EFFECTS OF CALCIUM CHLORIDE ON PORTLAND CEMENTS AND CONCRETES

EFFECT OF CALCIUM CHLORIDE ON THE STRENGTH DEVELOPMENT OF CONCRETE STORED AT LOW TEMPERATURES

By Jason C Yates

SYNOPSIS

Concrete cylinders, 6 by 12 in. in size, made at 70°F, were stored in rooms maintained at various temperatures between 20° and 40°F until 1 day before testing in compression. The specimens were placed in air at 70°F and the steel molds were removed 1 day before testing. The concretes contained 0, 2, 3 or 4 percent of calcium chloride by weight of cement. Additions of calcium chloride increased the strengths at all ages with each storage temperature; the increases were most marked at ages less than 7 days and temperatures of 32°F and lower. Except for ages less than 3 days or storage temperatures lower than 32°F the increases in strength were about the same with the 2 percent as with the 4 percent additions of calcium chloride.

In continuation of the studies of the effects of additions of calcium chloride on various properties of portland cements and concretes, inaugurated in 1932, a fellowship was re-established at the National Bureau of Standards by the Calcium Chloride Association in June, 1939, A part of the study reported by Rapp in 1934 (1)[1] dealt with the effect of calcium chloride on the strength of concrete cured at several temperatures within the range 40° to 90°F. This paper gives data on the strengths of similar concretes stored at temperatures within the range 20° to 40°F.

MATERIALS

The cement used in this series was of the same brand, cement "C," of the normal portland cement included in the previous studies reported by Rapp. The fine and coarse aggregates were from the Potomac River and complied with the requirements of Federal Specification for Aggregate for Portland Cement Concrete, SS-A-281; the maximum size coarse aggregate was 1 in. The calcium chloride was a standard brand of commercial material complying with the requirements of A.S.T.M. Specification for Calcium Chloride, D98-34.

[1] Figures in parentheses refer to list of references at end.

METHODS

In planning the testing procedure, consideration was given to the general requirement: "Whenever the temperature of the surrounding air is below 40°F all concrete placed in the forms shall have a temperature of between 70°F and 100°F" (2). In accordance with this recognized specification all the materials (cement, aggregates, water, and calcium chloride) were stored in a constant temperature room at 70°F for a period sufficiently in advance of use to insure their uniformity of temperature. Following mixing of the concrete in the proportion 1:2:4 (cement: sand: gravel) by weight with a water-cement ratio of 6 5 gallons per sack of cement, and the respective percentage of calcium chloride by weight of cement, 6 by 12-in. concrete cylinder specimens were molded in steel forms and immediately placed in a constant temperature room at the respective low temperatures being studied. All the molds were stripped on the day the specimens were tested. The specimens were removed from the low temperature room and

stored at 70°F for 24 hours (except specimens tested at the age of 1 day, which were removed from the low temperature room in the morning and tested late in the afternoon of the same day) in advance of testing to insure that no ice was present when the specimens were broken.

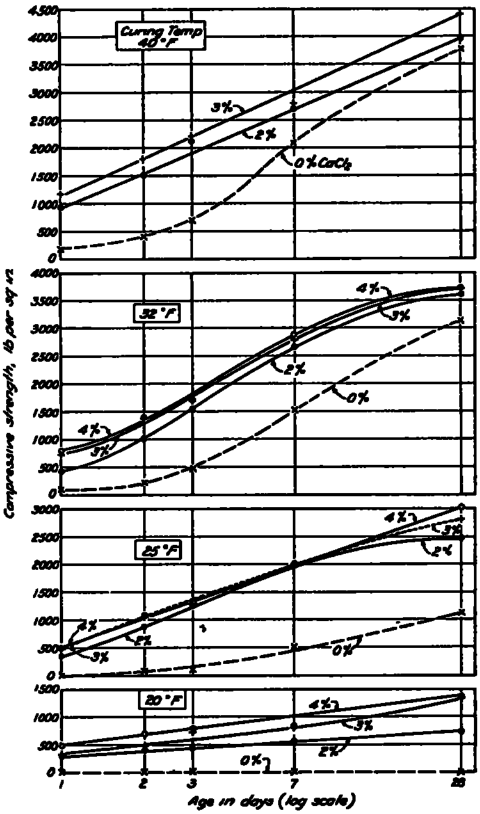

Figure 1. Strengths of Concretes, with and without Additions of Calcium Chloride, at Four Temperatures.

In a second series the specimens were stored for 7 days at 20°F, then removed and stored at a temperature of 70°F until tested.

TEST RESULTS

Figure 1 gives the average compressive strength of the concretes at the various ages and for the several storage temperatures. Each compressive strength given is the average of those of three cylinders.

20°F Series

Plain concrete stored at 20°F developed no strength throughout the 28-day test period, although all the materials were initially at a temperature of 70°F. All the specimens had frozen and upon removal from the mold they crumbled. The concrete mixtures containing calcium chloride developed strength gradually, although at a slower rate than is characteristic for the higher temperatures. Three and 4 percent of calcium chloride showed definite advantage over 2 percent of calcium chloride by weight of the cement, the amount generally recommended for normal temperatures. For example, the average 7-day strength of concrete containing 2 percent of calcium chloride was 550 lb. per sq. in., with 4 percent, 830 lb. per sq. in.; the 28-day strengths were 730 and 1,370 lb. per sq. in., respectively.

25°F Series

The plain concrete specimens stored at 25°F did not develop sufficient strength for testing at an age of 1 day. Following the first day, however, strength developed slowly, with 510 lb. per sq. in. being attained in 7 days and 1,130 lb. per sq. in. in 28 days. Concrete containing calcium chloride developed a strength of approximately 2,000 lb. per sq. in. in 7 days; the strengths at 28 days were 2,470, 2,810, and 3,030 lb. per sq. in. for the mixes containing respectively 2, 3, and 4 percent of calcium chloride by weight of cement. It may be noted that the 1-day strength of concrete with 3 and 4 percent of calcium chloride approximated 7-day strength of plain concrete, and that 2- and 3-day strengths of all mixes containing calcium chloride approximated 28-day strengths of the plain concrete.

32°F Series

Although the plain concrete specimens stored at 20° and 25°F showed little or no strength at 1 day, specimens stored at 32°F developed a strength of 100 lb. per sq. in. in that time. The 7-day strength was approximately 1,500, and the 28-day approximately 3,100 lb. per sq. in. In comparison, the strengths of the concrete containing 4 percent of calcium chloride were 790, 2,890, and 3,730 lb. per sq. in. at 1, 7, and 28 days, respectively. As may be noted from Figure 1 there was a noticeable improvement in the early strength development of concrete containing 3 and 4 percent of calcium chloride over that containing 2 percent; however, the 28-day strengths of all the concretes containing calcium chloride were approximately the same. In this series it may be noted (Fig. 1) that the 1-day strengths with 3 and 4 percent of calcium chloride approximated the 5-day strength of plain concrete; the 3-day strengths of mixes containing calcium chloride were equal to the 7-day strengths of plain concrete; and the 7-day strengths of calcium chloride mixes approximated the 28-day strength of plain concrete.

40°F Series

The data of Figure 1 show that the strength of the concrete without calcium chloride was but 170 lb. per sq. in. at 1 day, whereas the strength of the concrete containing 2 percent of calcium chloride was 950 lb. per sq. in. Although the strength of the plain concrete increased to only 700 lb. per sq. in. at 3 days, the strength of the concrete containing 2 percent of calcium chloride increased to 2,130 lb. per sq. in. However, at 28 days the strength of the plain concrete (3,780 lb. per sq. in.) almost equalled the strength of the concrete with 2 percent of calcium chloride (3,980 lb. per sq. in.). Insofar as early strength development is concerned it is to be noted (in Fig. 1) that the 1-day strength of concrete containing calcium chloride (2 percent) approximated the 4-day strength of the plain concrete, while the 3-day strength of concrete containing calcium chloride was equal to the 7-day strength of the plain concrete.

Series at 20°F for 7 Days—Followed by Curing at 70°F

This series of tests was designed to ascertain the effect of higher temperatures on the rate of strength development of concrete which had initially been subjected to a period of low temperatures. The data on concretes stored at 20°F for 7 days, followed by storage at 70°F, are plotted in Figure 2. The specimens of plain concrete tested after 1 day's curing at temperature of 70°F (8 days of age) had developed no measurable strength; at subsequent ages the gain in strength was, however, consistent with the strengths after 7 and 28 days at 70°F, being 2,200 and 3,700 lb. per sq. in., respectively. In contrast to the complete lack of strength of the plain concrete at 1 day, the specimens containing calcium chloride had developed strengths ranging from 1,530 to 1,820 lb. per sq. in. after 1 day at a temperature of 70°F; the strengths after 2 days ranged from 2,220 to 3,130, and after 28 days from 5,330 to 6,230 lb. per sq. in. As in the low-temperature series (20°F for example) concrete containing calcium chloride up to 4 percent by weight of the cement developed strength in excess of that attained by concrete containing 2 percent of calcium chloride. It may be noted that after 7 days' storage at 20°F, the concrete then being stored at 70°F, the gain in strength exceeded that of the concrete stored continuously at 40°F.

DISCUSSION OF RESULTS

Figures 3 and 4 serve to illustrate the critical effect of temperature on the rate of strength development of concrete. The

adverse effect of low curing temperature on the strength of concrete, particularly at ages up to 28 days, has been long recognized, and several studies have been most extensive in their scope. McDaniel (3) studied the effects of temperatures varying from 30 to 90°F on concrete strengths up to 28 days, and his data have been widely used as reference. These data were corroborated by Lord (4) in For example, the 28-day strength of concrete cured at 25°F was but 1,130 lb. per sq. in., as compared to 3,150 lb. per sq. in. for concrete cured at 32°F; while concrete in which 4 percent of calcium chloride had been incorporated showed a strength of 3,030 lb. per sq. in. when subjected to 25°F temperature and 3,730 lb. per sq. in. at 32°F. From a review of Figures 3 and 4 it may be noted that

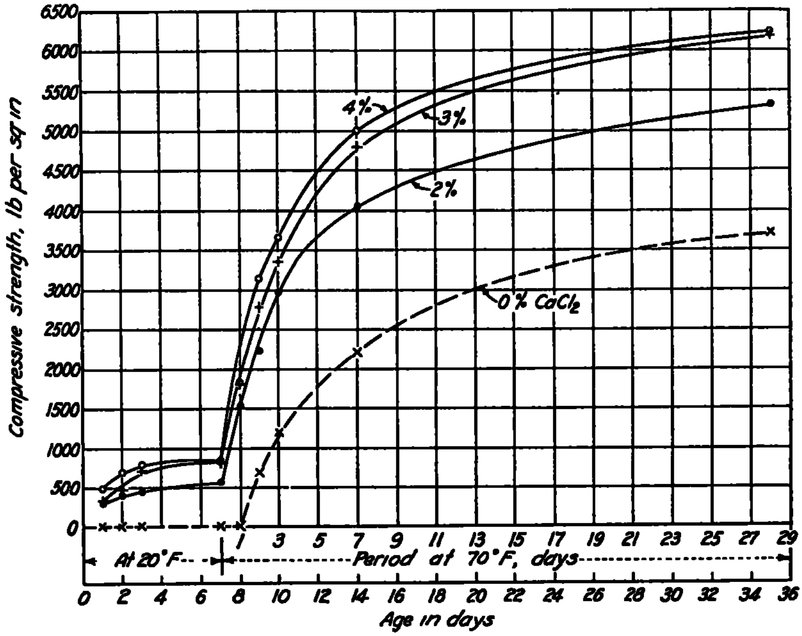

Figure 2. Strengths of Concretes Stored at 20° F for 7 Days, Then Stored at 70° F Until Final Testing

field tests made during the construction of Wacker Drive, Chicago.

The foregoing studies show quantitatively the extent to which calcium chloride is effective in overcoming the effect of low temperatures on the rate of strength development of concrete. Significantly it should be noted that under conditions of this study, in which all the materials were initially at a temperature of 70°F, plain concrete developed little strength when cured at a temperature below 25°F. In fact, temperatures below 32°F markedly affected the strength of the plain concrete. Rapp's conclusions (1) to the effect that concretes containing calcium chloride had greater strengths at all ages than those without calcium chloride and that calcium chloride was more effective for the lower temperatures, appear to be fully corroborated, despite the differences in the curing temperatures covered.

SUMMARY

Six by 12-in. cylinders of concrete at a temperature of 70°F were cast in steel molds and then stored in air at various temperatures between 20 and 40°F until

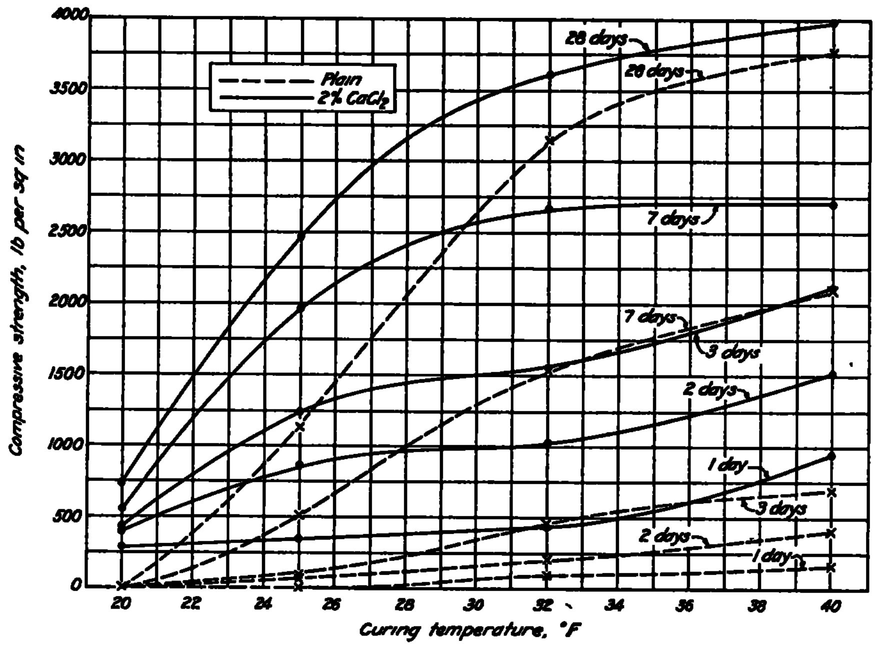

Figure 3. Relation Between Curing Temperature (20° to 40° F) and Strengths of Concretes with 0 and 2 Percent of Calcium Chloride

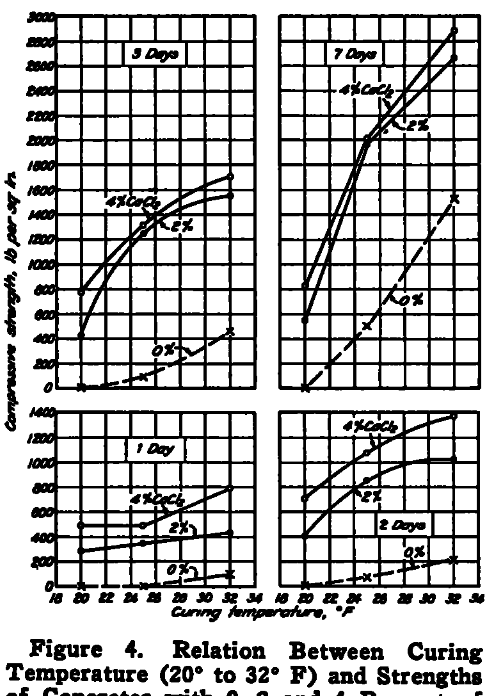

Figure 4. Relation Between Curing Temperature (20° to 32° F) and Strengths of Concretes with 0, 2 and 4 Percent of Calcium Chloride.

1 day before testing in compression. The molds were removed and the specimens placed in air at 70°F 1 day before testing. The composition of the concretes was the same for all specimens except for the amount of calcium chloride, which was 0, 2, 3, or 4 percent by weight of the cement. The results of the compressive tests seem to justify the following conclusions:

(1) Additions of calcium chloride increased the strengths of concrete at all temperatures (20 to 40°F) and all ages (1 to 28 days).

(2) The effect of addition of calcium chloride on the strength of the concrete was most marked at the lower temperatures.

(3) Concretes containing 4 percent of calcium chloride by weight of cement developed considerably greater strengths during storage at temperatures of 32°F and lower than those containing 2 percent of calcium chloride; this difference was greatest at ages less than 3 days.

(4) With the storage temperature above 32°F and for ages exceeding 3 days, additions of more than 2 percent of calcium chloride by weight of cement did not cause a material increase in strength.

REFERENCES

1 "Effect of Calcium Chloride on Portland Cements and Concretes," *Journal of Research*, National Bureau of Standards, 14, 499 (1935) RP782.

2. Building Regulations for Reinforced Concrete (A.C.I. 501-36T), *Proceedings*, Am Concrete Inst, 32, 407 (1936).

3. A. B. McDaniel, "Influence of Temperature on the Strength of Concrete"—Bul. No. 81, Engr. Exp. Sta. Univ. of Illinois.

4. A. R. Lord, "Notes on Concrete—Wacker Drive," Chicago, *Proceedings* Am. Concrete Inst., 23, 28 (1927).

DISCUSSION ON EFFECT OF CALCIUM CHLORIDE ON STRENGTH OF PORTLAND CEMENTS AND CONCRETE STORED AT LOW TEMPERATURES

PROF. C. H. SCHOLER, *Kansas State College:* It should be noted that all of these data are based upon one cement only. The effectiveness of the chloride was undoubtedly made possible by the heat of hydration liberated during the hardening process. The depression of the freezing point by such low concentration of the salt is negligible and damage due to freezing was undoubtedly prevented only by the heat of hydration being sufficient to permit the hardening process to continue. The amount of heat liberated on hydration, especially during the first hour varies very widely. Anyone expecting to place concrete at temperatures as low as 20°F should be exceedingly cautious, not depending upon so weak a solution as 2 percent giving adequate protection against frost damage.

I think some data on the rate at which heat of hydration was liberated with calcium chloride additions are available from several sources. It will be well to know whether or not the particular cement used was one of those most favorably acted upon by calcium chloride or least favorably acted upon by the calcium chloride.

MR. YATES: Rapp's studies reported in the 1934 proceedings of the Highway Research Board revealed that calcium chloride integral curing accelerated the initial rate of heat liberation of cement, although the heat developed at 24 hours did not differ by more than a few calories. In view of these findings and the results of strength tests on concretes prepared from 11 cements and cured at temperatures ranging from 40 to 90°F, he concluded that, "The lower the temperature, the more effective is the use of calcium chloride. . . . . There is an added advantage of using calcium chloride in cold weather in the increased rapidity with which it causes the development of heat."

These low temperature studies using a typical standard portland cement were initiated to study the effects of calcium chloride in concretes cured at temperatures (20 to 40°F) below the minimum temperature studied by Rapp. Although the concrete containing calcium chloride (2 to 4 percent) did not freeze at the lowest temperature (20°F) the rate of strength development at this low temperature was not such as would permit of reasonably early form-stripping. When concrete is being placed at freezing temperatures, and lower; provision should be made to supplement its use by covering and heating. As reported by Rapp, however, "Calcium chloride decreases the curing time and the time necessary for the use of coverings or other means of maintaining a satisfactory temperature for hydration."