

Pressures Developed in Cement Pastes and Mortars by the Alkali-Aggregate Reaction*

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Measurements with a special pressure cell, using an SR-4 strain gage as the sensitive element, show that the alkali-aggregate reaction in cement pastes and mortars may develop pressures in excess of 2,000 psi.

● IN HIS DISCUSSION of the alkali-aggregate problem, Hansen (1) showed that the cement paste could act as an osmotic membrane across which hydrostatic pressures might arise to cause the disintegration known to occur with high alkali cement and opaline aggregates (2). Also McConnell and co-workers (3) measured pressures in excess of 550 psi, using a neat cement disc as an osmotic membrane and water glass (38 percent sodium silicate, Na_2O to SiO_2 ratio of 0.30) as the solution. This pressure is of the same order of magnitude as the tensile strength of concrete and could perhaps cause the observed disintegration. However, at higher concentrations of electrolyte (which form at the surface of pure opal (3, p. 123) one might expect much higher pressures such as were found in the following tests.

APPARATUS AND PROCEDURE

The pressures developed were measured with a special pressure cell turned from a solid piece of cold rolled steel (Fig. 1). An SR-4 type AB-3 strain gage wrapped in a spiral around the outside acted as the sensitive element. Because of the difficulty of removing the cement mixtures a new cell was required for each test.

In order to calibrate the device the cap on the cell was replaced by a special plate drilled and tapped to take a $\frac{1}{4}$ inch nipple. Oil was then pumped in under known pressures varying from 50 to 2,000 psi. The response observed on the SR-4 strain gage was linear and acceptably reproducible when the hydrostatic pressure was repeatedly cycled.

In an actual test the cement paste or mortar was packed into the cell with a $\frac{1}{4}$ inch diameter rod. The mortar was struck off flush with the surface of the flange and the cell sealed with a steel plate so that no moisture could be lost or gained. An initial pressure reading (shown on the curves as zero psi) was immediately taken which gave an indication of from 250 to 750 psi pressure above that of the empty cell. Increase or decrease in pressure was then read on the strain indicator every few hours at the start of the test, and later at intervals of several days.

The cause of the initial pressure mentioned above is not known. However, several possibilities may be advanced, the most probable of which is that the mortar is tightly packed in the cell which thus makes possible the negative pressures indicated later in the paper. Second, stresses may be set up when tightening the screws in the cell cap to close the cell, particularly if a grain of sand or other foreign matter becomes lodged under the cap.

Several different mixtures were tested: (a) A cement paste, using 100 g of high-alkali cement (1.10 percent NaO , 0.09 percent K_2O) with 25 cc water, and 4 g of opal from Carson City, Nev. (analysis in Table 1) sized between No. 16 and No. 20 (US standard) sieves. (b) A similar paste using low-alkali cement (0.00 percent NaO , 0.29 percent K_2O). (c) Mortar made with 100 g of low-alkali cement, 40 cc water and 200 g graded Ottawa sand. (d) A mortar similar to No. 3 using a high alkali cement. (e) A mortar similar to No. 4 with 6 percent of the sand replaced by opal sized between No. 50 and No. 100 (US standard) sieves.

*Presented at the open meeting of the Committee on Durability of Concrete—Chemical Aspects; January 8, 1957.

RESULTS AND DISCUSSION

The results of five typical tests are shown in Figure 2. Pressures measured in comparable tests differed from those shown by about 25 percent. The highest pressures (about 2,100 psi) were obtained in about 140 days using a paste of high-alkali cement and opal. The development of this high pressure in a closed system is compatible with the facts that Na^+ and water are known to migrate through the cement paste (4) and that their reaction with opal can cause an increase in the volume of the opal in excess of 300 percent (5). The control sample using low-alkali cement and opal showed no appreciable pressure over the same period.

Mortars made with high-alkali cement, and using opal as 6 percent of the aggregate, also developed considerable pressure: about 400 psi in 190 days. The three compositions which did not contain both high-alkali cement and opal developed only low pressures.

In the course of this investigation it seemed desirable to determine if creep in the metal of the cell was a significant factor after prolonged pressures. A cell which had indicated a pressure in excess of 1,700 psi over a period of 142 days was opened and, without disturbing the cement, placed in a vacuum desiccator. After evaporation had

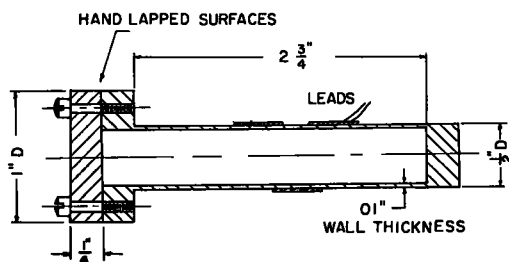


Figure 1. Cell used to measure pressures developed by the alkali-aggregate reaction material is CR steel.

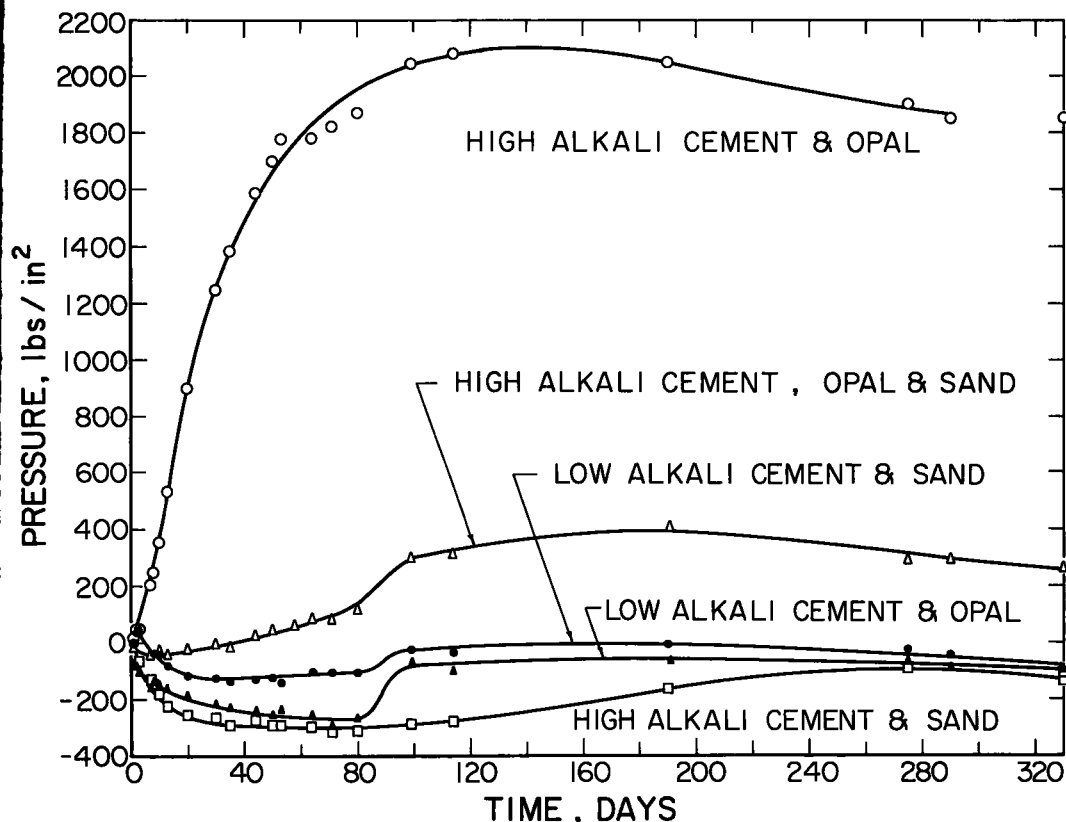


Figure 2. Pressures developed by the alkali-aggregate reaction over a period of 320 days.

continued for 60 days the indicated pressure dropped to less than 70 psi signifying the absence of any excessive creep in the gage. This drop in pressure also indicates that there had been no permanent volume increase caused by reaction or by recrystallization in the mortar and strongly suggests that the pressures developed in the cell are due to osmotic forces generated in the vicinity of the reactive aggregate.

The cell was originally packed under considerable positive pressure. The "negative pressure" indicated by the curves at early ages for all mixtures except that developing the highest pressure is attributed to the shrinkage which is known to occur during hydration of cements (6).

ACKNOWLEDGMENTS

The help of David Watstein and R. C. Valore, Jr., in designing the pressure cell and strain gage, and the assistance of Donald Hubbard in preparing the manuscript, is gratefully acknowledged.

REFERENCES

1. Hansen, W. C., "Studies Relating to the Mechanism by Which the Alkali-Aggregate Reaction Produces Expansion in Concrete." Proc. ACI 40 213-227 (1944).
2. Stanton, Thomas E., "Expansion of Concrete Through Reaction Between Cement and Aggregate." Proc., ASCE 66, 1781-1811 (1940).
3. McConnell, D., R. C. Mielenz, W. Y. Holland, and K. T. Greene, "Cement-Aggregate Reaction in Concrete." Proc., ACI 44, 93-128 (1947).
4. Vivian, H. E., "Studies in Cement-Aggregate Reaction, II. The Effect of Alkali Movement in Hardened Mortar." Council for Scientific and Industrial Research, Bulletin No. 229, 47-54 (1947).
5. Pike, Robert G., Donald Hubbard, and Herbert Insley, "Mechanisms of Alkali-Aggregate Reaction." Proc. ACI 52, 13-34 (1955).
6. Bogue, R. H., "The Chemistry of Portland Cement." 2nd ed. p. 623, Reinhold Pub. Corp., New York (1955).

TABLE 1 — ANALYSIS OF OPALS^a

Item	Percent
Loss on ignition (1,100 C)	5.32
HF residue	4.30
SiO ₂ (by difference)	90.38
Fe ₂ O ₃ ^b	0.54
Al ₂ O ₃ ^b	2.72

^a Analysis by E. B. Clark of the National Bureau of Standards.

^b The HF residue was fused and dissolved and "R₂O₃" precipitated with NH₄OH and ignited. The Fe₂O₃ was determined in the ignited precipitate and the remainder of the R₂O₃ assumed to be Al₂O₃.