EFFECT OF CALCIUM CHLORIDE ON THE STRENGTH OF CONCRETE MADE FROM MIXES OF LOW WATER CONTENT

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SYNOPSIS

Compressive strength data were obtained on concrete cylinders prepared in the laboratory from mixes, having water contents of 6 5 to 3 5 gal per bag of cement and containing 0, 1, and 2 per cent of calcium chloride Increasing the amount of calcium chloride resulted in increasing the strengths of the concretes, particularly at the earlier ages

Strength measurements were made also on concrete block and pipe prepared, with and without calcium chloride, at a local concrete-products plant In these experiments the mix (containing approximately three gallons of water per bag of cement) was the same as that regularly used at this plant for both products The plant practices of mixing, molding, and curing were followed Additions of calcium chloride increased the compressive strength of the block and the crushing strength of the pipe

The data, previously reported (1)[1] on the effect of calcium chloride on the strength of concrete, were obtained on mixes having a water content of approximately 6.5 gal. per bag of cement In order to obtain additional data with mixes having lower water-cement ratios, laboratory and plant experiments were conducted. In the laboratory, cylinders were prepared from mixes having water contents ranging from 3.5 to 6 5 gal. per bag of cement. At a local concrete-products plant, block and pipe were prepared from mixes containing approximately 3 gal. per bag. The details of mixing, molding, and curing used at this plant were followed

Part I

LABORATORY PROGRAM

Materials

The cement designated as "C" was the same cement used by Yates (2) in former tests The Potomac River fine and coarse aggregate complied with the requirements of Federal Specification SS-A-281a (3). The maximum size of coarse aggregate was 1 in. The calcium chloride was a brand of commercial material containing 80 1 per cent of anhydrous calcium chloride.[2] This material complied with the requirements of A S.T.M. Specification D-98 (4).

Procedure

All of the materials were stored in a constant temperature room maintained at 70 deg F. sufficiently in advance of use to attain that temperature. Four series of cylinders were prepared from mixes containing 3 5, 4.5, 5.5, and 6 5 gal. of water per bag of cement, respectively. The mixes contained 0, 1, and 2 per cent of calcium chloride by weight of cement, respectively.

A Lancaster bowl mixer operating for 5 min was used to insure thorough blending of the mixes containing 3 5 and 4.5 gal. of water per bag of cement. The 6 by 12 in. cylinders were cast in steel molds.

To afford a basis of comparison, the cylinders were compacted to approximate a weight of 29 lb. In the case of mixes

[1] Numbers in parentheses refer to the list of references at the end of the paper

[2] Hereafter "per cent of calcium chloride" indicates the quantity of commercial material

containing 5 5 and 6 5 gal. per bag, the cylinders were compacted according to the three-layer-rodding method outlined in A.S.T M Test Method C-39 (5). With drier mixes, however, an internal vibrator was used having a frequency of approximately 10,000 vibrations per minute. When compacting the mixes containing 3 5 and 4 5 gal per bag, the vibrator was operated for 55 and 40 sec , respectively, on each layer The cylinders in the four series had an average weight of 29.0± 0.1 lb.

After 24 hours in a curing room, maintained at 70 deg. F. and approximately 100 per cent relative humidity, the molds were stripped and the cylinders stored in the same room until tested Compressive strength tests were made at 1, 2, 3, 7, and 28 days.

Results

The data on the compressive strengths and time of aging of the concrete cylinders are given in Table 1. Each value is the average of three tests. The results are plotted in Figures 1, 2, 3, and 4.

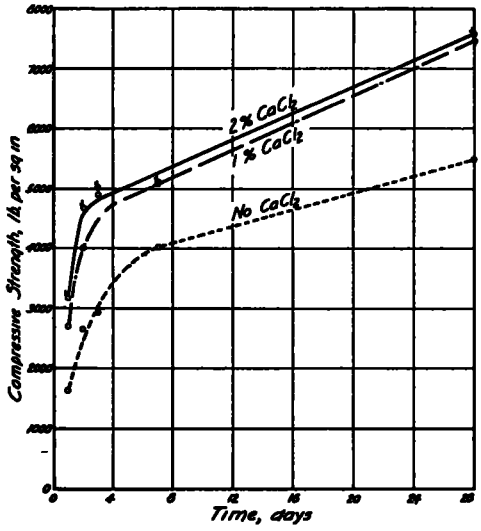

Figure 1. Compressive Strength, 6 by 12-In. Cylinders, 1:2:4 Concrete by Volume, 3.5 Gal. of Water Per Bag of Cement.

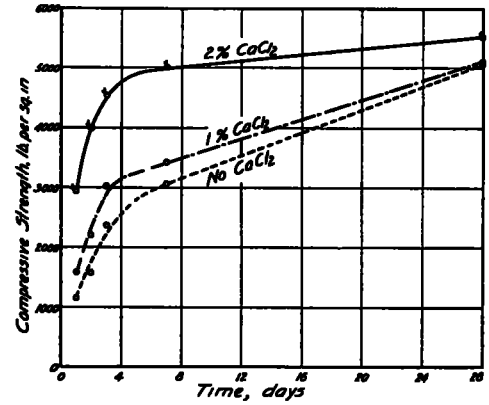

Figure 2. Compressive Strength, 6 by 12-In. Cylinders, 1:2:4 Concrete by Volume, 4.5 Gal. of Water Per Bag of Cement.

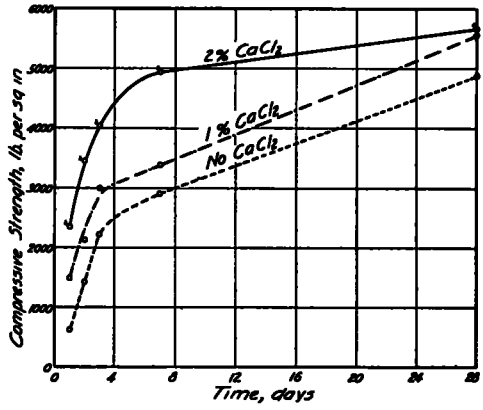

Figure 3. Compressive Strength, 6 by 12-In. Cylinders, 1:2:4 Concrete by Volume, 5.5 Gal. of Water Per Bag of Cement.

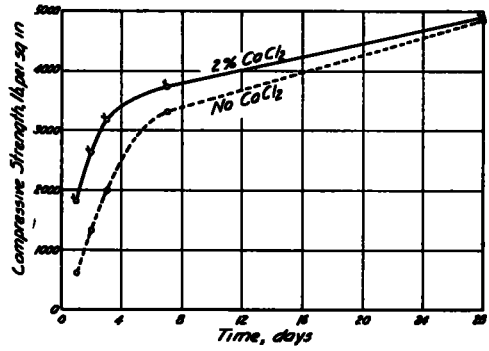

Figure 4. Compressive Strength, 6 by 12-In. Cylinders, 1:2:4 Concrete by Volume, 6.5 Gal. of Water Per Bag of Cement.

TABLE 1

COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS

Size—6 by 12 in.
Proportion—1·2 4 (cement sand gravel) by weight
Aggregate—
Fine—Potomac River sand
Coarse—Potomac River gravel.
Cement—Standard Portland "C"

Age, days	Compressive strength			Increase in compressive strength	
	No $CaCl_2$, lb per sq in	1 per cent $CaCl_2$,[a] lb per sq in	2 per cent $CaCl_2$,[a] lb per sq in	1 per cent $CaCl_2$,[a] per cent	2 per cent $CaCl_2$,[a] per cent
SERIES 1 WATER 3 5 GAL PER BAG, (MIXES VIBRATED)					
1	1,630	2,700	3,170	66	94
2	2,650	4,000	4,660	51	76
3	2,930	4,890	5,000	67	71
7	4,030	5,070	5,080	26	26
28	5,490	7,470	7,590	36	38
SERIES 2 WATER 4 5 GAL PER BAG, (MIXES VIBRATED)					
1	1,150	1,570	2,930	36	155
2	1,570	2,200	3,980	40	154
3	2,360	3,010	4,530	28	92
7	3,050	3,410	4,990	12	64
28	5,070	5,100	5,520	1	9
SERIES 3 WATER 5 5 GAL PER BAG, (MIXES RODDED)					
1	640	1,500	2,350	134	267
2	1,430	2,140	3,450	50	141
3	2,240	3,000	4,050	34	81
7	2,900	3,380	4,950	17	71
28	4,880	5,570	5,670	14	16
SERIES 4 WATER 6 5 GAL PER BAG, (MIXES RODDED)					
1	610		1,820		198
2	1,340		2,640		97
3	1,990		3,180		60
7	3,310		3,730		13
28	4,860		4,890		1

[a] $CaCl_2$ percentage of commercial material by weight of cement

The figures and the data of Table 1 show that the additions of calcium chloride increased the compressive strength of the concretes. Concretes containing 2 per cent of calcium chloride were stronger than those containing 1 per cent of the accelerator. The percentage increase obtained by additions of calcium chloride was greatest at one day and became less with increasing age until it reached a relatively small value for specimens 28 days old Although the results of the tests were not always concordant, the effects of age on the percentage increase in strength tended to become greater as the water content increased from 3 5 to 6 5 gal. per sack of cement.

From Figure 1 (3.5 gal. per bag), for example, it is evident that concretes containing calcium chloride had strengths at 1 day of approximately the same order of magnitude as those of plain concrete at 3 days. The strength of concrete containing 1 per cent of calcium chloride at 2 days was almost identical with that of plain concrete at 7 days. The strength of concrete with 2 per cent of calcium chloride at 2 days was somewhat higher than that with no calcium chloride at 7 days.

Strengths developed in the series containing 4 5 gal per bag, Figure 2, show trends similar to those reported above At earlier ages, however, the effect of 2 per cent of calcium chloride is more pronounced than that of 1 per cent.

Comparison of Figures 2 and 3, for the series having water contents of 4 5 and 5.5 gal. per bag of cement, respectively, reveals small strength differences (150 lb or less) for most of the cylinders containing comparable amounts of calcium chloride Instances of greater strengths in the 4.5 series (480 to 580 lb.) are as follows· Cylinders with no calcium chloride at 1 day, and those with 2 per cent at 1, 2, and 3 days. At 28 days, however, the reverse is true. Because of the lower water-cement ratio, greater strengths of concretes would be expected in the 4.5 series than those of concretes in the 5 5 series A possible explanation of the lower strengths, exhibited by the cylinders in the 4 5 series, is that segregation occurred in the mix as the result of overvibration during compaction The three-layer-rodding method, employed in compacting the mix in the 5.5 series, was accompanied doubtless by little if any segregation

Comparing Figure 4 with Figures 2 and 3 shows that the strengths of the cylinders of plain concrete in the 6 5 series were greater than those in the 4.5 and 5.5 series at 7 days At 1, 2, 3, and 28 days, however, the strengths in the two series 6 5 and 5 5 were approximately the same, the differences ranging from 20 to 150 lb

PART II

PLANT PROGRAM

Materials

The cement was the same as that used at the plant The Potomac River fine and coarse aggregate complied with the requirements of Federal Specification SS-A-281a (3). The coarse aggregate was essentially pea gravel ($\frac{3}{8}$ to $\frac{1}{4}$ in) The calcium chloride was a brand of commercial material complying with the requirements of A S T.M. Specification D-98 (4)

Procedure

The materials for the manufacture of the concrete block and pipe were proportioned 1 2 2 (cement sand: gravel) by weight, using a water content of approximately three gallons per bag. Following the practice at this plant, 1 and 2 per cent of calcium chloride, by weight of cement, was added to the mixing water To afford a basis of comparison, specimens were also prepared of plain concrete. The ingredients were mixed for approximately five minutes in a pugmill having a capacity

of 10 cu ft The concrete as mixed had zero slump In molding the building block, 8 by 8 by 16 in with a shell thickness of 1 in , the mix was compacted with a small vibrator powered by two 3 h p. electric motors and equipped with a pallet stripper. In the case of the pipe, 8 by 36 in., compaction of the mix was effected with a tamper, striking with a force of 500 to 600 lb. per sq. in , at a frequency of 600 blows per minute.

In conformity with the procedure at this plant, the units were first "steam cured" at approximately 90 deg. F. in a saturated atmosphere. This curing was overnight (approximately 12 hr.) for the block, and 36 hr. for the pipe. On removal from the curing room, the block and pipe were stored out of doors in stock-piles to await testing.

The tests were conducted during the months of December and January with the following temperature, the record extending over the period of 28 days Highest 66 deg F., lowest 7 deg , mean maximum 40 6 deg , mean minimum 26 8 deg., average of the mean 33 7 deg

At definite intervals the blocks were transferred to the National Bureau of Standards, capped and their compressive strength determined. The pipes, however, were broken at the plant with the equipment at hand, using the three-edge-bearing method outlined in A.S.T.M. Test Method C14-41 (6) Inasmuch as the instrument was not calibrated the results serve primarily for comparative purposes

TABLE 2

COMPRESSIVE STRENGTH OF CONCRETE BLOCK[a]

Size—8 by 8 by 16 in
Proportion—1 2 2 (cement. sand gravel) by weight
Aggregate—
Fine—Potomac River sand
Coarse—Potomac River pea gravel
Water = Approximately three gallons per bag of cement

Age, days	Compressive strength			Increase in compressive strength	
	No $CaCl_2$, lb per sq in	1 per cent $CaCl_2$,[b] lb per sq in	2 per cent $CaCl_2$,[b] lb per sq in	1 per cent $CaCl_2$,[b] per cent	2 per cent $CaCl_2$,[b] per cent
1	540	1,020	1,200	89	122
3	1,060	1,500	1,650	42	56
7	1,470	2,010	1,960	27	33
28	1,710	2,400	2,530	40	48

[a] The concrete building block were made during December 1941 and January 1942 at a concrete-product plant and tested at the National Bureau of Standards

[b] $CaCl_2$—percentage of commercial material by weight of cement

Results

Concrete Block The data obtained from the tests on the building block are given in Table 2. Each strength value represents the average of 12 individual tests on block at 1, 3, and 7 days, and 3 tests at 28 days. The results are plotted in Figure 5

The spread of strengths was rather large. For example, at three days the strengths of 12 blocks containing no calcium chloride ranged from 570 to 1570 lb , while those of blocks containing 1 per cent ranged from 870 to 2080 lb , and those with 2 per cent from 1120 to 2120 lb. This is not surprising considering the variability in preparation of the blocks at the plant, storage out of doors and the

number of blocks (twelve) tested. Despite these large spreads it is evident that the average compressive strength of the blocks increased with increasing percentages of calcium chloride

Concrete Pipe The data obtained from the tests on the concrete pipe are given in Table 3 Each crushing strength value is the average of four individual tests on pipe at 1, 3, and 7 days The results are shown in Figure 6

As in the cases of the concrete cylinders and blocks, it is evident that the addition of calcium chloride increased the strength of the concrete pipe and that the increase was greatest at the earlier ages

TABLE 3

CRUSHING STRENGTH OF CONCRETE PIPE[a]

Size—8 by 36 in
Proportion—1 2 2 (cement sand. gravel) by weight
Aggregate—
Fine—Potomac River sand
Coarse—Potomac River pea gravel
Water = Approximately three gallons per bag of cement

Age, days	Crushing strength			Increase in crushing strength	
	No $CaCl_2$, lb per lin ft	1 per cent $CaCl_2$,[b] lb. per lin ft	2 per cent $CaCl_2$,[b] lb per lin ft	1 per cent $CaCl_2$,[b] per cent	2 per cent $CaCl_2$,[b] per cent
1	770	1,140	1,150	48	49
3	1,320	1,460	1,600	11	21
7	1,430	1,690	1,790	18	25

[a] The concrete pipe were made during December 1941 and January 1942 at a concrete-product plant and broken at the plant with the equipment at hand, using the three-edge-bearing method outlined in ASTM Method C 14-41

[b] $CaCl_2$—percentage of commercial material by weight of cement

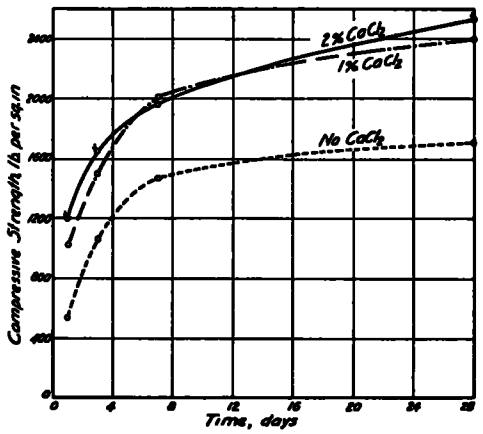

Figure 5. Compressive Strength, 8 by 8 by 16-In. Concrete Building Blocks, 1: 2: 2 Concrete by Volume, 3.0 Gal. of Water Per Bag of Cement.

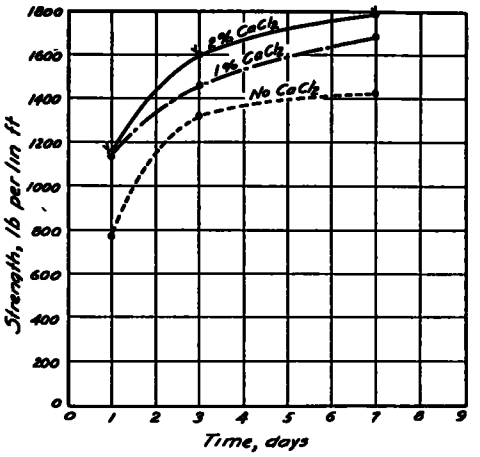

Figure 6. Strength of 8 by 36-In. Concrete Pipe, 1: 2: 2 Concrete by Volume, 3 0 Gal. of Water Per Bag of Cement.

REFERENCES

1. Paul Rapp, "Effect of Calcium Chloride on Portland Cements and Concretes," *Journal of Research,* National Bureu of Standards 14, 499 (1935) RP 782
2 J. C Yates, "Effect of Calcium Chloride on the Strength Development of Concrete Stored at Low Temperatures," *Proceedings,* Highway Research Board, Vol. 21 (1940).
3 Federal Specification SS-A-281a for Aggregate, for Portland Cement Concrete
4 A S T M Specification D-98 for Calcium Chloride
5 A S T M Specification C-39 for Method of Test for Compressive Strength of Concrete
6 A S T M. Test Method C-14-41 for Concrete Sewer Pipe