11th ICAAR 11e CIRAG Québec 2000
11th International Conference on Alkali-Aggregate Reaction
11e Conférence Internationale sur les Réactions Alcalis-Granulats

ACCELERATED ASR TESTING OF CONCRETE PRISMS INCORPORATING RECYCLED CONCRETE AGGREGATES

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ABSTRACT

This study is investigating techniques and procedures to assess the potential for ASR in concrete and concrete made from recycled concrete aggregate (RCA) which was known to have ASR, or is capable of ASR under conditions of increased alkali. The methods evaluated include prisms with variable surface to volume ratio, increased temperature, microwave energy, increased alkali content, and ultrasonic energy.

Concrete prisms with cast parallel holes are significantly accelerated in the ASTM test and variation between samples is lowered. The expansions of concrete cubes with cast holes sealed in evacuated plastic bags with water were found to be greatly accelerated as compared to standard prisms in the ASTM test. Solid cubes sealed in evacuated plastic bags with water in the presence of microwaves are greatly accelerated. The modified ASTM C 1260, Modified ASTM C 1293 and the microwave energy tests effectively accelerate ASR in concrete prisms.

Keywords: ASR, alkali, concrete, recycled concrete, accelerated testing, prisms, microwave

INTRODUCTION

Many miles of concrete pavement in the United States are known to have Alkali-Silica Reaction (ASR) and eventually will require rehabilitation, replacement or recycling. Little is known about the case when recycling is elected as an option to consider. The effect of using Recycled Concrete Aggregate (RCA) in concrete, which has been obtained from concrete with ASR, has not been adequately researched. Present testing procedures like ASTM C 1260 are too conservative to use to evaluate the use of RCA because the concrete would have to be crushed to retrieve the original aggregate and the true reactivity of the RCA would not be known. For instance, the case when the available alkali has been lowered such that the ASR reaction has gone to completion, the RCA would be innocuous in a recycled mix with restricted alkali. This would not be apparent from ASTM C 1260 testing.

There is a real need for an accelerated test to evaluate RCA for possible use in recycled concrete where the proposed mix could be quickly tested. The ASTM C 1293 test is presently used as a means of accepting a given concrete but unfortunately the test must be conducted for up to 12 months before a decision can be made. This paper deals with the initial development of accelerated testing procedures to evaluate concrete made with RCA, which has ASR or potentially could develop ASR under increased levels of alkali.

MATERIALS

A section of Wyoming I-80 near Cheyenne, which showed deterioration from ASR, was recycled in 1992 using RCA. Most sections of this recycled pavement showed no signs of continued ASR, however several miles began to show ASR after only 3 years. The aggregates used in the WY I-80 concrete and WY I-80 RCA was selected as test aggregates to develop accelerated ASR tests. These aggregates geologically are of volcanic origin and contain a variety of rocks (granite, basalt, diorite, crystal-vitric tuff, rhyolite, and andesite). The portland cement elected as a control (except as noted) had an equivalent Na_2O alkali content of 1.37% (K_2O = 1.45% and Na_2O = 0.42%) with a MgO content of 3.2% and an autoclave expansion of 0.11%. A quantity of the original reacted section of I-80 was obtained and stored under nitrogen until crushed and used as RCA in the mixes.

The concrete test mixes were proportioned with a cement content of 402.7 kg/m^3 (678.6 lb/yd^3), 1,151.6 kg/m^3 (1,940 lb/yd^3) of coarse aggregate and 827.9 kg/m^3 (1,395 lb/yd^3) of fine aggregate with a water-cement ratio of 0.43 and an air content of 6% +/- 1%. The coarse aggregate was either the original Wyoming aggregate or the RCA form I-80 without fines. The fine aggregate was innocuous glacial sand from New Hampshire.

METHODS

Modified ASTM C 1260

This test consists of performing a modified ASTM C 1260 test on concrete samples. The test is fast for the small 25 mm x 25 mm x 280 mm specimens because of the very high concentration of alkali, the increased fineness of the aggregate, and the high surface to volume ratio of the mortar bar sample. The standard test is not usable for RCA because of the restricted maximum aggregate size in the small molds. Modifications to the test included using larger 76.2 mm x 76.2 mm x 279 mm molds and varying the surface area to volume ratio of the samples. The following shapes were evaluated:

1. 76.2 mm x 76.2 mm x 279 mm solid prism
2. 76.2 mm x 76.2 mm x 279 mm prism cast with four 6.35 mm diameter holes
3. 50.8 mm x 50.8 mm x 279 mm cut from the standard solid prisms
4. 76.2 mm x 76.2 mm x 76.2 mm solid cube cut from a large solid prism
5. 76.2 mm x 76.2 mm x 76.2 mm cube cut from a large prism with four holes

Four holes with a 6.35 mm diameter were cast parallel to the longitudinal axis of the prisms as shown in Figure 1. The holes were equally spaced on the cross section such that a 19 mm maximum aggregate size could pass between the surgical tubes used to cast the 6.35 mm holes.

A 0.75 volume of 1 normal NaOH solution to unit volume of sample prism was used in the testing. These were selected so as to conform to previous work done by David Stark at CTL (1993) and Benoit Fournier at the International Centre for Sustainable Development of Cement and Concrete (1998). This is much lower than normally used in the ASTM C 1260 but maintaining the larger ratio is not practical due to the large tanks required.

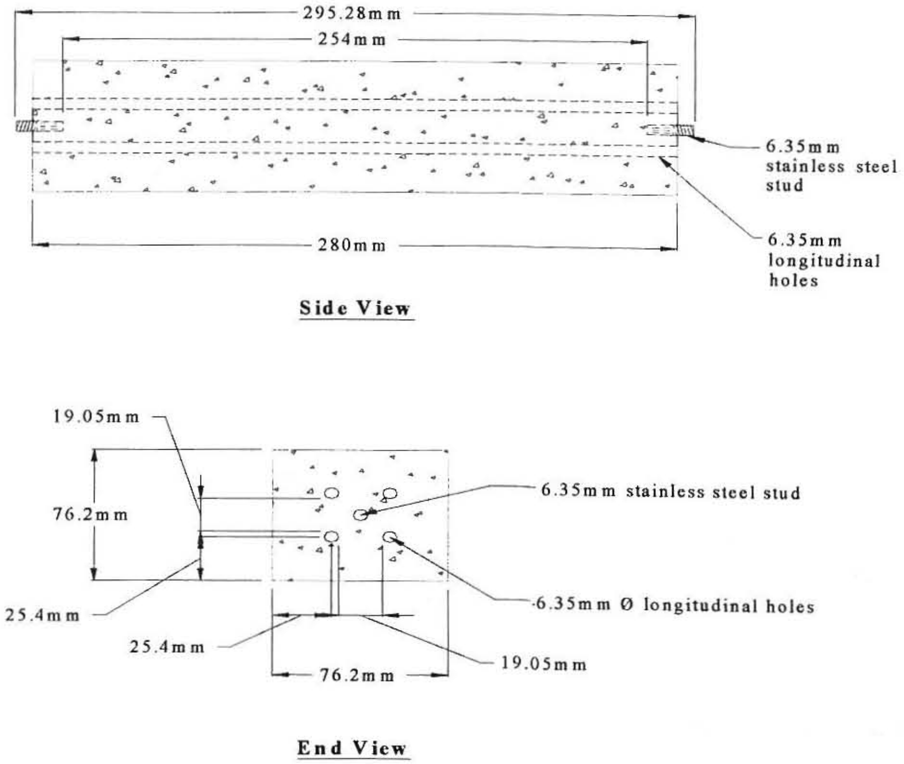


Fig. 1: Side and end view of the prisms with cast longitudinal holes.

ASTM C 1293 Test

When evaluating RCA concrete it is essential that a test be available to evaluate the actual mix design being proposed for use. The preferred test would not increase the alkali content past the level expected under actual field conditions and must be reasonably quick so a decision on mitigation may be made and evaluated prior to specifying the final concrete mix. The ASTM C 1293 test is the best presently available test for relating field performance to laboratory testing, however it takes up to one year of monitoring.

This test is used to compare the accelerated expansions of the evaluated tests. The object was to have statistically confident expansions comparable to the one year ASTM C 1293 but in a much shorter time period.

Modified ASTM C 1293 Over Water at 80°C

The standard ASTM C 1293 test is an excellent test, and is generally accepted as the controlling test for determining if ASR will be an issue in a given mix. The problem as previously discussed is that monitoring may take one year. This led to running the ASTM C 1293 at a higher temperature and different moisture conditions to see if it is possible to make an early evaluation of expected ASR expansion. The samples were stored over 80°C water after they were sealed.

The sealing process involved covering the prisms with Saran® wrap, duct tapping both ends, placing the wrapped sample in a plastic bag with 25 ml of water then evacuating with a vacuum pump and heat-sealing to assure constant moisture. Test samples were suspended above 80 °C water in a water bath used in the ASTM C 1260 test. Standard solid prisms, prisms with holes and cut prisms with the smaller 50.8 mm cross section were evaluated.

Microwave Energy

Microwave energy has been used in the concrete industry to determine the water-cement ratio of plastic concrete (Gress and El-Korchi 1986), and to accelerate the curing of concrete (Sohn and Johnson 1999). The microwave test is mechanically set up such that air at 38°C is discharged from the ASTM C 1293 test into a large insulated box, which contains six microwave ovens. Each oven has a safety high temperature shut off circuit and a timer to turn the magnetron on and off to control the amount of energy dispersed to the concrete. The procedure was to maintain the samples at 38°C while applying repeating bursts of microwave energy (7 seconds every 10 minutes giving a total of about 16 minutes of 1100 watts of microwave energy per 14.79 kg of sample per day = 74.4 watts per kg per day). This basically reproduces the ASTM C 1293 test but with the addition of microwave energy. The samples were sealed in plastic bags as described above.

RESULTS AND DISCUSSION

Modified ASTM C 1260

The plot of the ASTM C 1260 expansions for the WY aggregate is presented in Figure 2A and shows the 14-day expansion to be approximately 0.21%. Results from the modified test for concrete made with the WY aggregate are shown in Figure 2A. Figure 2B shows the RCA concrete to have a lower expansion than the WY aggregate concrete as would be expected due

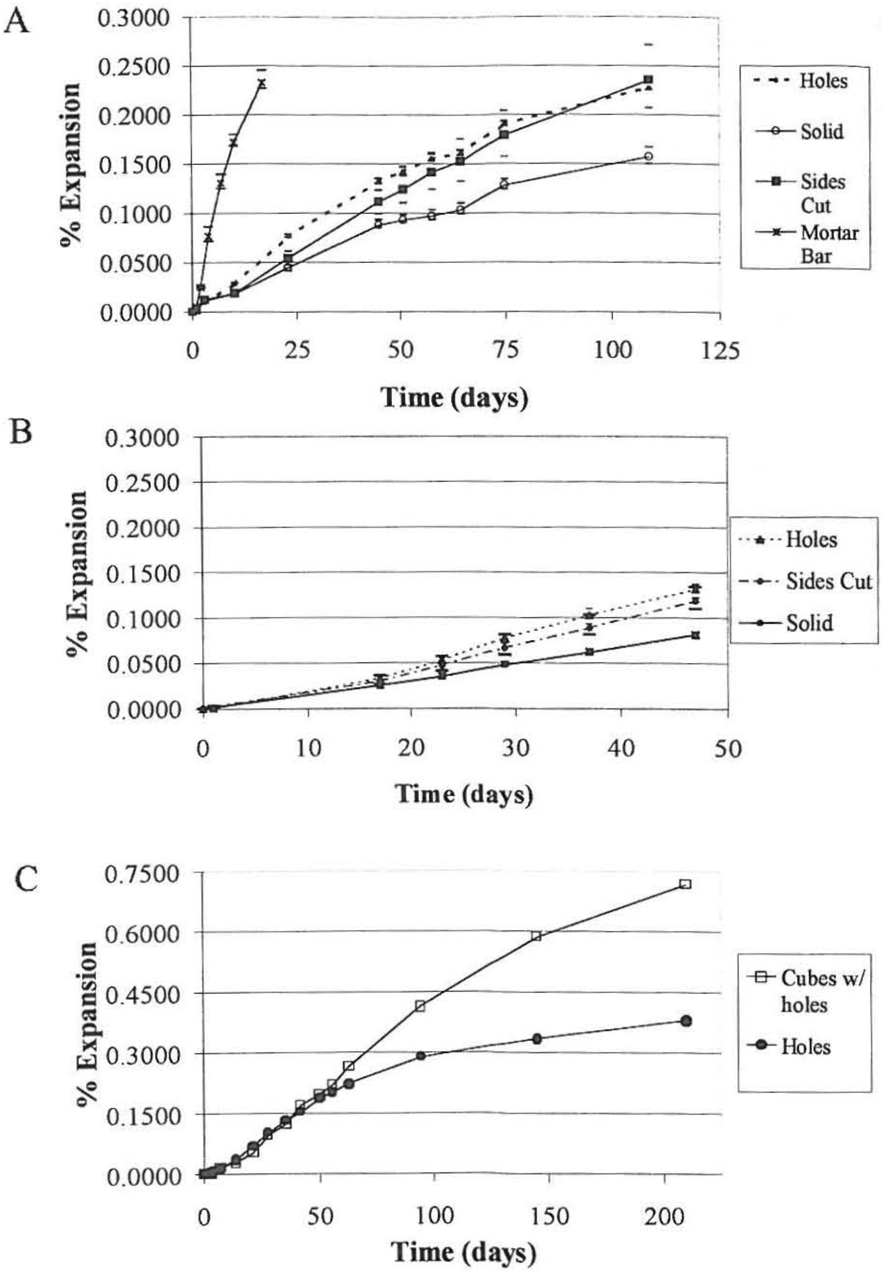


Fig. 2: (A) plot of standard ASTM C 1260 for Wyoming aggregate, (B), Plot of the ASTM C1260 Wyoming RCA concrete expansion data using cement with a Na_2O equivalent content of 1.15%. (C), Plot of the ASTM C1260 Wyoming RCA concrete using cement with a Na_2O equivalent content of 1.37%.

to less reactive aggregate per unit volume of sample and or more pore space within the RCA to contain ASR gel without expansion. The samples from these three figures were made with a cement from a different millrun and had an equivalent Na_2O content of 1.15% as compared to the control cement of 1.37%. These data show that the samples with holes and sides cut react significantly faster than the solid prisms. The holes also very much reduce the variation of the test data as shown by the data range bars while the cut sides increased the variation. Figure 2C shows the plot for the RCA concrete made with the cement with the higher equivalent Na_2O content. The 28 day expansions for the prisms with holes are 0.089 %, 0.077 % and 0.102 % for the aggregate concrete, RCA concrete with the lower equivalent Na_2O content and the RCA concrete with the control cement respectively. The RCA concrete expands less than the aggregate concrete whereas with higher alkali the RCA expanded more than the aggregate concrete.

These data show the RCA concrete to respond similarly to the NaOH but at a slower rate than the new aggregate concrete. The rate of expansion is faster for the cut samples and samples with holes. The samples with holes, cut faces, and solid have surface/volume ratios of approximately 1.5, 2.0 and 1.3 respectively. In that the prisms with holes expand at an increased rate suggest the mechanism of expansion is more related to diffusion than just exposed surface area. The holes provide internal access of the NaOH and the distance for the fluid to uniformly permeate the sample is greatly reduced.

All of these samples show expansions, which as per criteria developed by Benoit Fournier et al. (1999) would require some form of mitigation to reduce the expansion caused by ASR. These criteria show a good correlation between 0.04% expansion at one year for samples held at 38 °C and 100% RH (similar to ASTM C 1293) and with samples held at 80 °C in 1 normal NaOH for 4 months (similar to this modified ASTM C 1260).

ASTM C 1293 Test

Figure 3A shows the plot for ASTM C 1293 expansions for the RCA concrete. As with the other testing the samples with holes expand at a higher rate than the solid prisms. The cube samples expand almost 3 times as fast as the standard prism did at 14 days. Figure 3B shows the plot for the modified version of the ASTM C 1293 where the samples were sealed in an evacuated bag as previously described. The expansions are slightly higher than those of the standard test at 14 days and the data are more consistent showing little difference between samples except for the cubes with holes. The cube samples showed about two times as much expansion at 28 days when compared to the standard test.

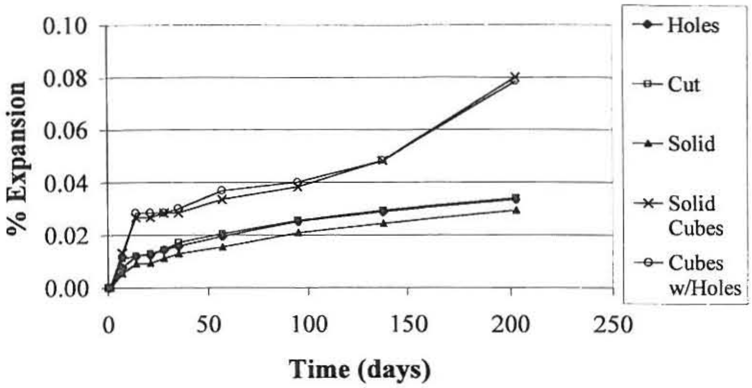
Modified ASTM C 1293 Over Water at 80°C

The results of storing the samples in sealed bags at 80°C are shown in Figure 4A. These data show expansions similar to the sealed samples at 38 °C except the expansions are slightly larger.

Microwave Energy

The microwave data are shown in Figure 4B and as with the other tests the small cubes show more expansion than the larger prisms. However, unlike the other testing procedures the solid prism samples, including the smaller cubes actually have higher expansions. This is most likely due to the deep penetration ability of the microwaves. The 21 day expansion of the solid cubes was 0.04%, about two times as much as the solid standard prism.

A



B

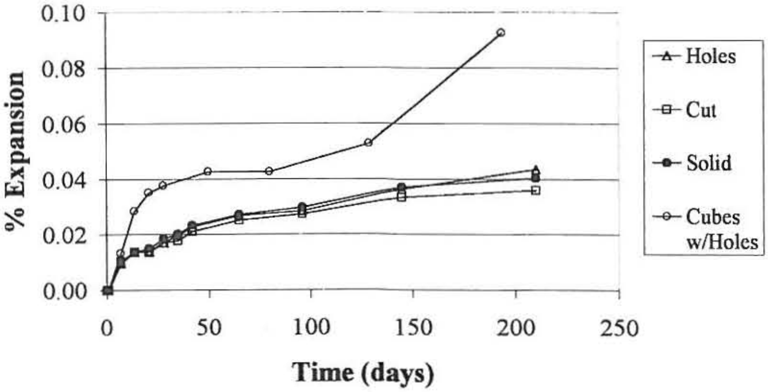
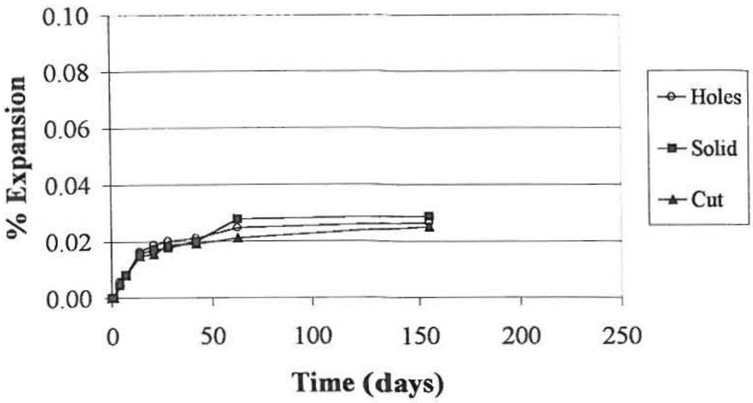


Fig. 3: (A), Plot of the ASTM C 1293 expansion data for Wyoming RCA concrete. (B), Plot of the Modified ASTM C 1293 expansion data for Wyoming RCA concrete samples sealed in evacuated plastic bags with 25 ml of water.

A



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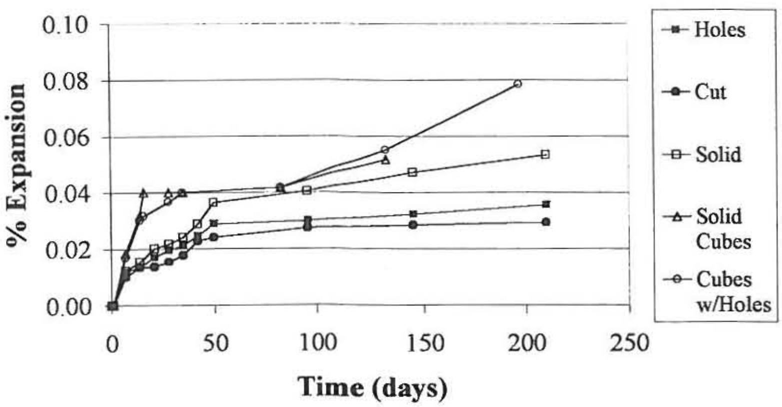

Fig. 4: (A), Plot of the Modified ASTM C 1293 expansion data for Wyoming RCA concrete at 80°C and samples sealed in evacuated plastic bags with 25 ml of water. (B), Plot of microwave expansion data for Wyoming RCA concrete with samples sealed in evacuated plastic bags with 25 ml of water.

CONCLUSIONS

Based on these data the following conclusions seem appropriate:

1. Concrete prisms with cast holes show accelerated expansions in the ASTM C 1260 test.
2. Prisms with cast holes show less variation between samples in ASR testing.
3. Cubes with cast holes vacuum-sealed with water in plastic bags show greatly accelerated expansion in the ASTM C 1293 test.
4. Increasing the temperature of the ASTM C 1293 test to 80 $^{\circ}$C only slightly increased expansions of the large prisms.
5. Solid cubes and prisms when subjected to low levels of microwave energy show accelerated expansion as compared to ASTM C 1293 sealed samples.

ACKNOWLEDGMENTS

The authors thank the US DOT FHWA for funding this project. Special thanks go to the FHWA technical representative, Dr. Stephen Forster, for his contribution of personal support and technical guidance.

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