Chemical Expansion of Fresh Concrete By Use of Aluminum Powder And Its Effect on Strength

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Laboratory evaluation of the expansion of fresh concrete resulting from the addition of powdered aluminum is described. The results show that the restraining of the fresh concrete is as important as the amount of expansion agent in determining the compressive strength of the hardened material.

It was found that the increase in volume due to the expansion agent reduces the strength of the hardened mixture, whereas confinement of the fresh mixture to retard expansion restores the strength according to the final volume achieved by the fresh mixture. Results are presented that show the change in volume that can be expected for various amounts of expansion agent and the effect of uniaxial confining pressure on the expansion and strength.

•IN the past three decades, many researchers have experimented with expansive cements in connection with the need for compensating for shrinkage (1, 2, 3, 4, 5). Chemical agents were added that caused the concrete to expand, but in many cases the expansion occurred after a long period of time, even months after placement (1). The expansion studied in this investigation is a rapid volumetric increase occurring before the hardening of the concrete. The use of aluminum powder in grouting has stimulated research on the expansion of fresh concrete and its effect on the mechanical properties of the hardened material (3, 4).

This study is an attempt to extend knowledge of the physical properties of a sand-cement grout which expands, prior to setting, as a result of the addition of powdered aluminum as the expansive agent. Addition of the aluminum causes a chemical reaction that produces hydrogen gas. As more gas is evolved, the grout expands and the air content increases. The major portion of the expansion occurred within 90 minutes of the mixing period. The rate of expansion is a function of the amount and fineness of the aluminum added, as well as of the temperature during the setting of the concrete (2). In this research only one type of aluminum powder was used and conditions during setting were the same for all specimens; therefore, it was assumed that the expansion characteristics were a direct function of amount of aluminum added.

The objective of this study was to evaluate the compressive strength and expansion characteristics of an expansive grout. This was studied by the addition of various amounts of the expansion agent, and the evaluation of the pressures exerted by the fresh concrete during expansion and formation of the compressive test specimens.

After hardening, the specimens were moist-cured for 28 days and then tested for their compressive strength. The relationships between strength, percentage of aluminum powder, and restraining pressures were then evaluated. These relationships give an indication of the amount of expansion that can be expected from the fresh con-

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crete or the pressure exerted when it expands, and also what compressive strength can be expected when the grout sets with and without this pressure.

These relationships were found to be fairly well defined between the limits of aluminum added. Aluminum was added in the amount of 0.01, 0.025, 0.05, and 0.07 percent by weight of cement. At the outset, a preliminary study was made in which aluminum was added in the amount of 1 and 10 percent. The 1 percent aluminum expanded on the order of 30 percent to 40 percent and did not set; the 10 percent completely disintegrated while undergoing the setting process. The aluminum percentages vary over a wide range for this particular type of expansive grout and give a good idea of the percentages that should be used in future work.

LABORATORY PROCEDURE

Specimen Fabrication

At the outset of the experiment a preliminary study was made in which different amounts of aluminum powder were added to get an approximation of the maximum expansion to be expected for each percentage of aluminum used. This was done so that the final height of the specimens in the study could be made as close as possible to the necessary 12 in. used in the standard 6- by 12-in. cylinder, for the various amounts of expansion agent and restraining conditions.

The compressive tests on the hardened material were performed with 6- by 12-in. cylinders, cured, cast, and tested according to ASTM standards. The restraining effect was produced by placing weights on circular plates which were on the surface of the fresh concrete in the cylinders. The volumetric change was determined by the movement of the circular plates. Therefore, it should be noted that the volume change and restraining pressures were uniaxial in concept, thus approximating the condition of grouting reinforcing bars or filling voids in hardened media with grout.

Concrete Mix Design

The concrete mixture, which was a sand-cement grout, was proportioned as follows:

1. Cement-sand ratio, 1:2 by weight;
2. Water-cement ratio, 0.50 by weight; and
3. Aluminum powder added in amounts of 0.01, 0.025, 0.050, and 0.070 percent by weight of cement.

The cement was Type I portland cement. The powdered aluminum was that type used as a base for No. 1 Cres-Lite paint, produced by Crescent Bronze Powder Co., Los Angeles, California.

Itemized Laboratory Procedure

1. For each percent of aluminum (0.025, 0.050, 0.070), eight cylinders were cast (two for each confining condition). Two cylinders each at 0 and 0.01 percent aluminum were also cast. (These were left unrestrained in the cylinders, and only 28-day strength was recorded.)
2. The sand-cement-aluminum-water mixes were placed in 6- by 12-in. cylinders so that the final expanded length of the grout would be approximately 12 in.
3. Circular plates $5\frac{7}{8}$ in. in diameter and $\frac{1}{2}$ in. in thickness were placed on top of the grout in the cylinders.
4. Weights of 5, 20, and 85 lb were placed on the circular plates to attain restraining pressures of 0.177, 0.708, and 3.01 psi respectively. The standard cylinders were left unconfined by plates.
5. Measurements of change in length of the cylinders were made until expansion was negligible. The measurements were made by recording the movement of the restraining plates on the surface of the fresh concrete in the cylinder molds. Readings were taken on two sides of the cylinder and averaged.
6. The cylinders were left in the laboratory with weights still intact for 24 hours.

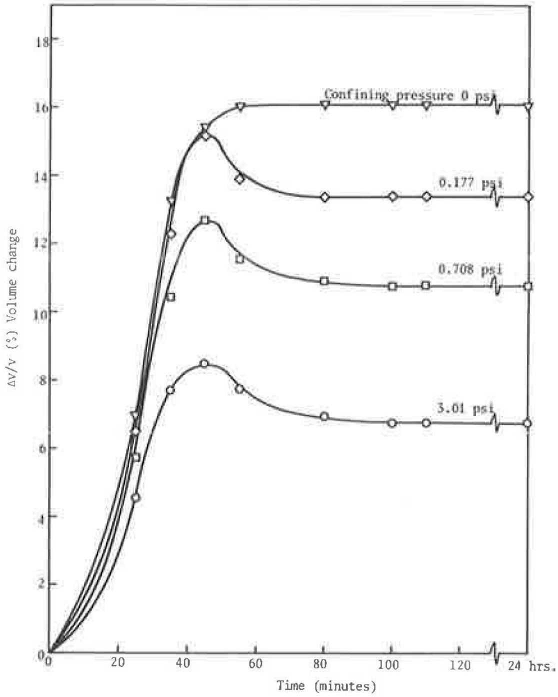

Figure 1. Volumetric expansion of concrete with 0.025 percent aluminum.

7. A final reading was taken, and the weights were removed after the 24-hour period.

8. The cylinders were moist-cured for 28 days.

9. The cylinders were then capped and loaded to failure in the compression machine.

RESULTS AND DISCUSSION

In this research emphasis was placed on the effect aluminum has on the mechanical properties of concrete. The curves of percentage of volumetric expansion vs time (Figs. 1, 2, 3) for the three percentages of aluminum show that, as might be expected, the rate of expansion and final amount of expansion increase as the percent of aluminum increases.

Also as expected, the increase in aluminum powder results in a marked decrease in strength. However, a restraining pressure applied to the cylinders during the setting period results in a reduction in the rate and total expansion, and an increase in the strength of the hardened specimens. The loaded or restrained cylinders for the 0.050 and 0.070 percent aluminum reached a maximum expansion, then dropped and leveled off at some lesser expansion. The 0.025 percent aluminum mixture does not show this characteristic. This is the result of the 0.050 and 0.070 percent aluminum cylinders exerting enough expansion pressure in the production of gases to achieve a release pressure which, when it occurred, resulted in a decrease in volume at the end of the gas-producing cycle; however, the mixes with 0.025 percent aluminum did not produce the gas pressure necessary to achieve this action.

Figures 4, 5, and 6 relate the maximum expansion, confining load, and 28-day compressive strength. Figure 4 shows that the maximum volumetric expansion vs confining load curve might be extrapolated and the resulting x-axis intercept would represent the forces required to restrain the cylinders to zero

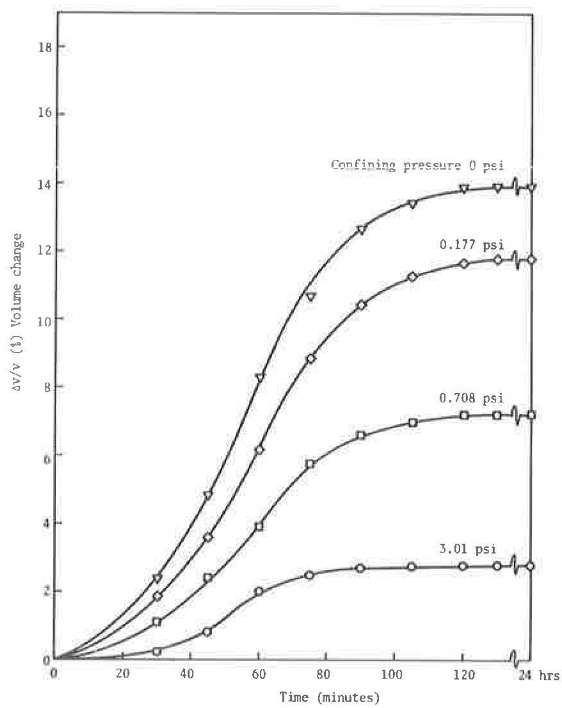

Figure 2. Volumetric expansion of concrete with 0.050 percent aluminum.

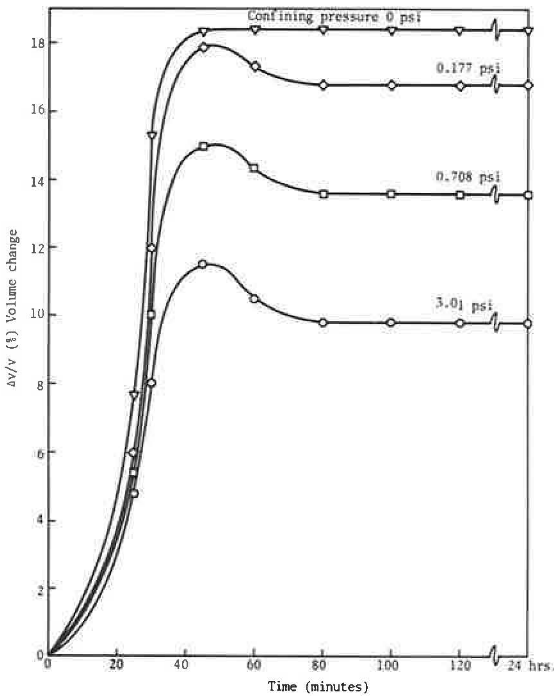

Figure 3. Volumetric expansion of concrete with 0.070 percent aluminum.

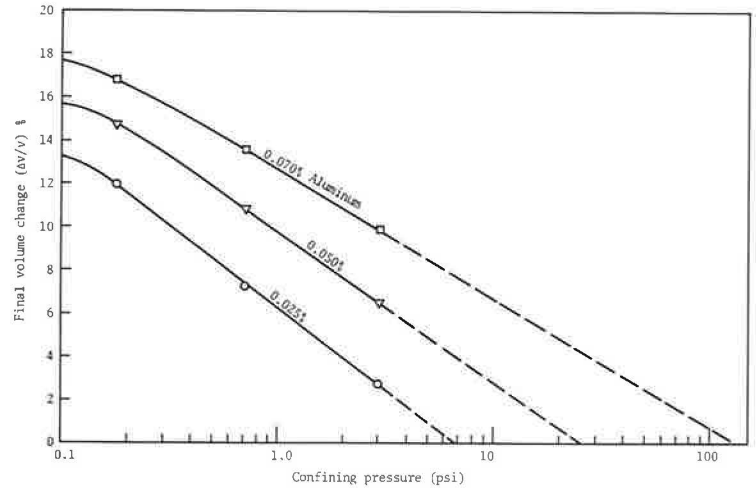

Figure 4. Effect of confining pressure on final volumetric expansion.

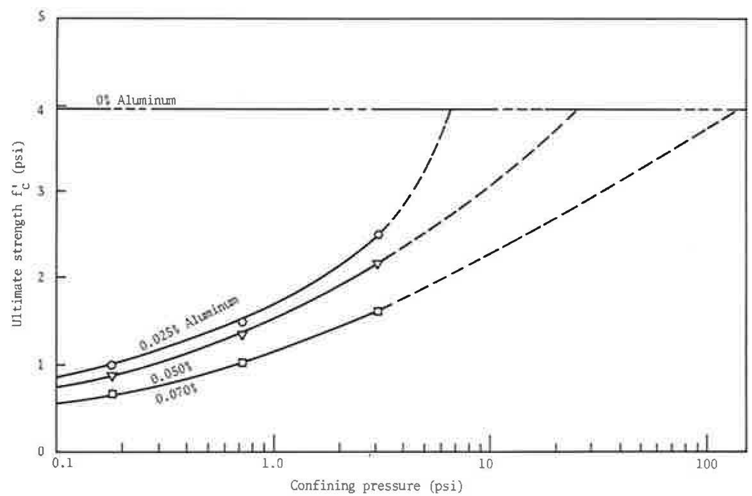

Figure 5. Effect of confining pressure on 28-day strength.

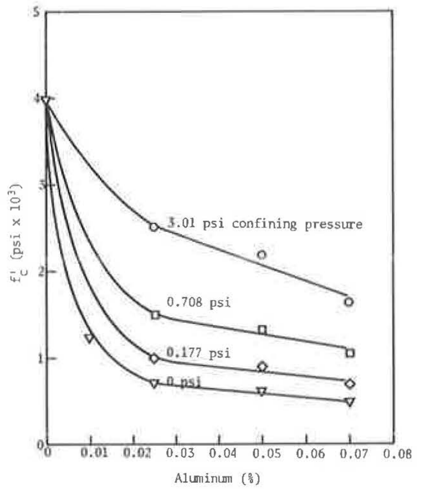

Figure 6. Relationship between compressive strength and percent aluminum.

expansion. Similarly, the strength vs confining pressure curves in Figure 5 can be extended to the pressures predicted from Figure 4, which are necessary to fully restrain the concrete from expanding. The resulting extrapolated compressive strengths are all close to the average f_c' value (3,980 psi) for the cylinders cast with no aluminum present. Although the accuracy of the extrapolation is questionable, the increase in compressive strength resulting from larger confining pressures is apparent. This indicates that the loss in strength acquired by the presence of aluminum is due only to the additional voids caused by the increase of air content. That is, if the cylinders containing aluminum were not allowed to expand they would have the same compressive strength as cylinders in which no aluminum was added. This implies that the chemical reaction that takes place has no other effect on the mix than the production of hydrogen gas, which is entrapped and thereby increases the air content and volume. This is also indicated by the curve of percentage of aluminum vs 28-day strength (Fig. 6). It is seen that as the confining load on the cylinders increases the compressive strength approaches 3,980 psi.

Figure 4 shows that after a minimal restraining load has been applied to the concrete, the volumetric expansion is inversely proportional to the log of the confining load. Figure 6 indicates that a marked decrease in strength occurs up to 0.02 percent aluminum, after which addition of aluminum has less effect on the strength.

CONCLUSIONS

The results of this study show the increase in volume that can be expected with the addition of various amounts of powdered aluminum to a concrete mixture. The expansion is the result of gas produced by the mixture and occurs prior to hardening. The expansion is difficult to control for little or no confining pressure, and the results

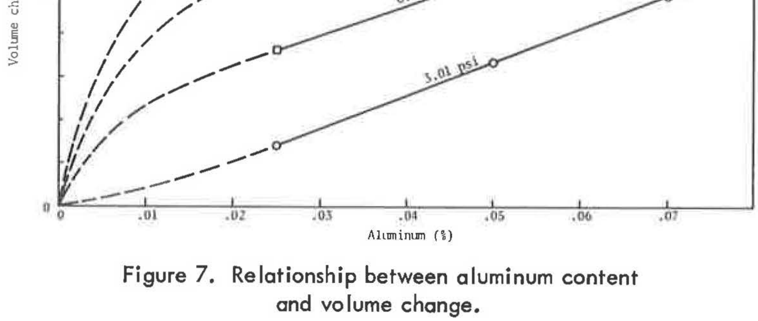

Figure 7. Relationship between aluminum content and volume change.

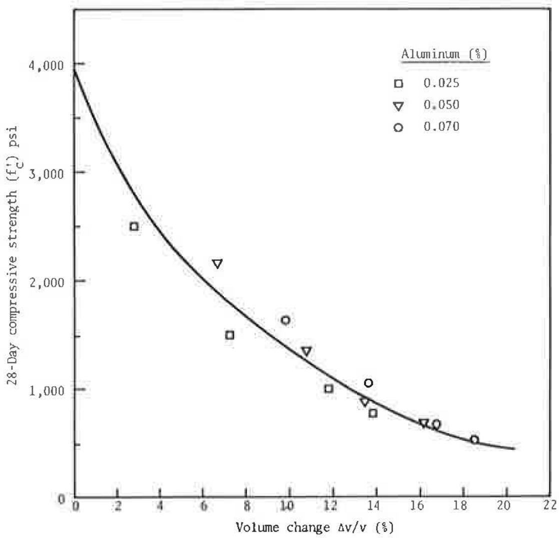

Figure 8. Relationship between strength and volume of voids.

in general indicate that the increase in volume is very sensitive to small quantities of the expansion agent. However, the expansion becomes linear for large quantities of the expansion agent (Fig. 7). Figure 7 also indicates that the expansion is easily controlled with the addition of very small confining pressures. Therefore, controlled expansion is possible with the magnitude and control depending upon the amount of the expansion agent and the confining pressures.

Although there is a significant reduction in strength occurring with the addition of the expansion agent, this reduction is dependent upon the final volume change of the fresh mixture. This is shown in Figure 8, in which the strength data are related to the volume change of the fresh mixture, irrespective of the confined condition or percentage of the expansion agent. This reduction in strength indicates the adverse effect of voids in concrete on the compressive strength. Moreover, since the reduction in strength is the result of the formation of voids during the expansion, the final 28-day strength of the hardened mixture can be predicted if the final volume change is known.

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