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RAPID METHODS OF PREDICTING ALKALI REACTIVITY

Peter P. Hudec* and Joseph A. Larbi**

*Geology Department, University of Windsor,
Windsor, Ont. Canada, N9B 3P4
**Fac. Civil Engineering, Delft Univ. of Technology,
2628 CN Delft, The Netherlands

1. ABSTRACT

Alkali reactivity determination by standard ASTM C227 and CSA (Canadian Standard Association) A23.2-14A methods takes up to a year. Most concreting projects require test results within weeks. A rapid, reliable method that correlates well with the standard methods is described. Several variations of the rapid method are possible.

Existing concrete or concrete blocks cast specifically for the test can be used. In case of cast concrete, either 28 day moist or water curing, or 24h 80°C accelerated hot curing can be employed. 19mm or 26mm diameter concrete cores, 60 to 70mm long comprise the test specimens.

Changes in the length of the core after exposure to hot (80°C) 1N NaOH solution, or hot saturated NaCl solution are measured every two days for three weeks using a specially designed double LVDT (linear variable differential transformer) capable of measuring length changes to 10^{-8} cm.

Water/cement ratio, curing method, specimen diameter, and the reactive solution all have a significant effect on the results. Water/cement ratio of less than .45 gives the most correlatable results with standard tests.

2. INTRODUCTION

The need for a quick and reliable test method for Alkali Reactivity (AR) has been evident for some time. In any major project in which concrete is used, the lead-time for testing the aggregates for AR using the current 'standard' methods is seldom available. ASTM chemical test for aggregates[1] does not always detect reactivity, especially the silicate and carbonate variety; the ASTM mortar[2] and CSA concrete tests[3] take up to a year to complete. A variety of other rapid tests for aggregates designed to detect their potential silica reaction have been proposed: the BSI gel-pat test[4], the German dissolution test[5]' and the Osmotic Cell test[6] are some examples. However, the reactivity of aggregate in these tests does not always correlate to the reactivity of the concrete using the cement and additional fine or coarse aggregate available at the job site. A rapid test on the actual concrete mix is preferable. The test should work equally well on alkali silica, silicate, and carbonate reactive aggregate.

Rapid testing requires that the alkali reaction be speeded up. Elevated temperature and the excess of alkalis have been used to accelerate the reaction. A test that holds much promise was developed by Oberholster and Davies [7]' the so-called South African method. The test uses mortar prisms prepared in accordance with ASTM C-227 method. The prisms are de-molded after 24h, and hot-cured at 80^{o}C for 24 hours. The initial length is determined at this time. Subsequent length measurements are taken daily for 14 days while the prisms are immersed in hot 80^{o}C 1 N NaOH solution.

The same method to accelerate the reaction was used in this research. However, the specimen size was much smaller, and the measuring device used was, by necessity, much more sensitive. Specimens consisted of 19mm and 26mm diameter cores approximately 70mm long. The material was both concrete and mortar (for comparison). The details of the method are given below.

3. THE EXPERIMENTAL METHOD

3.1 Specimen Preparation:

The following aggregate types from Ontario were used in this study:

A. Three reactive coarse aggregates from stockpiles maintained by Ontario Ministry of Transportation. These aggregates, described by Rogers[8] were stockpiled by the ministry specifically for comparative AR research. One aggregate is silica-reactive (Sudbury), one silicate?-reactive (Stitsville), and the third carbonate-reactive (Kingston).

B. Two carbonate-reactive aggregates from Cornwall.

C. Crushed chert nodules from glacially-derived gravels near London.

D. An inactive carbonate aggregate as a control.

Portland cement, ASTM Type (I) with 0.781% Na_2O equivalent, and local, non-reactive quartz sand were used as the other components in the casting of the specimens.

Concrete Mix Proportions: Water/cement ratio of 0.42, sand/cement ratio of 1.6, and total aggregate/cement ratio of 4. Coarse aggregate was proportioned equally from four sizes: 9.5mm (3/8"), 6.7mm (1/4"), 4.75mm (No.4), and 2.36mm (No.8). Fully-graded, inactive quartz sand was used as a filler.

Mortar Mix Proportions (Chert only): The chert and inactive aggregate was crushed to sand size, and used in the proportions to water and cement as specified by ASTM C227. The chert content of the sand was adjusted to 0, .5%, 1%, 5%, 10%, and 20% of the total sand on each sieve size.

Sufficient amount was mixed to produce two blocks of each aggregate type, measuring 12cm x 12cm x 9cm. One set of the blocks was moist-cured at a temperature of about 22 C for a period of 28 days. Another set, after 24h initial set, was rapid cured for 24h at 80^{o}C.

At the end of the curing period each of the blocks was cored to produce four 19.0 mm (3/4") diameter cores, and four 26.0mm (1") cores. The cores were trimmed to an approximate length of 60 mm and dimples (indentations) were made at the center of each end. The dimples enabled the specimens to be held in place during the length measurement. This obviated the need for casting steel pins at the end of the specimens.

Sufficient block remained to create another full set of cores. This approach allowed repeat experiments on the same mix, and treatment of cores from the same block to study the treatment effect on AR (reported in companion paper).

Concrete prism using the above aggregate were cast, cured, and tested according to CSA A-23 method. The results were used as basis of comparison for all rapid test results.

3.2 <u>Length Measurements</u> (Rapid Method)

The small size of specimens required a very accurate measurement of their length. LVDT (linear variable differential transformer) has been used for such measurements in the past. However, the specimen had to remain in the machine, the environment around the sample (temperature, moisture, etc.) was changed, and the specimen's response measured.

To utilize the sensitivity of the LVDT, and allow the removal of the sample to its environment, two LVDTs of different sensitivities were utilized. The 'coarse' LVDT, connected to a micrometer dial, was used to bring the sample within the measuring range of the more sensitive 'fine' LVDT. The 'coarse' LVDT has a sensitivity of 0.001 mm. The 'fine' LVDT is spring loaded, and has a sensitivity of 0.0001 mm. A linear relationship (r=.99) exists between the coarse and fine LVDT readings, and the two readings together are used to obtain the length readings. All measurements are under computer control. The operator is instructed through series of prompts to enter information about the sample, and to take the readings. The schematic diagram of the Double LVDT is shown in Figure 1.

The LVDT is calibrated against a standard ceramic core at the beginning of each measurement set. The set consists of three cores per sample or condition. A second standard ceramic core is measured at the end of the measurement set. Seven individual length readings are taken per core. A statistically 'cleaned' average (+/- 1 standard deviation) is obtained, which is then adjusted to the two ceramic core averages. In this way, variation in the instrument due to temperature and other factors are minimized. The multiple readings and statistical 'cleaning' give very accurate and reproducible results. The reproducibility of measurement on a single core was determined to be +/- 0.0002 mm. Averaging of the results for three cores improves the reliability of the data. The automation allows handling of several tens of samples with ease. The computer data files obtained by the Double LVDT are transferred to an IBM-compatible PC spreadsheet for calculation of length changes and plotting of results. A spreadsheet template was pre-programmed to handle all computations and plotting automatically.

The Double LVDT is, at the moment, a research-grade equipment, but can easily be adapted for routine testing.

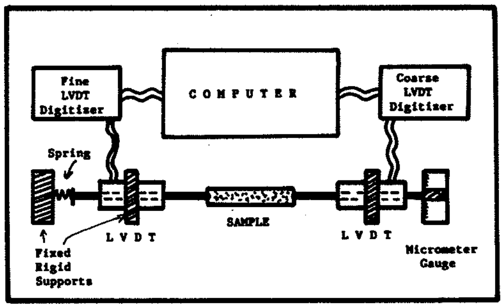

Fig. 1 Schematic Diagram of The Double LVDT Length Measuring Equipment

4. RESULTS OF EXPERIMENTS

4.1 The Effect of Curing:

Companion concrete blocks were cast, de-moulded after 24h, and cured by two different methods: One set was cured in water at 80°C for 24 hours, and the other in water at room temperature (22°C) for 28 days. No appreciable difference was noted, except that the 28-day cure gave more consistent, less variable results. Greater scatter about the expansion trend line was noted with the hot-cure samples. This, however, could simply be an experimental aberration.

4.2 The Effect of Water-Cement Ratio:

The water cement ratio plays an important part in AR testing, especially in the smaller size specimens. The W/C ratio of 0.45 resulted in more than double the expansion of concrete with the 0.55 ratio. This is illustrated in Figures 2 and 3. Note that the difference in expansion affects only the concrete containing the reactive aggregate. The small expansion of the non-reactive aggregate concrete remains unchanged. Opposite results to the above were obtained by Davies and Obelhoster[9]. They showed a near linear increase in expansion with increase in W/C ratio.

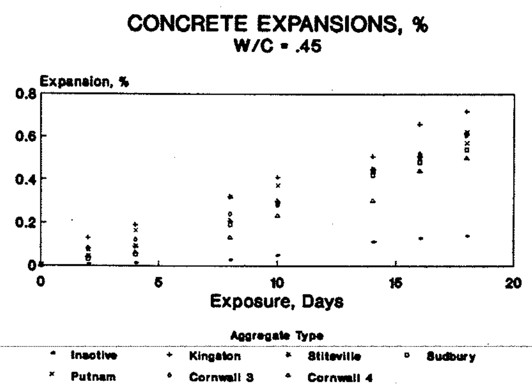

Fig. 2. AR Expansion of w/c 0.45 Concrete

The difference can be attributed to the greater porosity and permeability of the concrete with higher W/C ratio, accommodating the expansion products and forces. The W/C ratio may affect only the early expansion by delaying it; the long-term expansion may prove to be the same. Rapid testing methods must address this question with more research.

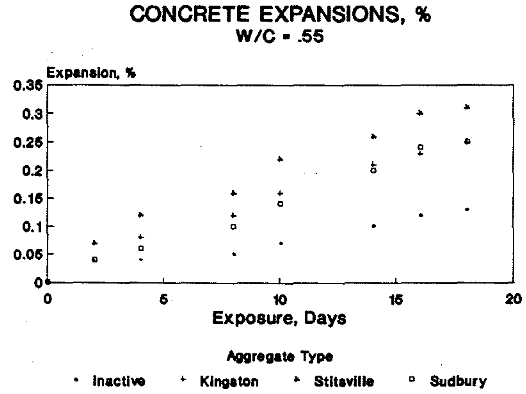

Fig. 3. AR Expansion of w/c 0.55 Concrete

4.3 The Effect of Specimen Size:

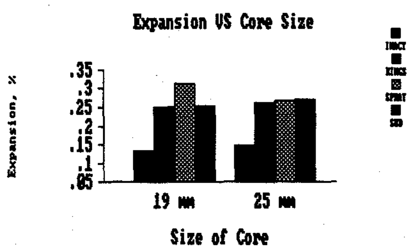

Fig. 4. Effect of Core Size on AR Expansion

The size of the core diameter did not affect the expansion appreciably (Fig. 4). This is somewhat surprising, since the aggregate size relative to the concrete specimen volume was considered to be of importance. A small core size may not include a representative sample of the reactive aggregate in the concrete; it may also prevent the development of expansive pressures by diffusing the reactive products to the periphery of the core. However, the experiments indicate that a significant and equivalent expansion can be obtained even in relatively small size cores of concrete.

This finding, if corroborated, suggests that smaller samples of concrete than those currently used may be taken for AR testing. The small sample could be taken from existing concrete, and would not adversely affect the function or aesthetics of the structure.

4.3 Mortar Expansions and the Pessimum Effect

Mortar blocks were prepared according to ASTM C227-86 method. Putnam chert used in the above experiments was crushed and substituted for each of the sand fractions in proportion of 0, 0.5, 1, 5, 10, and 20 percent. After de-molding (24h), the mortar blocks were fast cured at 80°C for 24h, cored to 26mm diameter, and prepared for accelerated testing.

The results of the test are given in Fig. 5. It can be seen that no difference in expansion can be seen in concentrations up to 1%. In greater concentrations, the amount of expansion at any time is exactly

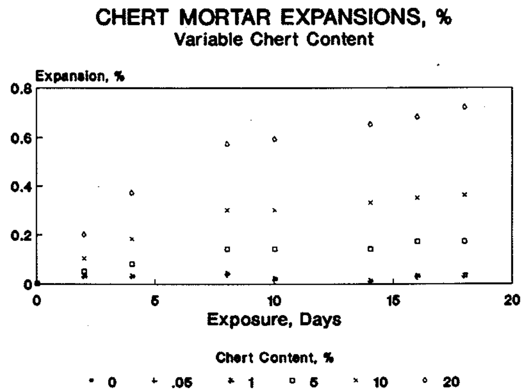

Fig. 5 AR expansion of mortar cores with different chert contents

proportional to the chert content: doubling the chert content doubles the expansion. No pessimum effect could be detected up to 20%; perhaps it exists at greater concentrations. However, pessimum effect is obtained at the optimum concentration of both silica and the alkali[10]. In the case of accelerated testing in hot, 1 N NaOH solution, the pessimum effect should not be observed, since there is an excess of alkalis. Oberholster and Davis[7] also observed linear relationship between opal content and expansion.

The expansion observed in the mortar with 20% chert is approximately the same as that of concrete of w/c ratio of 0.45 containing chert as coarse aggregate. Presumably, the mortar with greater chert content would have proportionately greater expansion. However, the results indicate that both the mortar and concrete can be used in AR rapid testing, but the 'acceptable' limits have to be adjusted.

4.4 Comparison to Standard Tests

The expansion results obtained on 19mm cores with the w/c ratio of 0.45 were compared to the ASTM C227 prism expansion on mortars made with the same aggregate. The data were correlated by linear regression. The equations derived are given below for the silica reactive aggregate.

Expansion % C227 Months	= Exp. % Rapid Days	Constant	R
PUTNAM CHERT	= 0.543 x Exp	+0.02	.986
SUDBURY	= 0.381 x Exp	+0.02	.956
COMBINED	= 0.487 x Exp	+0.02	.947

The good correlations allow the calculation of probable C227 expansion from the accelerated test results. For instance, the expansion observed on day 12 of the rapid test would calculate to equivalent expansion expected on month 12 of the ASTM C227 test. Best correlation is obtained when the same aggregate type is correlated; however, even the correlation of the combined sample is good.

The detailed description of the method, and the comparison of standard vs. rapid testing on the 19mm core is given in [10].

5. CONCLUSIONS

A number of items emerge from the results of the accelerated AR testing method described here:

1. Concrete shows significant AR expansion in a sample that is relatively small compared to the size of the aggregate.
The expansion is similar for samples of two different volumes (19mm and 26mm diameter cores).

2. The expansion of concrete in the rapid test is smaller than the expansion of the mortar containing the same aggregate.

3. The rapid AR expansion is very dependent on the water-cement ratio of the mix.

4. The pessimum effect is not found in the hot NaOH test, because the method provides an excess of alkalis.

5. Good correlation is obtained between the ASTM C227 mortar method expansion and the expansion of even the smallest size (19mm) concrete cores in the rapid method. The regression equation can be used to predict the C227 expansion from the rapid method results.

6. ACKNOWLEDGMENTS

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