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EFFECTS OF CAL AS AN ACCELERATOR OF THE HARDENING OF PORTLAND CEMENT MIXTURES

BY

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Bureau of Standards

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EFFECTS OF CAL AS AN ACCELERATOR OF THE HARDENING OF PORTLAND CEMENT MIXTURES[1]

By Roy N. Young

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[1] As explained in the introduction, the effect of calcium chloride in Portland cement mixtures has been quite thoroughly investigated, and the use of hydrated lime in such mixtures is not uncommon in practice. There are no restrictions on the use of these materials in concrete, but their application in the form of calcium oxychloride, or "Cal," has been covered by patents. In view of the importance to users of cement and concrete of knowing the properties of this material and its value as an accelerator, particularly in comparison with calcium chloride, a cooperative investigation was undertaken by the Bureau of Standards and the patentee, the results of which are given in this paper.

I. INTRODUCTION

A demand for a practical and efficient material for accelerating the hardening of Portland cement mixtures has received considerable attention in recent years. The need for such a material becomes of more consequence with the introduction of more rapid methods in construction and with the increasing amount of concrete repair and replacement work. Serious problems arise when it becomes necessary to interrupt or divert traffic for the duration of time required for concrete to harden sufficiently. The increased cost of lumber for forms has necessitated a more judicious use of such material, and its removal for further use as soon as the strength of the concrete will allow. This applies even more to the use of steel forms, which are rapidly replacing wooden forms in a great many types of concrete construction.

Considerable work toward the development of an accelerator for concrete has been done by the U. S. Bureau of Standards,[2] which found that calcium chloride was the most effective of the various substances tested. Comprehensive tests were made on concrete gaged with solutions up to 10 per cent commercial calcium chloride for the purpose of substantiating the results of the preliminary tests and also to determine if any injurious effects would result at later periods from the use of this accelerator. The increase in strength obtained at the age of two or three days over that of similar concrete gaged with water was from 30 to 100 per cent.[3] At the age of one year there was no indication that the addition of this salt had any deleterious effect on the durability of concrete. The three-year test pieces are now being broken with results showing further evidence that calcium chloride does not effect the ultimate integrity of concrete.

Inasmuch as the use of commercial calcium chloride in concrete is attended by difficulties caused by its highly hygroscopic property and by the handling of the solution, Charles Catlett[4] conceived the idea of introducing the salt by means of Cal, a material by which the above difficulties might be eliminated. Furthermore, Cal possesses possibilities which calcium chloride does not have, owing to the fact that the products of its decomposition by water are calcium chloride and calcium hydroxide, equivalent in effect to a simultaneous addition of calcium chloride and finely divided hydrated lime. Since both calcium

[2] Engineering Record, 74, pp. 266–267; 1916.
[3] Annual Report of the Director of the Bureau of Standards; 1918.
[4] Patent No. 1282188; patent No. 1308932.

chloride and hydrated lime are being used separately in cement mixtures to produce certain desirable effects, it was not considered that the use of Cal introduces anything new in the making of concrete, excepting the manner in which these materials are added.

Influenced by the above considerations, an investigation was inaugurated by Mr. Catlett, with the cooperation of the Bureau of Standards, for the purpose of studying the effects of Cal on Portland cement mixtures. The most important object was to learn the value of this material as an accelerator of the hardening of concrete.

While a greater part of the work preliminary to the main series of concrete tests deals with the effects of Cal on the early time strengths of cement mixtures under various conditions, it also includes miscellaneous tests bearing on questions which might preclude the use of this material with Portland cement, or limit its use to special mixtures or kinds of construction work.

Acknowledgment is made to G. M. Williams for assistance in planning the concrete tests, to Watson Davis for assistance in conducting these tests, and to A. B. Peck for the microscopic work.

II. NATURE OF CAL

Cal is essentially an oxychloride of calcium. A number of investigators have prepared crystals of this salt by boiling calcium hydroxide in a fairly strong solution of calcium chloride, filtering rapidly, and allowing the filtrate to cool. An analysis by Beesley [5] indicated that the formula was $3CaO.CaCl_2$, $14H_2O$. According to Rose [6] and André,[7] the crystals have the formula $3CaO.CaCl_2$, $16H_2O$. Grimshaw [8] found the constituents in the ratio $3CaO.CaCl_2$, $15H_2O$, but considered the formula $ClCa.O.Ca(OH)$, $7H_2O$ to be simpler and more intelligible.

Calcium oxychloride is readily soluble in water, in which it decomposes into calcium hydroxide and calcium chloride. It is also soluble in alcohol. The salt is acted upon by carbon dioxide, forming calcium carbonate and calcium chloride. Over sulphuric acid, in a vacuum or in the air, it parts with a portion of the water of crystallization. The crystals are needle-shaped and were

[5] Pharmaceutical Journal, 9, p. 568.
[6] Schweigger's Journal für Chemie und Physik, 5, pp. 29–155.
[7] Comptes Rendus, 92, p. 1452.
[8] Chemical News, 30, p. 280.

prepared by the writer from very minute size up to 1¼ inches in length, depending largely upon the rate at which the solution was cooled. The composition of the crystals made under various conditions was in all cases the same and agreed closely with the formula given by Grimshaw.

Cal is made by pulverizing the product resulting from a mixture of lime, calcium chloride, and water. The material used in the following tests was made by the Mellon Institute at Pittsburgh, Pa., in September, 1918, by mixing together 100 parts hydrated lime, 55 parts commercial calcium chloride, and 50 parts water. During several weeks exposure to the atmosphere it became hard and dry.

There was a question as to whether this material was chiefly a mechanical mixture or a product of chemical reaction. A microscopic examination was made, and it was found to consist of fairly well developed crystals of calcium oxychloride lying in a groundmass of minute irregular crystals which resembled the larger ones in every other respect. There was only a small percentage of calcium hydroxide present. Other samples were prepared by treating separately quicklime and hydrated lime with various concentrations of calcium chloride solutions. These proved to be of the same nature as the Cal just described, with the exception that the larger crystals varied in size and relative number among the different samples.

The first lot of Cal was ground without further drying than that which it received by exposure to the atmosphere. The finished product was a dry, white, rather fluffy powder which analyzed as follows:[9]

	Per cent
Loss on ignition	43.93
Hydrochloric acid insoluble	.15
SiO_2	.71
R_2O_3	.51
CaO	41.15
MgO	3.58
Cl_2	11.47
SO_3	.71
	102.21
O=Cl	2.59
Total	99.62
CO_2	3.78
Water (loss−CO_2)	40.15

[9] The Cal used in the concrete tests was dried and will be described later.

If Cal is exposed to the air, it gradually takes up carbon dioxide and becomes damp. However this action is comparatively slow and should not cause trouble if the material is handled in the same way as hydrated lime.

A sample of Cal which had been exposed to the laboratory air for eight months and another which had been stored in a cloth bag for about three years were used for treating mortars in compression tests. The results indicated that exposure does not lessen the effectiveness of Cal as an accelerator of the hardening of Portland cement mixtures.

III. EFFECT OF CAL ON THE SETTING TIME OF PORTLAND CEMENT

The effect of Cal on the setting time of normal Portland cements may be seen by examining the results given below. The set was hastened in all cases and to a greater extent by the larger percentage of Cal.

TABLE 1.—The Setting Time of Normal Portland Cement Treated with Undried Cal

[The percentage of water is calculated on the basis of the combined weights of the cement and Cal]

Cement	Ratio (percentage) Cal to cement	Ratio (percentage) water to total mixture	Initial set		Final set	
Sample Nos.:			H.	M.	H.	M.
1	None	23.4	4	0	8	10
	5	21.9	2	15	5	45
	8	21.0	1	50	5	30
2	None	23.2	3	35	6	45
	5	21.7	1	50	4	10
	8	20.8	1	25	3	30
3	None	23.4	3	40	7	0
	5	21.9	2	45	5	45
	8	21.0	2	5	4	25
4	None	24.0	4	40	7	30
	5	22.5	3	0	5	40
	8	21.6	1	50	3	40
5	None	22.5	3	35	6	25
	5	21.0	1	55	2	55
	8	20.1	1	5	1	55

It will be noticed that the percentage of water necessary for normal consistency decreases as the amount of Cal increases. This may be explained in part by the fact that the Cal contains considerable water which is set free upon its decomposition and which is in excess of that necessary to give plasticity to the resulting products.

Cal was added to a number of quick-setting cements with the result that they were made normal. This may seem contradictory to the results obtained with normal cements as shown above, but it should be remembered that the setting time in such cases is not controlled by Cal alone. Ground Portland cement clinker is usually quick setting, and therefore gypsum is added as a retarder in order to meet commercial requirements. If Cal is added to a finished cement, the effect on the set will be the resultant effect of both Cal and gypsum. The effect of Cal alone on ground cement clinker is as follows:

TABLE 2.—The Setting Time of Ground Cement Clinker Treated with Cal

Cal	Ratio (percentage) water to mixture	Initial set	Final set
		H. M.	H. M.
None	25.0	Flash ..	.....
2 per cent	24.5	1 10	5 0
4 per cent	23.1	3 10	6 10
6 per cent	21.7	2 55	5 45
8 per cent	21.3	2 30	4 20
10 per cent	20.0	1 10	3 25

It will be seen that the maximum retardation is produced by 4 per cent of Cal, and that the retardation diminishes with increasing or decreasing amounts. Hence it seems reasonable that an addition of Cal to a normal cement already containing gypsum should hasten the set in the same way that an addition of Cal to the clinker already containing 4 per cent of Cal will hasten the set. Also, if a cement containing gypsum is quick setting, an addition of Cal in increasing amounts should increase the retardation until a maximum retardation is reached due to the combined effect of Cal and gypsum.

IV. EFFECT OF CAL ON THE SOUNDNESS OF PORTLAND CEMENT

No indication of unsoundness has appeared in normal cement treated with Cal. Unsoundness, as determined by the steam test, may be corrected by the addition of Cal, according to the results of tests given below. This action is probably due to an increased hydration of the free lime before the cement sets.

A very unsound cement was used in a 1:3 mortar which was molded into 2-inch cubes and stored in air after 24 hours. At the end of 8 months, the plain mortar test pieces were entirely

disintegrated. The test pieces made from the same mortar to which 5 per cent of undried Cal was added were still very firm, although a few disintegration cracks had developed.

TABLE 3.—Effect of Cal on the Soundness of Portland Cement

Cement laboratory No.	Soundness after addition of various percentages of undried Cal			
	0 per cent	2 per cent	5 per cent	8 per cent
42895...	Unsound; slightly warped, not hard.	Sound; very slightly warped.	Sound; very slightly warped.	Sound.
42896...	.....do.....	Unsound; warped, hard.	Sound; very slightly warped, hard.	Sound; very slightly warped, hard.
43015...	Unsound; very soft....	Unsound; warped, not hard.	Sound.....	Sound.
43200...	.....do.....	Sound.....	.....do.....	Do.
5.....	.....do.....	.....	Sound; slightly warped, hard.	Do.

V. EFFECT OF CAL ON THE EARLY COMPRESSIVE STRENGTH OF PORTLAND CEMENT MORTARS

1. WATER STORAGE

A series of tests was made on five different brands of cement, using 1 part cement to 3 parts Standard Ottawa sand. Per centages of undried Cal varying from 0 per cent to 8 per cent of the cement were added to the dry mixtures. Also, mortars were made from each brand of cement by gaging the mixtures with a 4 per cent solution of commercial calcium chloride. This concentration was used for the reason that it was found to be the most satisfactory in tests previously conducted by this Bureau.

Mixes containing additions of Cal up to 5 per cent were, in some cases, gaged with the same quantity of water as was used in the plain mortar for normal consistency. Consequently the excess of water contained in the Cal produced a wetter consistency than normal, and probably resulted in somewhat smaller increases in strength over the plain mortars than would have been obtained if the consistencies had been the same throughout. All other mixes were of normal consistency as calculated from the normal consistencies of the neat mixtures, or as nearly as could be judged by the operators. The results of these tests are shown in Fig. 1. In general, with each increase in the amount of Cal added to the mortar there is an increase in strength at each of the three periods tested.

8559°—20——2

2. AIR STORAGE

Some of the above tests were repeated, with the exception that the test pieces were stored in the laboratory air rather than in water. The results of these tests are shown in Fig. 2. It is evident from the much lower strengths of the 28-day test pieces stored in air that there was a very rapid drying out of these test pieces, as might be expected on account of their size. The effect of Cal under the conditions of these tests is remarkable.

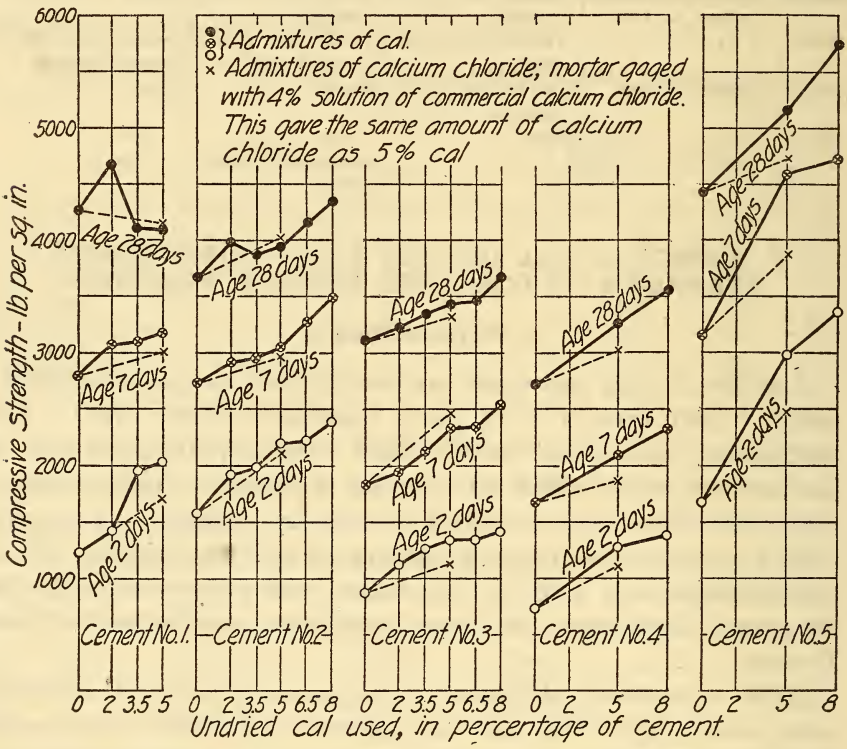

FIG. 1.—*Compressive strength of mortar at various ages treated with Cal or calcium chloride and stored in water*

The strength of the treated mortar at 2 days is considerably above that of the untreated mortar at 28 days.

3. COLD STORAGE

It is a well-known fact that the rate of hardening of cement is affected by the temperature conditions. One difficulty arising from this is slow setting and hardening, which often occurs during cold weather. Tests in which the test pieces were stored in a refrigerator at a temperature slightly above freezing indicate

that such difficulties may be overcome by the use of Cal. Also, Cal may be a means of protection against freezing in that it greatly reduces the critical time during which freezing is injurious.

4. MIXTURES OF CEMENT AND CAL STORED IN AIR

As it might be desirable to mix an accelerator with cement at the mill during the process of grinding or before it is packed, a series of tests was made to determine the effects of air storage on mixtures of cement and Cal. The mixtures in these tests were portions of the ones from which the mortar tests shown in Fig. 1 were made. About 2 kg of each mixture were placed in

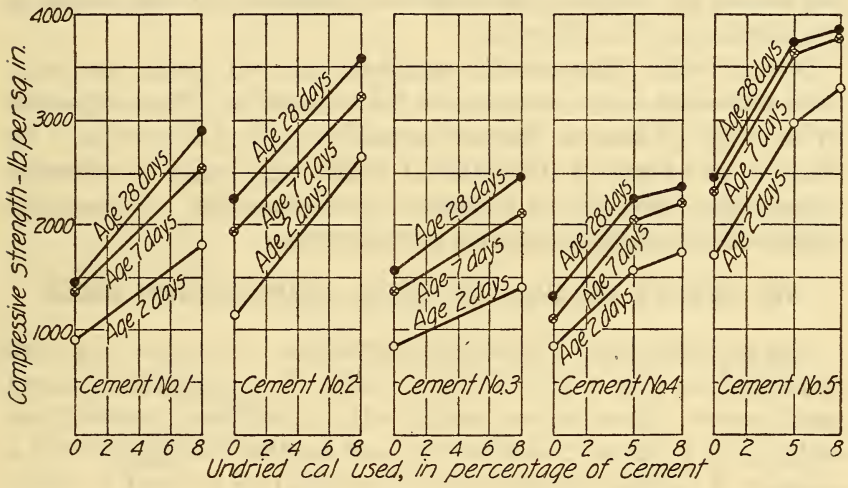

FIG. 2.—*Compressive strength of mortar at various ages treated with Cal and stored in air*

a small canvas bag and stored in the laboratory air. At the end of 90 days mortar cubes were made under as nearly as possible the same conditions as those existing during the former tests.

All samples of cement and mixtures of cement and Cal deteriorated during the storage period. There was a tendency for the mixtures to form lumps and pack. The mortar tests showed no marked increase in strength of mortar containing Cal over that of the untreated. After these tests were started, it was found that the Cal used gives up considerable moisture when exposed to the air, so no doubt that in this instance the moisture given up by the Cal which was mixed with the cement did much toward affecting this deterioration. It was not determined whether the result might be entirely attributed to this loosely

held water or whether the Cal increased the amount of moisture taken up by the cement from the air. It may be possible that a change in the method of manufacture of Cal will produce a material which can be mixed with cement without ill effects and at the same time retain its efficiency when the mixture is used in concrete.

VI. EFFLORESCENCE

Two small brick walls were built on the roof of a building where they were exposed to the weather. Plain mortar (1 part cement to 3 parts Potomac River sand, by weight) was used in constructing one of the walls, while 8 per cent undried Cal was added to the mortar used in the other.

Considerable efflorescence was observed, but there was very little difference in the amounts on the two walls. There appeared to be slightly less on the one containing the Cal mortar. An analysis was made of the material which was caused to effloresce by artificial means from a mortar containing Cal. It consisted chiefly of the alkali carbonates and chlorides.

VII. EFFECT OF CAL ON STEEL REINFORCING BARS

One-half-inch steel reinforcing bars about 4½ inches long were embedded in 3 by 6 inch cylinders made of 1:3 standard Ottawa sand mortar. One set was made with no addition, one with an addition of 5 per cent undried Cal, and another was gaged with a solution of calcium chloride which furnished an amount of anhydrous calcium chloride equal to that contained in the 5 per cent addition of Cal. These cylinders were stored exposed to the weather. At the end of eight months one test piece from each set was broken, and the only signs of corrosion found were a few rust spots on the bar embedded in mortar containing calcium chloride. Of course, these tests furnish no conclusive information, but it is interesting to note that corrosion had not appeared on the bar in the mortar containing Cal. Such tests should be continued for a number of years and under various moisture conditions.

VIII. EFFECTS OF CAL AND CALCIUM CHLORIDE ON CONCRETE

1. DESCRIPTIONS AND TESTS OF MATERIALS

(*a*) CAL

It was found advantageous to drive off a portion of the water in the Cal, and therefore in preparing the lot used in the following tests the lump material was dried. This was done in such a way that it was not exposed to the atmosphere or gases from the burner during the operation. The crushing was done in a small jaw crusher and the grinding in a pebble mill. A sample of about 100 pounds was mixed thoroughly by placing it in the pebble mill lightly loaded with pebbles. The entire quantity was quartered down for the chemical sample. An anlysis of this sample was made several days before the tests were started, and the chlorine content was again determined after all the concrete was mixed, to learn if any change in the percentage, caused by exposure to the air, had taken place during this time. It may be seen by the results given below that equal weights of the material taken at any time during the tests furnished practically equal amounts of calcium chloride.

CHEMICAL ANALYSIS OF CAL

[Laboratory No. 56971]

	Per cent
Loss on ignition	21.42
Insoluble material	.80
Soluble material:	
SiO_2	1.00
R_2O_3	.60
CaO	58.10
MgO	4.75
Cl_2	15.68
SO_3	.91
	103.26
O=Cl	3.54
Total	99.72
CO_2	5.12
Water (loss−CO_2)	16.30
Chlorine content after about eight weeks	15.50

(*b*) CALCIUM CHLORIDE

A solution of calcium chloride was made from commercial calcium chloride and filtered through a finely woven cloth, separating considerable insoluble matter. After a sample was taken for chemical analysis, the solution was kept in an air-tight container

until used. The samples for chemical analysis of this calcium chloride solution were taken at the same time as those for the analysis of Cal. The analysis of this solution follows:

RESULTS OF ANALYSIS OF CALCIUM CHLORIDE SOLUTION

[Specific gravity at 24° C=1.338]

	Per cent
Ca	12.16
Cl_2	22.31
Mg, less than	.10
Chlorine content after the concrete mixing was completed	22.42

(c) CEMENT

On account of the somewhat varying effectiveness of Cal on different brands of cement as indicated by the mortar tests, it was decided that no less than three brands should be used in this series. These brands were chosen from those used in the mortar tests for the reason that they had been found to fairly well represent the range of Portland cements with regard to early time strengths and that they could be purchased on the market at Washington, D. C.

The entire lot of each brand was thoroughly mixed on canvas and then placed in metal containers until used. The chemical and physical tests of these cements are given in Table 4.

TABLE 4.—Chemical and Physical Tests of Cements

Nature of determination	Test results for laboratory numbers—		
	45003	45076	45101
Chemical:	Per cent	Per cent	Per cent
Loss	2.01	2.43	1.76
Insoluble residue	.20	.17	.40
Silica	19.78	22.39	20.72
Oxide of iron	3.40	2.20	1.90
Oxide of alumina	7.26	5.58	5.82
Lime	62.56	60.00	63.48
Magnesia	1.72	4.07	4.02
Sulphuric anhydride	1.91	1.78	1.63
Sodium oxide	.....	.87	.43
Potassium oxide	.....	.42	.38
Physical:			
Water used—			
Neat	23.0	23.0	23.0
Mortar	10.3	10.3	10.3
Fineness (200-mesh sieve)	84.5	81.6	87.1
Time of set—	Hr. Min.	Hr. Min.	Hr. Min.
Initial	2 55	2 55	3 45
Final	6 30	6 00	6 55
Soundness	O. K.	O. K.	O. K.
Tensile strength—	Lbs./in.²	Lbs./in.²	Lbs./in.²
7 days	282	200	318
28 days	370	313	455

(*d*) AGGREGATE

Potomac River aggregate was used in this series and was purchased in 5-ton lots at Washington, D. C. The gravel was washed, dried, and stored in sacks until used. To insure uniformity, just before each day's run of mixing, a sufficient amount of gravel for all mixes for one proportion and for one brand of cement was mixed by shovel on a concrete floor and resacked in lots of accurate weight for one batch. The sand was treated in the same manner excepting that it was not washed, as it was in good condition when received. The results of the physical tests of these materials are given below. The weights per cubic foot used in proportioning were 95 per cent of the weight per cubic foot of packed material. A metal cubic-foot measure was used in this determination.

WEIGHTS PER CUBIC FOOT

	Pounds
Sand	120
Gravel	114

TABLE 5.—Mechanical Sieve Analysis of Aggregate

Sieve No.	Size opening	Per cent passing		Sieve No.	Size opening	Per cent passing	
		Sand	Gravel			Sand	Gravel
	Inches				Inch		
	1½	.....	100	4	0.185	95	1
	1	.....	91	8	.093	81	.....
	¾	.....	71	14	.046	69	.....
	½	.....	51	28	.0232	51	.....
	⅜	.....	26	48	.0116	15	.....
3	.263	100	8	100	.0058	4	.....

2. METHODS AND APPARATUS

(*a*) PROPORTIONING

The proportioning of the cement, sand, and gravel was by volume, but for the sake of convenience and accuracy the materials were measured by weight. The cement was assumed to weigh 94 pounds per cubic foot.

In all mixes in which a direct comparison was made between Cal and calcium chloride, an exact weight of the calcium chloride solution was used which contained an equivalent weight of chlorine as added by means of the Cal.

(*b*) CONSISTENCY

The consistency of the various mixes was measured by means of the "flow table," which has been developed by the Bureau of Standards.[10] It is believed that this method is the most satis-

[10] Williams, Engineering News Record, 84, p. 1044.

factory of any so far devised for determining the relative "flowability" of concrete. The method is sensitive through a wider range of consistencies than the slump method, and the results are consistent and reliable.

Two consistencies were chosen as standards in the concrete tests. The 1 : 1½ : 3 concrete was rather stiff and represented the type of concrete often used in road construction. All batches of this proportion were made to have a relative flowability as near 150 as possible.

The 1 : 2 : 4 concrete was considerably wetter and was of such consistency as is often used in reinforced-concrete construction. The relative flowability sought in this case was 200.

From two to three flow tests were made on each batch in order that very nearly the desired consistency might be produced before the final test was made. This final test was to be made 10 minutes after the water was added to the dry mixtures.

(c) MIXING

In the preliminary tests on concrete contradictory results were obtained under certain conditions in that the strengths of the treated concrete at seven days were lower than the corresponding strengths of the untreated concrete. Considerable work was done to determine the cause of this before it became evident that the different method used in mixing the concrete was the source of the difficulty. In every instance the mortars were mixed by kneading with the hands, and the batches were sufficiently small to allow thorough mixing within one and one-half minutes. The batches of concrete were considerably larger and were mixed by turning with a trowel. Consequently they did not receive as vigorous or thorough mixing as applied to the mortars. When these concrete mixes were duplicated and mixed by machine the results were of the same order as those obtained in the mortar tests. No further investigation was made in this direction, but it is believed that the results obtained with the hand-mixed concrete were exceptional.

In the following tests the mixing was done in a model 15 Wonder mixer. Sufficient material was used in each batch to provide some in excess of the amount necessary for six 6 by 12 inch cylinder test pieces. After the dry materials were placed in the mixer a part of the water was added and the mixer was started. More water was then added until about the proper consistency was obtained. At the end of 2 minutes from the time the first water

was added the mixer was stopped and a "flow" test was made. When only two flow tests were made within 10 minutes after the water was added the mixer was run 45 seconds just previous to the making of the final flow test. Later three flow tests were made instead of two, and the mixer was run for 30 seconds before each of the last two tests. This additional mixing of all batches was necessary in order that water might be added if needed to increase the flowability to the desired degree and at the same time that all batches might be given an equal amount of mixing.

(*d*) MOLDING AND CAPPING

All test pieces in this series were 6 by 12 inch cylinders. The molds used were made from wrought-iron pipe cut in lengths of 12 inches and slit perpendicularly to the axis of the cylinder. This slit was kept closed during molding by bolts through angles riveted to the cylinder on each side of the slit. The molds were filled in three layers, each layer being puddled with a five-eighth-inch steel rod. The bottom caps were formed by placing the molds on a layer of stiff neat cement which was spread about one-half inch thick on sheet iron a short time before molding the test pieces. The molds were filled to less than one-fourth inch from the top. After about an hour the filling was completed with a thin neat cement paste and smoothed off with a trowel. This method gave good solid caps which required very little grinding to produce a plane bearing surface.

(*e*) STORAGE

At the end of 24 hours the test pieces were removed from the molds. Three of the test pieces from each batch were stored in damp sand, and the remaining three were stored in the air of the laboratory. Hence, the results obtained under the two storage conditions are strictly comparable with respect to materials, quantity of mixing water, etc. The daily average room temperatures where test pieces were stored in air gradually lowered throughout the storage period from about 72° F. to about 60° F. The temperature of the damp sand averaged about 5° F. below these temperatures at the beginning of the tests, but toward the end the temperatures of the two storages were about the same. The average relative humidity was approximately 65 per cent.

(*f*) TESTING

Specimens 62–1–1 to 62–3–3 and 62–13–1 to 62–15–3,[11] inclusive, were tested on a 200 000-pound Riehle testing machine. All others

[11] The numbering system is merely a local means of identifying the test pieces.

were tested on a 100 000-pound Riehle machine. A single thickness of blotting paper was placed between each end of the specimen and the bearing plate. The test piece was centered on a spherical bearing block which was then shifted into place. The upper surface of the test piece was fitted squarely against the upper bearing surface by turning the test piece and upper part of the block horizontally first in one direction and then in the other while the movable head was being lowered onto the test piece.

3. RESULTS OF STRENGTH TESTS

The results of the strength tests are given in Table 7.

The most important facts deduced from these data are as follows:

1. In all cases, the strength of the treated concrete was greater than that of the corresponding untreated concrete at the two and seven day periods.

2. The strength of the treated concrete was practically the same as that of the untreated at the 28-day period.

3. The effect of Cal at the 2-day period was very nearly the same for all cements, proportions, and conditions of the tests. This may be seen by examining the data given below.

TABLE 6.—Percentage Increase in Strength of Concrete Due to Cal at the Two-Day Period

Resulting from—	Maximum	Minimum	Average
Cement No. 45003	75	60	66
Cement No. 45076	80	55	65
Cement No. 45101	66	52	58
Proportion 1 : 1½ : 3, stiff consistency	61	52	58
Proportion 1 : 2 : 4, wet consistency	80	52	68
Stored in damp sand	80	52	65
Stored in air	69	52	61

4. The results produced by Cal and calcium chloride are practically the same.

Since the primary reason for using an accelerator in Portland cement mixtures is to produce a given strength in less time than ordinarily required and thereby effect a saving, it is important to express laboratory tests on this basis. If time-strength curves of both the untreated and corresponding treated mixtures are plotted together, it is very convenient to compare the ages at which they have equal strengths. In this series of concrete tests, the strength of the treated concrete at two days was equal to that of the untreated at from three to four and one-half days. Mortar tests indicated that more marked results may be obtained by increasing the percentage of Cal.

Although very uniform results were obtained under various conditions at the 2-day period, there was considerable variation at the 28-day period. Furthermore, Cal generally increased the strength of mortars at the 28-day period, while it seemed to have little or no effect on the concrete at this age. A number of mortar tests were made with variations in proportions and percentages of Cal to cement and Cal to water, with the thought that they might determine the cause of these irregularities, but no conclusive results were obtained.

TABLE 7.—Compressive Strengths of Concrete to Which Cal and Calcium Chloride Have Been Added

[Additions of Cal throughout this series were 5 per cent of the cement. Cal and calcium chloride additions contained equal amounts of chlorine. Test pieces were 6 by 12 inch cylinders]

CEMENT NO. 45003

Batch	Addition	Proportion	Relative flowability	Water, per cent	Compressive strength in pounds per square inch					
					Stored in damp sand			Stored in air		
					2 days	7 days	28 days	2 days	7 days	28 days
62-1-1	None	1 : 1½ : 3	150	7.88	870	2390	3491	806	2370	3662
2	do	1 : 1½ : 3	156	7.88	915	2390	4035	882	2450	3351
3	do	1 : 1½ : 3	155	7.88	915	2290	3735	916	2190	3508
Average			155	7.88	900	2337	3754	868	2337	3507
62-2-1	Cal	1 : 1½ : 3	149	7.88	1488	3030	3775	1290	2470	3379
2	do	1 : 1½ : 3	148	7.88	1432	2770	3788	1598	2610	3600
3	do	1 : 1½ : 3	149	7.88	1435	2650	3687	1279	3000	3689
Average			149	7.88	1450	2817	3617	1390	2693	3556
62-3-1	$CaCl_2$	1 : 1½ : 3	148	7.88	1686	2700	3471	1515	2610	3339
2	do	1 : 1½ : 3	149	7.88	1347	2790	4089	1540	2790	3665
3	do	1 : 1½ : 3	154	7.88	1600	2790	3390	1300	2790	3604
Average			152	7.88	1540	2760	3650	1450	2730	3536
62-4-1	None	1 : 2 : 4	189	8.52	338	1222	2212	322	1090	1782
2	do	1 : 2 : 4	212	8.52	341	1148	2314	357	1109	1967
3	do	1 : 2 : 4	201	8.52	384	1236	2303	392	1374	1976
Average			201	8.52	354	1202	2278	357	1191	1908
62-5-1	Cal	1 : 2 : 4	190	9.28	593	1329	1765	601	1242	1612
2	do	1 : 2 : 4	200	8.89	674	1340	1750	553	1295	1591
3	do	1 : 2 : 4	213	8.89	586	1455	1976	656	1330	1612
Average			201	9.02	618	1375	1830	603	1289	1605
62-6-1	$CaCl_2$	1 : 2 : 4	217	8.58	686	1480	2112	636	1439	2012
2	do	1 : 2 : 4	196	8.28	740	1605	1943	756	1562	1998
3	do	1 : 2 : 4	200	8.28	716	1515	2282	636	1491	1800
Average			206	8.38	714	1533	2112	676	1497	1937

TABLE 7.—Compressive Strengths of Concrete to Which Cal and Calcium Chloride Have Been Added—Continued

CEMENT NO. 45076

Batch	Addition	Proportion	Relative flowability	Water, per cent	Compressive strength in pounds per square inch					
					Stored in damp sand			Stored in air		
					2 days	7 days	28 days	2 days	7 days	28 days
62-7-1	None	1 : 1½ : 3	156	8.14	389	952	2362	396	1045	1733
2	do	1 : 1½ : 3	150	7.94	452	1141	2231	408	1117	1855
3	do	1 : 1½ : 3	151	7.94	428	1041	2327	395	1050	1822
Average			152	8.01	423	1045	2307	400	1071	1803
62-8-1	Cal	1 : 1½ : 3	147	8.21	666	1226	2228	621	1385	1922
2	do	1 : 1½ : 3	152	8.21	704	1183	2217	672	1363	2029
3	do	1 : 1½ : 3	142	8.21	598	1176	2257	643	1315	1883
Average			147	8.21	656	1196	2234	645	1354	1945
62-9-1	$CaCl_2$	1 : 1½ : 3	148	8.02	676	1329	2362	690	1400	2093
2	do	1 : 1½ : 3	155	8.02	661	1230	2292	600	1383	2030
3	do	1 : 1½ : 3	161	8.02	617	1277	2041	684	1403	1971
Average			155	8.02	651	1279	2232	658	1395	2031
62-10-1	None	1 : 2 : 4	188	8.80	132	393	1290	146	406	748
2	do	1 : 2 : 4	198	8.80	138	416	1145	141	393	647
3	do	1 : 2 : 4	205	8.80	113	346	1131	147	445	729
Average			197	8.80	128	385	1189	145	415	708
62-11-1	Cal	1 : 2 : 4	209	9.04	229	526	1146	228	516	873
2	do	1 : 2 : 4	210	9.04	252	539	1020	262	569	842
3	do	1 : 2 : 4	196	9.04	209	524	1223	230	633	920
Average			202	9.04	230	530	1130	240	573	878
62-12-1	$CaCl_2$	1 : 2 : 4	201	8.80	274	572	993	279	534	870
2	do	1 : 2 : 4	196	8.80	218	533	1141	251	634	893
3	do	1 : 2 : 4	201	8.80	238	544	1139	229	525	854
Average			199	8.80	243	550	1091	253	564	872

Cement No. 45101

62-13-1	None	1 : 1½ : 3	156	7.94	1146	2900	3660	1184	2375	3330
2	do	1 : 1½ : 3	149	7.75	1306	2742	4060	1175	2258	3350
3	do	1 : 1½ : 3	152	7.75	1212	2640	3900	1177	2347	3295
Average			152	7.81	1221	2761	3873	1179	2327	3325
62-14-1	Cal	1 : 1½ : 3	152	8.06	1875	3133	3905	1995	2970	3635
2	do	1 : 1½ : 3	150	8.06	1800	2955	3885	1801	2747	3525
3	do	1 : 1½ : 3	149	8.06	1887	2994	.....	1850	2631	3810
Average			150	8.06	1854	3027	3895	1882	2783	3657

TABLE 7.—Compressive Strengths of Concrete to Which Cal and Calcium Chloride Have Been Added—Continued

CEMENT NO. 45101—Continued

Batch	Addition	Proportion	Relative flowability	Water, per cent	Compressive strength in pounds per square inch					
					Stored in damp sand			Stored in air		
					2 days	7 days	28 days	2 days	2 days	28 days
62-15-1	$CaCl_2$	1 : 1½ : 3	149	7.75	2020	3239	3845	1981	3061	4215
2	do	1 : 1½ : 3	150	7.75	1835	2982	4260	1973	2882	3720
3	do	1 : 1½ : 3	150	7.75	1943	2880	3940	1775	2800	3760
Average			150	7.75	1935	3034	4015	1910	2914	3898
62-19-1	None	1 : 2 : 4	200	8.67	535	1551	2757	457	1177	1808
2	do	1 : 2 : 4	199	8.38	504	1510	2422	524	1225	1965
3	do	1 : 2 : 4	196	8.92	537	1475	2523	476	1145	1739
Average			198	8.66	525	1512	2567	486	1182	1837
62-20-1	Cal	1 : 2 : 4	195	8.68	912	.....	2483	774	1448	2090
2	do	1 : 2 : 4	194	8.68	862	1554	2418	738	1504	1835
3	do	1 : 2 : 4	198	8.68	837	1648	2240	702	1371	2021
Average			196	8.68	870	1601	2380	738	1441	1982
62-21-1	$CaCl_2$	1 : 2 : 4	196	8.37	872	1694	2490	868	1434	2162
2	do	1 : 2 : 4	204	8.72	795	1782	2600	784	1578	1880
3	do	1 : 2 : 4	196	8.56	754	1654	2205	780	1458	1888
Average			199	8.55	807	1710	2432	811	1490	1977

IX. EFFECT OF CAL ON CONSISTENCY AND WORKABILITY OF CEMENT MIXTURES

The way in which Cal affects consistency depends largely upon the amount of water which it contains. When Cal containing 40 per cent water was added to cement or mortar, an appreciably wetter mix was the result. Cal containing 16 per cent water had no effect on the consistency or flowability of mortars, but it appeared to increase the plasticity or ease in working the mixtures with a trowel. In the concrete tests a very small increase in percentage of water was necessary in the mixes containing Cal over that added to the untreated mixtures in order to produce the same relative flowability. This was probably due to the fact that Cal causes earlier stiffening or setting and that the flowability tests were made 10 minutes after the water was added. This earlier stiffening is not objectionable if the concrete is placed shortly after mixing. On the other hand, it is at times very desirable, especially in construction requiring a finished surface, such as floors.

Cal was used in a concrete floor topping alongside of topping containing no accelerator, for the purpose of observing the effect under actual field conditions. The treated topping was ready for the finishing operation in about one-half the time required by the untreated, as judged by the finisher. This agreed very closely with the results of the laboratory tests on the rate of setting of the two mixes by means of the flow table.

X. SUMMARY

Cal is a material obtained by pulverizing the dried or undried product resulting from a mixture of either quicklime or hydrated lime, calcium chloride, and water. It is a dry white powder which may be handled in much the same way as hydrated lime, and with the same general keeping qualities. It is much more convenient to handle and use in making concrete than calcium chloride, either fused or in concentrated solution. Upon exposure to the air Cal gradually takes up carbon dioxide and becomes somewhat damp. However, tests indicate that long exposure does not affect its action as an accelerator of the hardening of Portland cement mixtures.

The setting of normal Portland cement mixtures may be hastened by Cal to an extent which is very desirable in concrete construction requiring a finished surface. The finishing operation may proceed with much less delay after the concrete has been placed, which should result in cutting down overtime labor. This hastening of the set is not objectionable in any type of construction providing the concrete is placed soon after it is gaged with water. It is believed that Cal increases the workability of Portland cement mixtures. However, no attempt was made to measure the extent of this effect, because up to this time no satisfactory test has been developed for measuring the workability of Portland cement mixtures.

Unsound cements may be greatly benefited or made sound by an addition of Cal. This effect was produced in neat pats subjected to the steam test and in mortar test pieces stored in air.

Limited tests indicate that quicksetting cements, either fresh or having become quicksetting on aging, may be made normal by the addition of Cal as used in cement mixtures.

There was no indication that the amount of efflorescence appearing on the surface of cement mixtures exposed to the weather is increased by the use of Cal.

The series of tests on the effect of Cal on steel reinforcing bars which were embedded in a thin layer of Cal cement mortar and exposed to the weather for eight months without showing any sign of corrosion, while favorable, is too limited to give assurance that corrosion will not occur under these conditions. Caution should, therefore, be exercised in the use of Cal in concrete containing steel reinforcement when the concrete is to be freely exposed to the weather or excessive dampness. It is believed that no bad effect will be produced in ordinary building construction.

Undried Cal mixed with Portland cement causes greater deterioration in the quality of the cement during storage than that which ordinarily takes place. Therefore, Cal should be added to the concrete materials during the mixing operation, preferably before the water is added.

All Portland cement mixtures treated with Cal attained greater strength at the 2-day and 7-day periods than the corresponding untreated mixtures. The percentage increase in the strength of mortar at the 2-day period obtained by an addition of 5 per cent Cal to cement ranged from 40 to 140. The strength of the treated mortar at two days was equal to the strength of the untreated mortar at three and one-half to eight days. These calculations are made from the results of tests in which the test pieces were stored in water, damp sand, or damp closet.

Treated mortars stored in the laboratory air attained at 2 days strength greater than that of the untreated mortars at 28 days. This was due to the rapid drying out of the small test pieces and the comparatively slow rate of gain in strength after the 2-day period. However, this indicates that Cal is especially advantageous in cement mixtures which are necessarily subjected to any drying-out action.

The increase in strength produced by 5 per cent Cal in concrete mixtures at the 2-day period ranged from 52 to 135 per cent, and the strength of the treated concrete at the 2-day period was equal to that of the untreated at from three to four and one-half days. On an average this represents a saving of approximately one-half the time in operations which are dependent upon the strength of the concrete at early periods. The effect of the air storage in the concrete tests was lessened in degree, owing to the high relative humidity which existed throughout the storage period.

It should be remembered that the increase in strength resulting from an addition of 5 per cent Cal does not represent the maximum which may be obtained except in very rich mixes. As much as 15 per cent Cal was used in mortar tests, giving an increase of 220 per cent at the 2-day period.

The general effect of Cal on Portland cement mixtures is the same as might be expected from the use of equivalent amounts of hydrated lime and calcium chloride.

The 3-year tests by the Bureau of Standards on concrete gaged with a solution of calcium chloride are sufficient grounds for believing that the addition of Cal will not injuriously affect the ultimate strength and integrity of Portland cement concrete.

WASHINGTON, May 26, 1920.