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The effects of temperature upon cement mortar

Herman C. Cowen

Phillip Florreich

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THESIS

—
Effect of Temperature upon Cement Mortars

—
COWEN AND FLORREICH

—
1895

THE EFFECTS
OF
TEMPERATURE
UPON
CEMENT MORTAR



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HERMAN C COWEN

PHILIP FLORREICH

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Thesis
FOR THE
DEGREE OF B. Sc.
IN
CIVIL ENGINEERING

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Probably no material in use by the Engineering profession at the present time has been subjected to more careful and rigid tests by expert Engineers than our hydraulic cements, both natural and artificial. While the manufacture and use of cements in America is of comparatively recent origin, this industry is fast assuming enormous proportions, and the use of cement is fast displacing many of our more common building materials. Its use in our more important structures has created an increasing demand for the best quality of cements, and the manufacturers have not been slow to comply with this demand.

Until in recent years it has been considered impossible to manufacture a grade of American cement, either Rosendale or Portland, which could compare even favorably with European brands, but recent comparative tests of the

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Until in recent years it has been considered impossible to manufacture a grade of American cement, either Rosendale or Portland, which could compare even favorably with European brands, but recent comparative tests of the

leading brands seem to show that American cements can be made which compare favorably with the imported cements, in all tests to which they have been subjected.

The manufacture of Rosendale cement in America was first begun, on a commercial scale, about 1820. The term "Natural cement" has frequently been employed to denote this cement, because it is generally made from a natural stone. The term 'Rosendale' has been proposed for this cement, because it was first manufactured at Rosendale, New York; and the term will be used with this distinction throughout this article.

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Portland cement is frequently called artificial cement, because the constituents are usually mixed artificially preparatory to the manufacture. The term Portland will be adhered to

throughout this article. The manufacture of Portland cement, in America, was first begun, on a commercial scale, about the year 1878, although it had been imported to a considerable extent since 1865.

Rosendal cement is, in general, a light, coarsely ground, and quick-setting cement, but attaining a less ultimate strength, both in tension and compression, than the Portland, which is heavier and slower-setting, and is usually harder-burned, more finely ground, and attains a greater ultimate strength.

The widely varying uses for which cements have been employed in recent years, together with the varying quality of cements which have been placed upon the market, has led to the adoption of a series of tests, to be applied to all cements offered for use in important construction. In order that tests by different experimenters may be comparative,

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The American Society of Civil Engineers has recommended a uniform system of tests to be applied to cements, and this system is now generally adopted throughout the United States.

In testing the strength of cements, the test for tensile strength is the one generally adopted, not that the test for compressive strength is of no value, but that the testing machines for this purpose are, comparatively, very costly, and perhaps in the majority of cases where it is desired to test a sample of cement, the machines for making the compressive tests are not available. There is therefore a very large amount of data obtainable in regard to the tensile strength of cements, but in nearly all of these tests, either no has been taken of the temperature during the time of making tests, or it has been stated to be that of

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The testing laboratory, usually about 60° or 70°. The lack of data on this subject, and the belief that variations of temperature must exert a considerable influence upon the hydraulic energy and tensile strength of cement mortars, has led the writers to carry out the series of tests which are given in this article.

These tests have been carried out in as strict accordance with the recommendations of the American Society of Civil Engineers, as was possible.

Because of the difficulty of making any prolonged tests at the higher temperatures, and in order that the tests might be comparative, the age of briquettes, when broken, was uniformly limited to two days; one day in air, and one day in water. The briquettes were kept on pieces of slate, and protected from air by damp cloth, before immersion,

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and were always broken directly from the water. The briquettes were of the standard form shown in figure 1, having a net section of one sq. in.

The machine used was a Riehle Bros, cement-testing machine. This machine has clips with a rubber bearing surface and has given good satisfaction, but little trouble being experienced in getting the briquettes to break in least section. Three briquettes constitute a test, and where there has been any considerable variation in the results, the test has been duplicated.

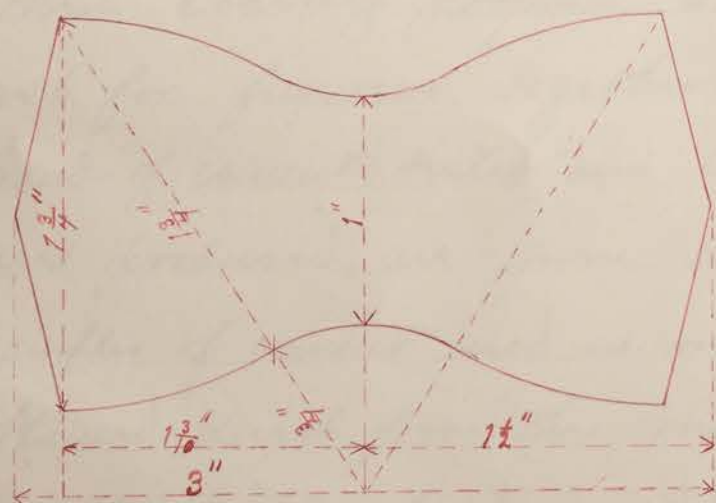


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fig 1

The tests which have been used are, (A) Test for fineness; (B) test for checking and cracking; (C) Time of setting at different temperatures; (D) Tensile strength.

In making the test for fineness three standard sieves were used, No. 50, No. 80, and No. 100, having respectively 2500, 6400, and 10000 meshes per sq. in. The test for fineness, while it is perhaps not as important as the others, is considered desirable. A given cement, finely ground, will bear a larger dose of sand and yet develop a given tensile strength, than will the same cement when coarsely ground. The results of the test for fineness, together with a list of the brands of cement tested, and locality in which they are produced, are given in Table I. The samples of cement used in making these tests were obtained direct from the manufacturer, except the sample of 'Flag brand', and 'Hiltons'; these two samples being of the cement found in the market.

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	% Retained on No 100 Screen			
	% Retained on No 80 Screen		% Retained on No 50 Screen	
<i>Black Diamond</i>	20	16	95	<i>Louisville Rosendale</i>
<i>Speed Mills</i>	26	23.2	15.2	<i>Louisville Rosendale</i>
<i>Flag</i>	21	16.5	9.	<i>Louisville Rosendale</i>
<i>Brooklyn Bridge</i>	20.8	13.6	6.4	<i>New York Rosendale</i>
<i>Utica</i>	27.6	23.2	11.2	<i>Illinois Rosendale</i>
<i>Akron</i>	21	16	6.5	<i>Ohio Rosendale</i>
<i>Saylor</i>	10	2.4	0	<i>American Portland</i>
<i>Atlas</i>	11	6	0.6	<i>American Portland</i>
<i>Hilton</i>	18.6	10.6	0.7	<i>English Portland.</i>

Table I

In making the test for checking and cracking, two pats of neat cement were made, each about three inches in diameter and one half inch thick. One of these was immersed in water, the other allowed to set in air, and their appearance closely noted from time to time. All of the brands tested apparently bore this test equally well, none of the pats showing any blotches, but remaining of a uniform color while induration was going on, and showing no cracks around the edges of the pats when fully set.

This series of tests was carried out in full at a uniform temperature of about 60° to 70°. See also the results from test (C).

The results of test "C" are given in Table II. In making this test the laboratory in which the pats were exposed was kept at a uniform temperature of 60°.

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Brands	Begun to Set					Fully Set				
	Temperature									
	32°	60°	100°	150°	212°	32°	60°	100°	150°	212°
Black Diamond	59'	34'	12'	4'	3'	1 ^h 38'	1 ^h 22'	22'	12'	10'
Speed Mills	36'	30'	10'	3'	3'	1 ^h 1'	52'	24'	14'	22'
Flag	13'	10'	2'	2'	2'	19'	15'	4'	9'	26'
Brooklyn Bridge	1 ^h 3'	1 ^h 26'	1 ^h 8'	20'	6'	2 ^h 50'	2 ^h 53'	1 ^h 13'	1 ^h 11'	47'
Utica	18'	16'	26'	18'	17'	1 ^h 3'	59'	48'	4 ^h 35'	5 ^h 41'
Akron	37'	35'	19'	5'	11'	1 ^h 19'	1 ^h 7'	37'	8 ^h 21'	1756
Saylor		24'	19'	1 ^h 7'	1 ^h 50'		1 ^h 29'	3 ^h 20'	8 ^h 42'	18 ^h 5'
Atlas	36'	42'	21'	8'	3'	3 ^h 40'	3 ^h 55'	2 ^h 30'	44'	35'
Hilton	50'	7'		1 ^h 0'	1 ^h 5'				7 ^h 33'	17'

Table II

Brands	Begun to Set					Fully Set				
	Temperature									
	32°	60°	100°	150°	212°	32°	60°	100°	150°	212°
Black Diamond	59'	34'	12'	4'	3'	1h 38'	1h 22'	22'	12'	10'
Speed Mills	36'	30'	10'	3'	3	1h 1'	52'	24'	14'	22'
Flag	13'	10'	2'	2'	2'	19'	15'	4'	9'	26'
Brooklyn Bridge	1h 3'	1h 26'	1h 8'	20'	6'	2h 50'	2h 53'	1h 13'	1h 11'	47'
Utica	18'	16'	26'	18'	17'	1h 3'	59'	48'	4h 35'	5h 41'
Akron	37'	35'	19'	5'	11'	1h 19'	1h 17'	37'	8h 21'	1756
Saylor		24'	19'	1h 7'	1h 50'		1h 29'	3h 20'	8h 42'	18h 5'
Atlas	36	42'	21'	8'	3'	3h 40'	3h 55'	2h 30'	44'	35'
Hilton	50'	7'				1h 10'	1h 5'		7h 33'	17'

Table II

The pats were about 3" in diameter and $\frac{1}{2}$ " thick, and were made as nearly uniform in size and degree of plasticity as was possible. The water and cement for each pat were separately heated to the degree at which the test was to be made, and were then quickly and thoroughly mixed and exposed on pieces of slate also heated to the same temperature as the water and cement. For determining the time of setting, the wire test was used as recommended by Gen. Gillmore. It is as follows; The pat is said to have begun to set when it just supports a wire $\frac{1}{2}$ " in diameter and loaded to weigh one quarter pound, and it is said to have fully set when it just supports a wire $\frac{1}{24}$ " in diameter, and loaded to weigh one pound.

The results of this test are also shown graphically in Fig 2, where the time of setting is plotted as vertical ordinates, and Temp., are plotted as abscissae.

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The results of this test are also shown graphically in Fig 2. where the time of setting is plotted as vertical ordinates, and temp., are plotted as abscissae.

A study of this table shows that in all the brands of Rosendale cement which were tested the time of beginning to set rapidly decreased as the temperature increased. The Utica cement showed the least variation in time, its curve in fig. 2 being almost a horizontal line. The 'Brooklyn Bridge' brand seems to be most radically effected by changes in temp.

At ordinary temp., it is comparatively a very slow setting Rosendale, requiring one hour and twenty-six minutes to begin to set at a temp. of 60° , but when the temp. was finally raised to 212° it began to set in six minutes, which is perhaps about the average time for Rosendale cement at that temperature.

The time until fully set also decreased as the temperature increased and with nearly all Rosendales the curve continued to drop until the highest temperature was reached. There were however two noticeable exceptions to this general rule. The Utica cement, at a

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temperature of 212° requiring five hours and forty minutes until fully set, and (2) the Akron brand, at the same temp., requiring eighteen hours to fully set. Both of these cements were apparently much injured by the increased temperature. The pats had but little strength and both were easily crumbled, even after being fully set.

All the Rosendale cements mixed at 212° were very badly checked and cracked while setting.

The table shows no general rule to be applied to the Portland cements, possibly because of the limited number of brands tested. The hydraulic activity of the Atlas cement steadily increased with the temp., while with the Hilton cement the minimum ordinate to its curve in fig 2 is found at the 100° point. From this point the curve for both 'Hiltons' and 'Saylor's' rises rapidly and has really little significance. Both cements were apparently ruined at 212° . The

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sample of "Hilton" requiring seventeen hours to set completely, the sample of Saylor's requiring eighteen hours. Both were soft and easily crumbled and appeared to have hardened by drying as much as by any chemical action of the cement.

None of the brands of Portland cements tested showed any signs of checking or cracking when fully set.

The effect of freezing upon the strength of neat cement mortar is shown in column six of Table No. III.

Three of the cements Flag, Akron, and Atlas brands, were received too late to be used in the freezing tests, and are not given in the table.

In making the tests for freezing, the briquettes were made of cement mixed with water at a temperature of 32° and immediately exposed to a temperature

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Brands	Temperature					Frozen
	32°	50°	75°	100°	150°	
Black Diamond	69 [#]	71 [#]	89 [#]	94 [#]	135 [#]	40 [#]
Speed Mills	110 [#]	105 [#]	99 [#]	99 [#]	118 [#]	82 [#]
Flag						
Brooklyn Bridge	53 [#]		44 [#]	57 [#]		58 [#]
Utica	33 [#]	40 [#]	60 [#]	76 [#]	100 [#]	*
Akron						
Saylor	131 [#]			260 [#]	390 [#]	154 [#]
Atlas						
Hilton	258 [#]	324 [#]	370 [#]	408 [#]	403 [#]	203 [#]

* Completely ruined

Table III

Showing Effect of Temperature
on Tensile Strength of Cements.

Brands	Temperature					Frozen
	32°	50°	75°	100°	150°	
Black Diamond	69*	71*	89*	94*	135*	40*
Speed Mills	110*	105*	99*	99*	118*	82*
Flag						
Brooklyn Bridge	53*		44*	57*		58*
Utica	33*	40*	69*	76*	100*	*
Akron						
Saylor	131*			260*	390*	154*
Atlas						
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Table III
Showing Effect of Temperature
On Tensile Strength of Cements.

varying from about 12° above zero, at time of exposure, to about 15° below zero during the night. The length of time during which the briquettes were exposed did not effect the strength of the briquettes, thus showing that all chemical action of the cement was suspended while the briquettes were exposed to a freezing temperature.

The briquettes in these tests were exposed to a freezing temperature for 24 hrs and were then immersed in water at a temperature of 60° for 24 hours, and were then broken directly from the water. The briquettes were exposed on pieces of slate. No tests were made in which the briquettes were frozen in water. I

The temperature of 32° , for the tests shown in column one of table No III, was maintained by keeping the briquettes,

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The temperature of 32° , for the tests shown in column one of table No III, was maintained by keeping the briquettes,

before immersion, in a vessel packed with melted snow. They were kept in this condition for 24 hours and then immersed for 24 hours in water containing melted snow and were then broken directly from water.

The higher temperatures were maintained by the use of a water bath and stove. We were constantly hampered for want of proper appliances, and had considerable trouble in maintaining a constant temperature for any length of time.

Although in most cases the temperature did not vary so much as 10° from the desired temperature. The original plan of these experiments included a test at the boiling point of water, but it was found impossible with the apparatus on hand to maintain this temperature for any length of time. Briquettes of some of the cements were

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boiled for one hour. The results of this test will be given in another place. The Utica cement cracked badly when exposed to freezing temperature and when immersed in water it became completely disintegrated and was reduced to a soft mud. The briquettes not being strong enough to be handled without breaking and crumbling.

As shown in table III, the Utica cement gives an almost constant increase in tensile strength for an increase in temperature. The Black Diamond, Saylor & Hilton also show an increase of strength with increase of temperature. The Speed Mills & Brooklyn Bridge brands do not show a regular increase, although the greatest tensile strength is obtained at the highest temperature in each case.

None of the other cements tested showed any signs of damage from freezing except the Brooklyn Bridge brand.

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the corners and edges of this cement were soft and easily crumbled although the briquettes which were frozen showed higher tensile strength than the tests of higher temperatures. Saylor also shows a higher strength when frozen than at 32°. Only small sample of Saylor & Brooklyn bridge brands were obtained and we were unable to make the 50° and 150° tests of Brooklyn Bridge and the 50° and 75° tests of the Saylor. For all tests above 32° the cement were mixed with water at 60°.

Experiments were also made with Speed Mills, Akron and Hilton brands to determine the effect of using mortar after it had begun to set.

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These briquettes were kept at a temperature
of 60° for 24 hours when they were

immersed in water of about the same temperature, for the same length of time. they were then broken directly from the water.

From the considerable variation in the strength of the briquettes from the same series, it seemed evident that the final strength varied rapidly with the time, after the cement had once begun to set.

Our tests of cements with sand are not as complete as we wished to make them. It was impossible at the time of our experiments, to obtain a sufficient quantity of sharp clean sand of necessary coarseness, with which to carry on tests of all the cements on hand, at the temperatures at which we tested the neat cements. The cements were tested at temperature of 32° . The proportions of sand & cement were 2 to 1 and 1 to 1. Briquettes of Hilton with these proportions

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were not injured by freezing
 The results of these tests are shown
 in following table.

	1 Cement 1 Sand	1 Cement 2 Sand		1 Cement 1 Sand	1 Cement 2 Sand
Hilton	71#	28#	Black Diamond	34#	14#
Speed Mills	56#	22#	Utica	26#	12#

The briquettes in these tests were kept at
 a temperature of 32° and then
 immersed in water containing melting
 snow for the same length of time, and
 then broken.

Some tests were also made to determine
 the effect clay & soil on cements.

The cements used in these experiments
 were Hilton and Akron. The clay & soil
 was pulverized before it was mixed
 with the cements. The clay was the
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	Neat	Soil				Clay		
		5%	10%	25%	50%	10%	25%	50%
Hilton	403 [#]	320 [#]	176 [#]	11 [#]	00 [#]	241 [#]	100 [#]	44 [#]
Akron	102 [#]	76 [#]	51 [#]	21 [#]	00 [#]			

		Begun Fully			Boiled	
Hilton	403 [#]	290 [#]	245 [#]	Utica	21 [#]	60 [#]
Akron	103 [#]	87 [#]	43 [#]	Diamond	62 [#]	89 [#]
Speed Mills	154 [#]	138 [#]	41 [#]	Hilton	280 [#]	403 [#]

Table IV

The results recorded in the first column were obtained from briquettes made before the cement had begun to set.

Those in 2nd column, from briquettes made after cement had begun to set and those in 3rd column after cement was fully set.

The results recorded in column four show the effect of boiling briquettes.

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The results recorded in column four show the effect of boiling briquettes.

The briquettes in this test were allowed to set for 48 hours, 24 hours in air and 24 hours in water at a temperature of 60°. They were then immersed in boiling water for one hour. The last column in table IV gives the strength of the same cements when kept at a temperature of 60° and not subjected to the boiling test. Some of the cements boiled showed any cracks, and to the eye were uninjured, but they all showed a considerable decrease in tensile strength.

This concludes the experiments made upon these cements. From the results of the experiments here given, and of many that are not given in this article, the writers feel warranted in drawing the following general conclusions.

Temperature exerts a considerable influence upon the hydraulic activity of cement mortars, and, in general, the activity increases directly with the increase of

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Temperature exerts a considerable influence upon the hydraulic activity of cement mortars, and, in general, the activity increases directly with the increase of

temperature. Our experiments would show that Portland cements are seriously injured if subjected to a temperature above 150° while setting.

An excess of water in mixing retards the setting of cement mortars, and may possibly permanently them

The addition of sand retards the setting of cement mortars.

All the brands of Portland, and with one or two exceptions, all the brands of Rosendale tested, were uninjured when briquettes of neat cement were subjected to severe freezing in air.

All quick-setting cements should be used as soon as mixed. Cement work is permanently injured if tampered with after setting has begun.

Cement mortar must not be allowed to dry too quickly.

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