Effect of Confinement on Deterioration of Concrete Made with Alkali-Carbonate Reactive Aggregate

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ABSTRACT

The effect of confinement on expansion and deterioration of concrete made with alkali-carbonate reactive aggregate was studied using post-tensioned concrete prisms and concrete disks confined in ring moulds. Flexure strength of confined three-year old concrete containing reactive aggregate was 80% of that of unconfined concrete made with non-reactive reference limestone, while the flexure strength of unconfined concrete was only 50% of that of the reference limestone. No evidence of dedolomitization was found in either concrete made with reactive aggregate. This suggests that the expansion of concrete containing reactive alkali-carbonate aggregate cannot be initiated by dedolomitization, as postulated for the mechanism of reaction.

INTRODUCTION

Field experience has shown that pre-stressing of concrete beams generally does not prevent cracking due to alkali-aggregate reaction. Elongated cracks tend to develop parallel to the reinforcing and pre-stressing is frequently lost due to cracking. Experiments now described were carried out to investigate the effect of confining pressure on the deterioration of concrete due to alkali-carbonate reaction, and to determine whether the degree of dedolomitization or reaction rim formation is affected.

EXPERIMENTAL DETAILS

Materials

Aggregate from the most expansive horizon of the Pittsburg quarry near Kingston, Ontario, Canada, was used as the coarse aggregate. A non-reactive quartz sand from Hull, Quebec, was used as the fine aggregate. The cement had an alkali content of 1.08% Na_2O equivalent. The mix contained the equivalent of 320 kg cement/m^3 concrete. The w/c was 0.45. Concrete prisms stored at 38°C and 100% humidity expanded by 0.4% in three years (Fig. 1).

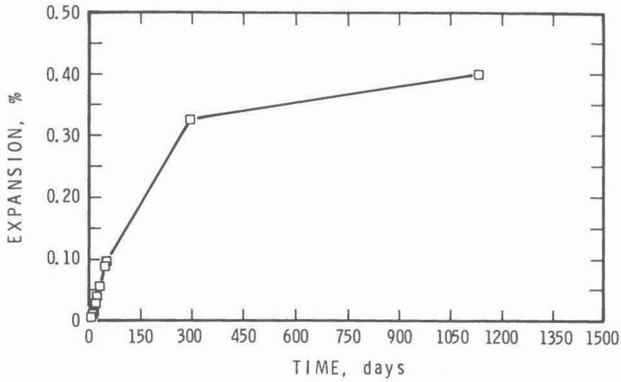

Figure 1. Expansion of unconfined concrete prism made with reactive alkali-carbonate aggregate and high alkali cement

Technique

Confinement of concrete was achieved by two methods; post-tensioning, and casting in ring moulds.

Post tensioning -- Concrete prisms 7.5 by 7.5 by 30 cm were cast with a hole down the length of the prism. After 24 h of moist curing the prisms were demoulded and a threaded post-tensioning rod was passed through the hole. Steel plates and nuts were placed on the ends. A confining pressure of 1200 N/m^2 was applied with a torque wrench.

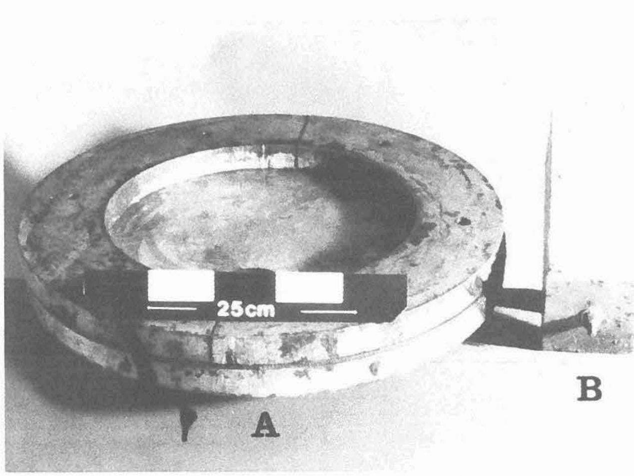

Figure 2. A -- Ring mould made from 2.5-cm thick steel plate
B -- Post-tensioned concrete prism 30 cm long

Ring moulds -- Concrete disks 2.5 cm thick and 28 cm in diameter were cast in circular moulds made of 2.5-cm thick steel plate 44 cm in diameter. Lateral expansion was prevented by the steel retaining ring. A post-tentioned prism and a ring mould are shown in Fig. 2.

Storage Conditions

After curing in the humid room for 24 h, the samples were transferred to storage at 38°C and 100% humidity for one year. They were then transferred to storage at 23°C and 100% humidity for another two years. At the end of the three-year storage period the concrete was examined.

RESULTS

After three years of moist storage the unconfined concrete prisms had expanded by 0.4% and showed extensive map cracking. The post-tensioned concrete prisms were also badly cracked, but the concrete disks from the ring moulds showed only fine cracks that appeared to be mostly re-cemented. Polished slabs prepared from all the samples were examined by low-power stereoscopic binocular microscope. The percentage of coarse aggregate particles showing reaction rims and both cracks and rims were determined. The results are shown in Fig. 3a. For comparison, the percentage of coarse aggregate particles without defects is shown in Fig. 3b.

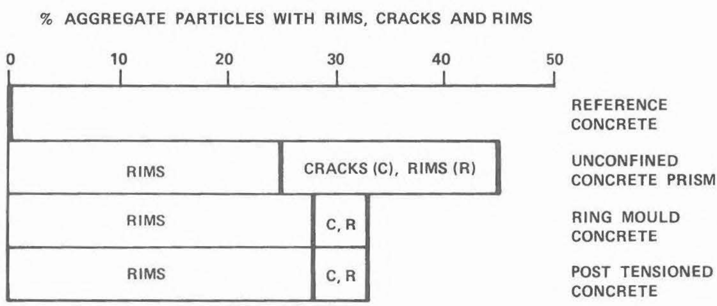

Figure 3a. Percentage of coarse aggregate particles with reaction rims or a combination of cracks and rims

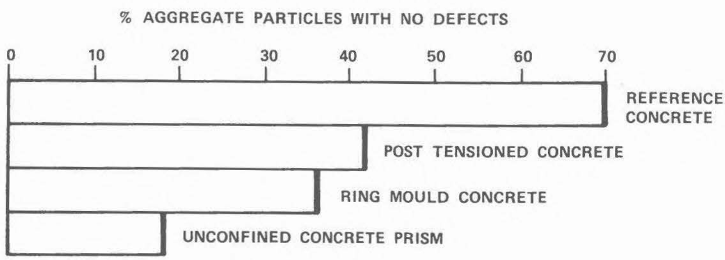

Figure 3b. Percentage of aggregate particles (in four concrete samples) with no defects, i.e., without reaction rims or cracks

Small beams 2.5 by 2.5 by 25 cm were sawn from the concrete samples and tested in flexure; Fig. 4 shows the flexure strength as a percentage of that of beams of non-reactive reference concrete. Reference concrete prisms 7.5 by 7.5 by 30 cm were made with non-reactive limestone from Ottawa, Ontario.

After three years of storage at 100% humidity the flexure strength of the concrete made with alkali-carbonate reactive aggregate and high alkali cement, and subjected to confining pressure, was about 80% of that of concrete made with the non-reactive reference concrete. By comparison, the strength of unconfined concrete made with the same reactive aggregate was only about 50% of that of the reference concrete (Fig. 4).

Examination of polished slabs of the concretes showed that in all samples, including the non-reactive reference beams, 20 to 30% of the aggregate particles were fractured, presumably in the crushing of the aggregate. There was no difference in the number of reactive aggregate particles exhibiting reaction rims in confined and unconfined concretes, but the number of particles showing both cracks and reaction rims was 25% higher in the unconfined concretes (Fig. 3a). The latter observation probably accounts for the improved flexure strength of the confined concretes. Similarly, the confining pressure appears to have increased the percentage of particles free from cracks or rims (defects) (Fig. 3b).

Owing to the observed effect of confining pressure on flexure strength and on the number of aggregate particles showing both cracks and rims, it was decided to examine the reaction rims to determine whether confining pressure had had any effect on the composition of the reaction rims or the degree of dedolomitization. Examination of reaction rims by XRD and EDXA in the SEM revealed no difference in composition between the centre of reactive aggregate particles and the dark rims (Fig. 5), which are probably due to physical alteration. EDXA showed that the Ca/Mg count ratio in dolomite rhombs from the reacted concrete was essentially the same as in unreacted aggregate. Spot analyses of various locations on dolomite rhombs taken from unconfined concrete showed no evidence of change in the Ca/Mg ratio at the centres and edges of the rhombs. The points analysed and the Ca/Mg ratios obtained for one rhomb are shown in Fig. 6. The mean value of the Ca/Mg count ratio measured from a number of dolomite rhombs in unreacted dolomitic limestone aggregate was 6.4, with a standard deviation from the mean of 0.9. The high value for the Ca/Mg ratio of 9.9 at one end of the rhomb is probably erroneous since this location also gave high counts for Si, Al, and K, indicating that the beam had probably excited cement paste near the edge of the sample. The electron beam excites a volume of about 2 μm diameter; for this reason it is difficult to obtain meaningful analysis from points

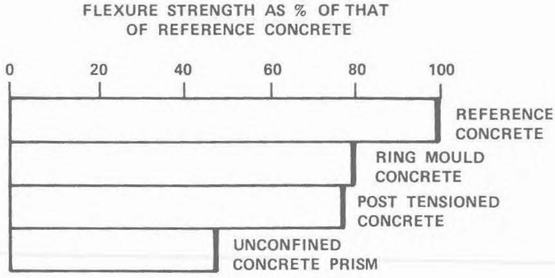

Figure 4. Flexure strength of concrete samples plotted as a percentage of that of reference concrete

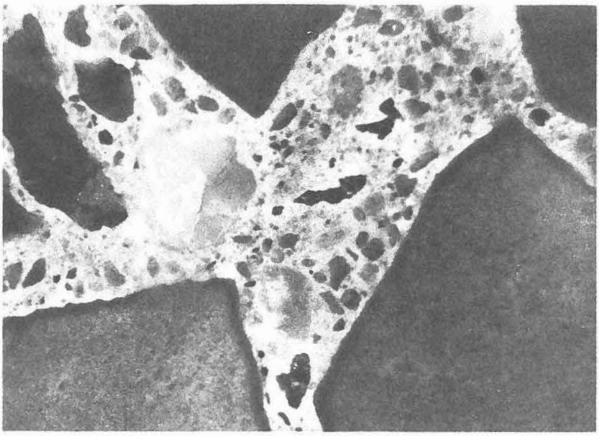

Figure 5. Dark reaction rims around particles of reactive dolomitic limestone aggregate in concrete

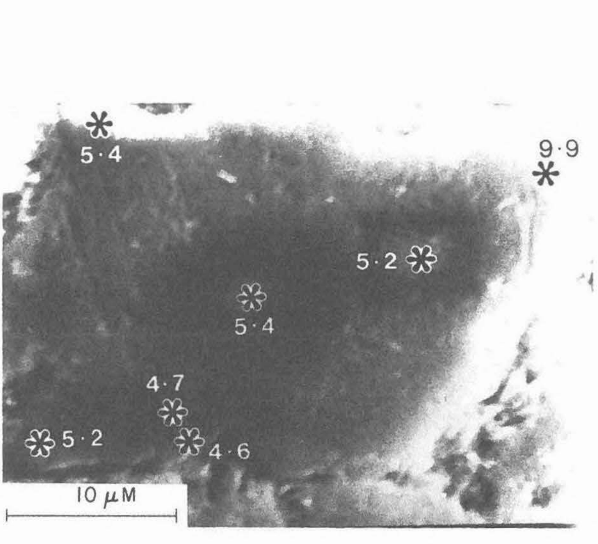

Figure 6. SEM micrograph of dolomitic rhomb in polished slab of reacted dolomitic limestone aggregate. (The location of the areas analysed is shown by *. The number beside the * gives the Ca/Mg count ratio)

near the edge of a grain. It must be concluded that although the concrete had expanded and cracked and reaction rims had formed around some particles of reactive aggregate, significant dedolomitization had not occurred as hypothesized by Swenson and Gillott (1964). Tentative confirmation of these conclusions was obtained by Litvan (personal communication) when he found, by XRD analysis, that significant dedolomitization (as shown by an increase in the calcite/dolomite ratio) did not occur in miniature rock prisms immersed in NaOH solution until much of the ultimate expansion and cracking had already occurred.

DISCUSSION

Several theories have been proposed to account for the expansion of dolomitic limestone in alkaline solution. The commonly accepted theory (Swenson and Gillott 1964) is that reaction of dolomite with alkali exposes "active clay minerals" which occur as inclusions in the dolomite rhombs; that exchange sites on the surface of the active clay particles adsorb Na ions; and that uptake of water by the altered clay particles results in swelling. As no evidence of dedolomitization could be found (in the present study) of concrete that had expanded and cracked, it would appear that dedolomitization may be a secondary effect occurring after expansion rather than the underlying cause.

The results of these experiments show that under laboratory conditions the flexure strength of confined concrete containing reactive carbonate aggregate may be up to 60% higher than that of unconfined concrete of the same composition. Although post-tensioned concrete showed improved flexure strength, the prisms exhibited extensive cracking. From this observation it may be concluded that it is unlikely that significant improvement in the durability of field concrete would be obtained by the application of confining pressure by means of post-tensioning or prestressing. It would not be feasible to apply the same confining pressure in the field as was achieved by the ring moulds. Furthermore, it must be realized that higher expansion and further deterioration of concrete containing reactive aggregates occurs in field concretes due to the combined effects of alkali-aggregate reaction, cycles of heating/cooling, wetting/drying, and freezing/thawing than in laboratory samples. For this reason it is not advisable to extrapolate from laboratory results directly to field concrete without first carrying out out-door exposure experiments.

REFERENCE

Swenson, E.G. and Gillott, J.E. 1964. Highway Res. Rec. 45:21-40.

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