1895

The effects of temperature upon cement mortar

Herman C. Cowen

Phillip Florreich

Department: Civil, Architectural and Environmental Engineering

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THESIS

Effect of Temperature upon Cement Mortars

COWEN AND FLORREICH

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HERMAN C COWEN PHILIP FLORREICH

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OF
TEMPERATURE
UPON
CEMENT MORTAR

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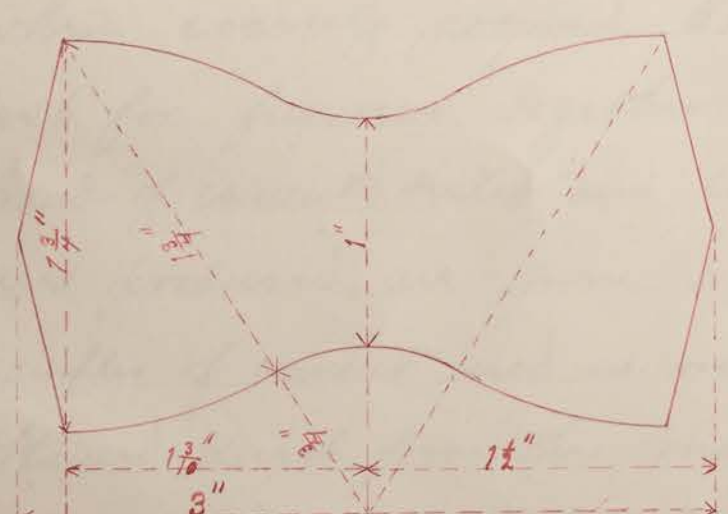
and were always broken directly from the water. The briquettes were of the standard form shown in figure 1, having a net section of one sq. in.,

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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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 test 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	
Black Diamond	20	16	9.5	Louisville Rosendale
Speed Mills	26	23.2	15.2	Louisville Rosendale
Flag	21	16.5	9.	Louisville Rosendale
Brooklyn Bridge	20.8	13.6	6.4	New York Rosendale
Utica	27.6	23.2	11.2	Illinois Rosendale
Akron	21	16	6.5	Ohio Rosendale
Saylor	10	2.4	0	American Portland
Atlas	11	6	0.6	American Portland
Hilton	18.6	10.6	0.7	English Portland

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 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'	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

Brands	Begun to Set					Fully Set				
	Temperature									
	32°	60°	100°	150°	212°	32°	60°	100°	150°	212°
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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 $\frac{1}{12}$" 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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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. (1) 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 'Saylors' 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 Saylors 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
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Brands	Temperature					
	32°	50°	75°	100°	150°	Frozen
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						
Hilton	258*	324*	370*	408*	403*	203*

* Completely ruined

Table III
Showing Effect of Temperature on Tensile Strength of Cements.

Brands	Temperature					
	32°	50°	75°	100°	150°	Frozen
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*	*
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varying from about 12° above zero,
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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.
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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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
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None of the other cements tested showed
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were obtained and we were unable to
make the 50° and 150° tests of Brooklyn
Bridge and the 50° and 75° tests of the
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were mixed with water at 60°.
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also made immediately after the
water was added to the cement.
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
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Our tests of cements with sand are not
as complete as we wished to make
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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 ordinary yellow impervious clay. The soil used was the ordinary black sandy loam

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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 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. None 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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The addition of sand retards the
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All the brands of Portland, and with
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Rosendale tested, were uninjured when
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All quick-setting cements should be
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Either loam or clay seriously injure the mortar, and the effect of loam or silt is found to be much more injurious than clay.

The strength of cement mortar is considerably reduced by immersion in boiling water.

School of Mines. — May 1895

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