins by 6 ins by 3.5 ins thick (15x15x9 cm). They were cured for 3 days underwater and then transferred to a shallow tank in which the water level was maintained at 3.4 inches (8.8 cm.). The AE microphones were attached to the tops of the specimens and a wet cloth was then placed so as to cover the rest of the exposed surface thus keeping the entire specimen moist (see Fig. 2). The tanks were then placed under an infrared heater so as to maintain a temperature of approx. 35deg. F. in the water. No accelerating chemical was used. The known accelerating effect of certain chemicals (e.g. sodium hydroxide) which could have been employed was thus replaced with the suspected milder effect of the elevated temperature. As before, this was done so as to make the test more severe i.e. to explore whether the reactions could be detected under the milder effect of the elevated temperature.

Sound energy emerging from the specimens was monitored continuously for several days. In this pilot study only the number of ring-down counts was used.

RESULTS

The results are shown in Fig 3. The following conclusions may be drawn from the graph.

1. The method can detect activity at early ages (5-10 days).

2. The method can establish detectable numerical differences among the various aggregates in as little as five days - even without accelerating chemicals.

3. The aggregates display acoustic activity which is directly related to their expected chemical reactivity. The all-glass aggregate has approximately 9 times the acoustic emission counts of the others.

4. The results indicate that the **sand** is the principal source of the reactions. The uppermost curve is distinguished from its neighbor only in the substitution of the Friant sand for the reactive glass sand and the difference in output is almost an order of magnitude. This is in accord with the fact that the reactions are probably occurring on the surfaces of the aggregate particles and sand obviously has a much higher surface area per unit weight of aggregate than does gravel.

DISCUSSION

The new test seems to offer substantial advantages over existing techniques. It is quantitative rather than qualitative. It detects differences after only a few cycles and long before any visual indication of distress. It can be applied to concrete as well as mortar. It offers promise that it may help to shed light on the internal processes occuring within the concrete mass. But perhaps most importantly it should be readily adaptable to a field test so that the condition of existing structures can be evaluated. Such a test is not available at present.

Proposed Field Test for Alkali-Aggregate Reaction.

One possible field test arrangement is shown in Fig 4. An annular ring is cut into the concrete to be tested. This ring may be filled either with water or with sodium hydroxide solution to promote any AAR. If desired the central sample could also be heated so as to accelerate the test. Advantages of such a test include (a) its non destructiveness (the annulus could easily be refilled at the end of the test) ; (b) its repeatability - the testing can be interrupted or resumed at will thus permitting the monitoring of the condition of the concrete through time; (c) its quantitative nature, and (d) it is performed directly on the structure to be tested (and not on a companion sample).

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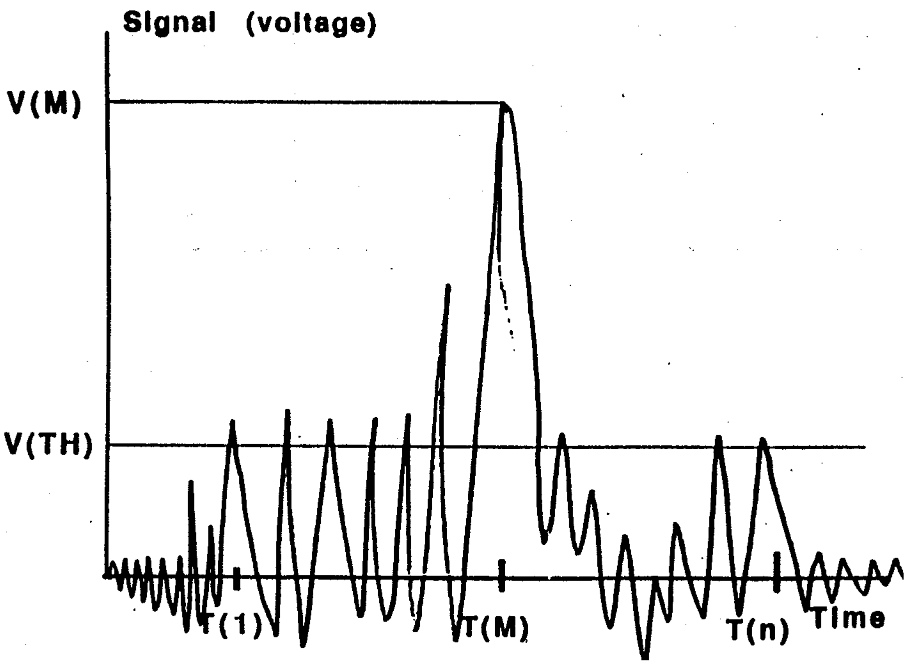

V(TH) = Threshold voltage
V(M) = Maximum voltage
T(1) = Time of first crossing
T(M) = Time at V(M)
T(n) = Time at last (n) crossing
Duration of event = T(n) - T(1)

Figure 1 Typical signal in AE events

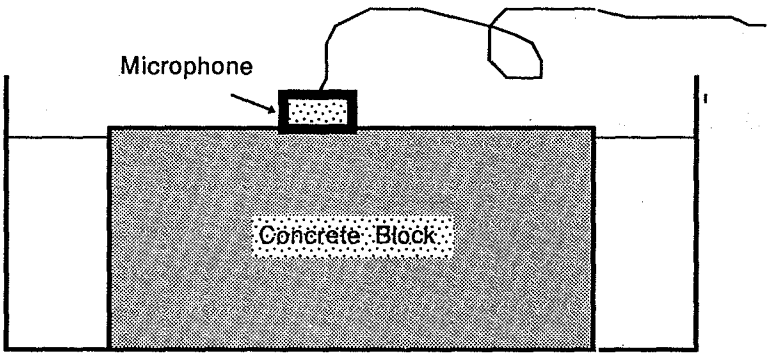

Figure 2 Acoustic emission test for alkali aggregate reaction

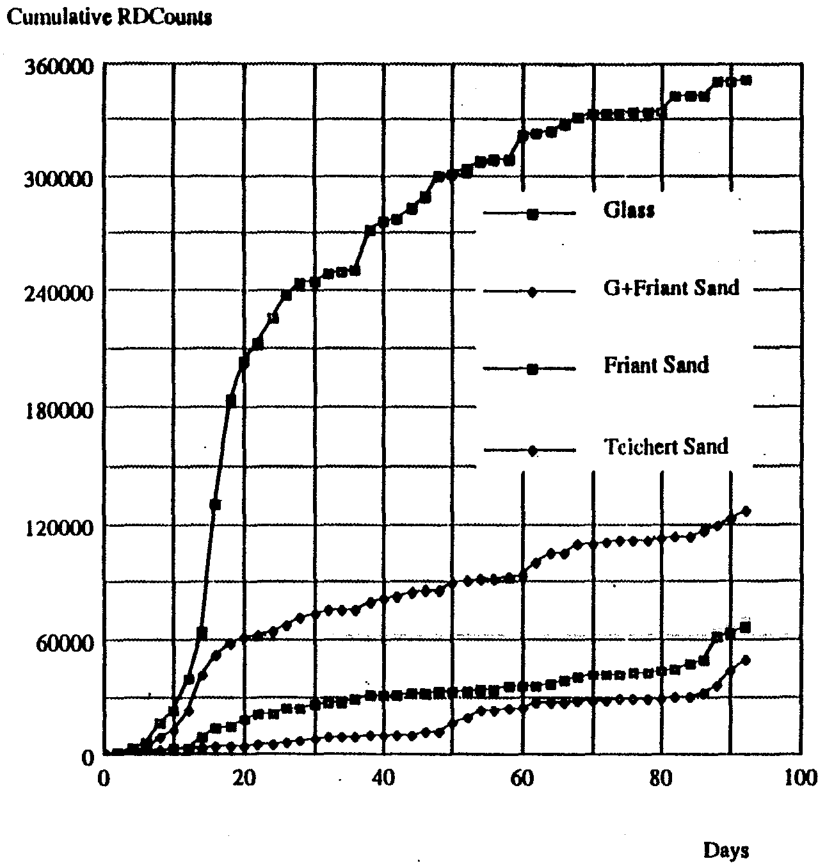

Figure 3 Acoustic emissions vs. time for concretes with different aggregates

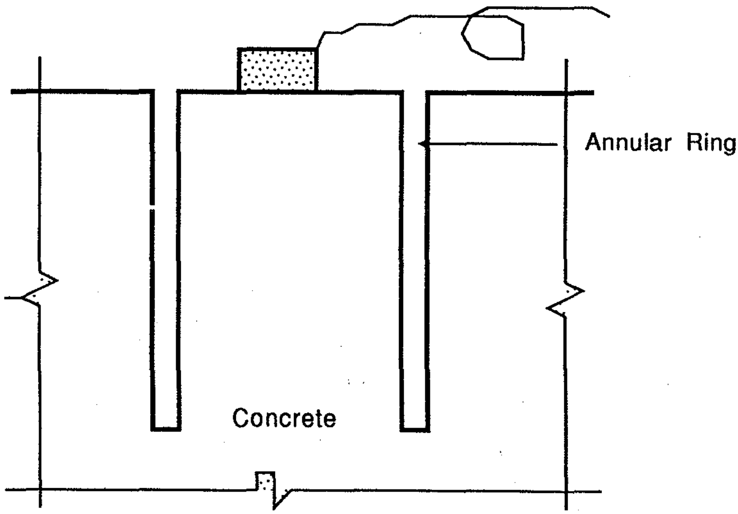

Figure 4 Possible field test for alkali aggregate reactions in concrete