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TEN-YEAR TESTS ON COMMERCIAL MASONRY CEMENTS

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ABSTRACT

In an investigation of the properties of 41 commercial masonry cements reported in 1934, additional specimens were made for tests at a later age. Two-inch mortar cubes made of these cements were tested in compression after both water and air storage for 10 years. Mortar bar specimens were measured for linear change after storage in water for 10 years.

The compressive strengths of the 1:3 (cement to standard sand) mortar cubes varied from 200 to 6,000 lb/in.^{2} at 10 years. Variables, such as type of cement, amount of mixing water, ratio of cement to sand, gradation of sand, as well as storage conditions are shown to affect not only the strength at 10 years but also the gain in strength between 28 days and 10 years.

The length measurements indicate a trend of greater expansion with greater magnesia content of the cement.

CONTENTS

I. INTRODUCTION

At the time of the investigation of the properties of 41 commercial masonry cements, reported in 1934,[1] comparable information relative to compressive strengths and volume change of masonry cement mortars after extended storage was not available. This report, in supplement to the original, concerns the compressive-strength tests and the expansion measurements of the masonry cement mortars at 10 years. The identification numbers of the cements are the same as in the original report. However, the chemical analyses of cements 38 and 39 were published in the original report in inverse order, and cognizance should be taken of this in the study of the relation of chemical composition to volume change.

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[1] J. S. Rogers and R. L. Blaine, *Investigation of commercial masonry cements*, J. Research NBS **13**, 811 (1934) RP746.

In the discussion of strengths of the mortars, the cements were classified into groups according to their general nature, as presented in the original report, namely:

P=Largely portland cement;
PL=Portland cement and hydrated lime mixtures;
PM=Portland cement mixed with unidentified materials;
PN=Portland cement and natural cement mixtures;
N=Natural cement;
S=Large amount of slag;
U=Not identified;
HL=Hydraulic or hydrated lime;

II. TESTS

Two-inch cubes were made of the mortars X, X–1, and Y, the composition and preparation of which are described in the original report. A summary of the compositions is given here to facilitate comparisons.

Mortar:	*Proportions*
X	1:3, by weight, cement: standard (20–30) Ottawa sand.[2]
X–1	1:2:1, by weight, cement: standard (20–30) Ottawa sand: fine testing sand.[3]
Y	1:2:1, by volume, cement: standard (20–30) Ottawa sand: fine testing sand.[3]

In all the mortars, the amount of water required for normal consistency (a flow of 100 to 115 on the standard 10-inch flow table) was used. In addition, 1 percent more and 1 percent less water (based on the dry weight of cement and sand) than that required for normal flow was used for both mortars X and X–1.

The sand and cement were mixed dry. Then water was added and mixing continued for 5 minutes. The mortars were allowed to stand 14½ minutes and were again mixed for one-half minute.

The 2-inch cubes made from the above mortars were stored in the damp closet for 2 days in the molds, after which the cubes were removed from the molds and stored in the damp closet for an additional 5 days. The specimens were then stored in water, and after 7 days half of the specimens were removed and stored in laboratory air until tested.

The 2-inch mortar cubes were tested in compression at 7 days, 28 days, 3 months, 1 year, and 10 years. Three specimens were tested at each age after both water and air storage.

Length measurements were made every week for 1 month, then every month for 1 year, and then at 10 years on the 1- by 1- by 8-inch mortar X bars described in the original report. These specimens, after 7 days of storage in the damp closet, were stored in water until measured. The companion bars, stored in air, were not measured, inasmuch as the glass plates that formed the ends of the bars had been broken off in many instances.

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[2] Federal Specification SS–C–158a, Cements, Hydraulic; General Specifications (Methods for Sampling, Inspection, and Testing), paragraph F–4l (1).

[3] Federal Specification SS–C–158a, Cements, Hydraulic; General Specifications (Methods for Sampling, Inspection, and Testing),paragraph F–4m (1).

III. RESULTS

1. COMPRESSIVE STRENGTH

(a) DRY VERSUS WET STORAGE

A plot of the results of the 10-year compressive-strength tests of the 2-inch cubes made of the 1:3, by weight, cement to standard (20–30) Ottawa sand mortar of normal consistency is presented in figure 1. The strengths of the water-stored specimens are plotted against those of the air-stored specimens.

It may be noted in figure 1 that all the cements classified in the natural (N) or slag (S) groups had greater compressive strength after water storage than after air storage. All the cements of the portland (P) group, 8 of 10 of the cements of the portland-with-unidentified-materials (PM) group, and 7 of 8 of the portland cement-hydrated lime (PL) group had greater strength after air storage than after water storage. The pairs of cements of the types portland-natural (PN), hydraulic or hydrated lime (HL), and unidentified (U) and one of each type in which the greater strength was obtained in water storage, whereas with the other cement of each type the greater strength was obtained with air storage. It may also be noted from figure 1 that 2 of 2 U, 1 of 2 PN, 1 of 2 HL, 3 of 4 N, 1 of 6 S, 1 of 10 PM, and 2 of 8 PL cements had compressive strengths of less than 1,000 lb/in.^{2} after 10 years of air storage. After 10 years of water storage, 2 of 2 U, 1 of 2 PN, 1 of 4 N, and 5 of 8 PL cements had compressive strengths less than 1,000 lb/in.^{2} Only six of the cements had compressive strengths of 1,000 lb/in.^{2} or less with both storage conditions. After

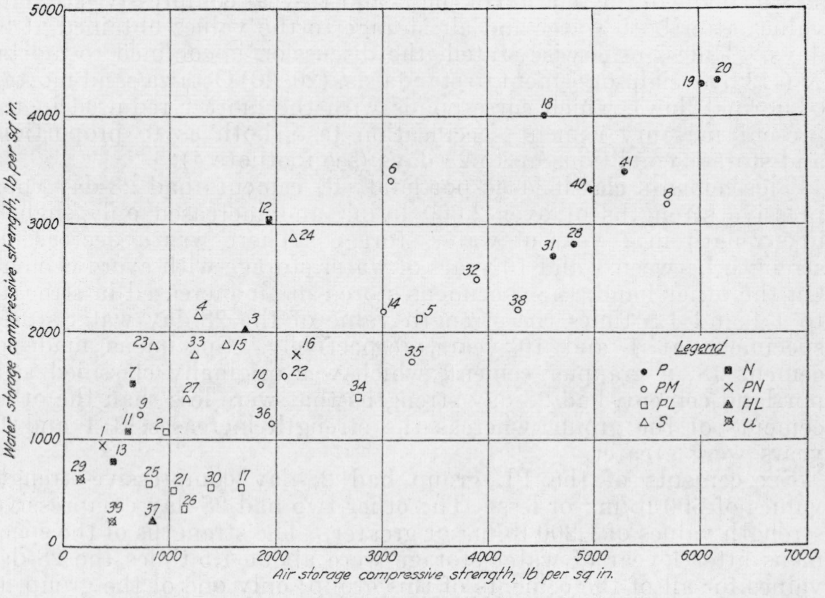

FIGURE 1.—*Relation of the compressive strengths after water and air storage for 10 years of 2-inch cubes made of 1:3, by weight, cement to standard (20–30) sand mortar of normal flow.*

10 years of water storage, 17 of the 41 cements had compressive strengths of 2,000 lb/in.^{2} or greater, and 18 cements had compressive strengths of 2,000 lb/in.^{2} or greater after air storage. Fourteen of the cements had 2,000 lb/in.^{2} or greater compressive strength with both storage conditions.

(b) INCREASE IN STRENGTH AT LATER AGES

Specifications [4] for masonry cements require compressive-strength tests at only 7 and 28 days. However, it is known that some types of cement have different rates of strength increase when exposed to damp or to dry conditions, and also that some types of masonry cement increase in strength and others do not. Therefore an analysis was made of the relation of the 1- and 10-year compressive-strength values after both water and air storage to the values obtained at 28 days. Unless otherwise stated, the discussion is confined to mortar X (1:3 by weight of cement to standards, (20–30) Ottawa sand mortar, of normal flow), which corresponds with the mortar required in the present masonry cement specification tests both as to proportions and storage conditions up to 28 days (see footnote 4).

The cements classified as portland (P) cements had 28-day compressive strengths of over 2,000 lb/in.^{2} and increased only slightly in strength in 1 year of water storage. There was a decrease in strength between 1 and 10 years of water storage with every cement. On the other hand, the specimens stored in air increased in strength to 1.4 and 1.8 times the strength value of the 28-day water-stored specimens at 1 and 10 years, respectively. Specimens made of cement 18, a grappier cement, which was originally classified as a portland cement, had 28-day strengths that were less than the other cements of the group, whereas the strength increases at 1 and 10 years were greater.

Six cements of the PL group had 28-day compressive-strength values of 500 lb/in.^{2} or less. The other two had 28-day compressive-strength values of 1,200 lb/in.^{2} or greater. The strengths of the specimens after 1 year of water storage were about 1.5 times the 28-day values for all of the cements of this group; only one of the group increased slightly in strength from 1 to 10 years, whereas six indicated a slight decrease in strength. The compressive strength after 1 year of air storage was about 2.0 times, and at 10 years, 2.7 times the values obtained for the 28-day water-stored specimens.

Nine of ten cements of the PM group had 28-day compressive strengths of about 1,000 lb/in.^{2} or greater. The cements of this group had compressive strengths after 1 year of water storage of 1.4 times the values obtained for the 28-day water-stored specimens. Only 2 of the 10 cements had further strength increases between the period of 1 and 10 years of water storage, and 7 of the 10 cements had slight strength decreases in the same period. After air storage for 1 and 10 years, the respective compressive-strength values were 1.6 and 1.8 times the 28-day strength values of water-stored specimens. Cement 9 had a 28-day compressive strength of 650 lb/in.^{2}, and the compressive strength of the specimens stored in air was only slightly higher at 1 year, whereas at 10 years the value had decreased slightly. One other cement in this group had a slight strength decrease between 1 and 10 years in air storage.

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[4] Federal Specification for Cement; Masonry SS-C-181b, and Standard Specifications for Masonry Cement ASTM Designation C-91-40.

Five of six of the slag (S) cements had 28-day compressive-strength values of 500 to 1,000 lb/in.^{2}. After storage in water the strength values were 2.0 and 2.8 times the 28-day values at 1 and 10 years, respectively. In air storage, however, the 1-year compressive-strength values were about 2.0 times the 28-day values, and only one of the six cements had an increase in strength between 1 and 10 years, whereas four of the six decreased in strength in the air storage. One of the six cements of this group decreased in strength between 1 and 10 years in both wet and dry storage.

Of the two cements of the PN group, one of the cements had a compressive strength of 170 lb/in.^{2} after 28 days of water storage, but increased to 2.3 and 5.7 times the 28-day value at 1 and 10 years respectively, when stored in water. After 10 years of storage in air the compressive strength was 2.3 times the values of the 28-day water-stored specimens. The other cement of this group had a compressive strength of 750 lb/in.^{2} at 28 days, and the value at 1 year of water storage was 2.5 times this value. The compressive strength decreased slightly between 1 and 10 years of water storage. The compressive strength at 1 and 10 years of air storage were, respectively, 2.1 and 2.9 times the values obtained on the 28-day water-stored specimens.

One of the cements of the HL group had a 28-day compressive strength of 400 lb/in.^{2}, and the respective 1- and 10-year values for water-stored specimens were 3.4 and 4.6 times, whereas the air-stored specimens were 2.4 and 3.9 times the 28-day strengths. The other cement of this group had a 28-day compressive strength of 220 lb/in.^{2} Water-stored specimens were only slightly stronger at 1 year than at 28 days, and at 10 years the strength was the same as at 28 days. The compressive-strength values of the air-stored specimens were 2.3 and 3.7 times the 28-day values at 1 and 10 years, respectively.

The two cements of the U group had 28-day compressive strengths of less than 100 lb/in.^{2} Both cements had a high percentage increase in strength when stored in water. The compressive-strength values of the air-stored specimens were 1.9 and 2.3 times the 28-day values at 1 and 10 years, respectively.

(c) EFFECT OF PROPORTIONS ON STRENGTH INCREASES

A comparison was made of the percentage strength increases at 1 and 10 years of both water- and air-stored specimens of mortar X made of standard (20–30) sand and mortar X–1 made of the graded sand. With many cements there was only a slight, if any, difference in the strength increase of the two mortars, whereas with other cements there were appreciable differences. However, no well-established trend was observed. It was noted in comparing these two mortars that mortar X-1 had, in almost every instance, greater 10-year compressive-strength values than the corresponding mortar X.

A comparison was also made of the ratio of compressive strengths at 10 years and 28 days of mortars X and Y proportioned 1:3 by weight and by volume, respectively. The leaner mortar specimens had the greater strength increases between 28 days and 10 years of water storage in 27 of 33 cements. These were divided as follows: 7 of 7 PL, 8 of 10 PM, 6 of 6 S, 1 of 4 N, 1 of 2 PN, 2 of 2 HL, and 2 of 2 U. However, with air storage, the leaner specimens did not have so great a strength increase as the 1:3 by weight mortar specimens. This was true in 30 of 33 cements, and these were apportioned as follows: 6 of 7 PL, 9 of 10 PM, 4 of 4 N, 5 of 6 S, 2 of 2 PN, 2 of 2 HL, and

2 of 2 U. No trend was noted with the portland cements, possibly because the 1:3 by weight and by volume were more nearly the same.

In table 1 is presented the effect of both water content and mortar composition on the strength ratios of five of the types of cement. The values presented are the averages of all the cements of each group. It may be noted that in considering any one type of cement the percentage compressive-strength increase was very nearly the same regardless of water content.

TABLE 1.—*Ratio of compressive strength values*

Mortar	Consistency [a]	Age and storage		Mortar	Consistency [a]	Age and storage	
		10 yr water / 28 day water	10 yr air / 28 day water			10 yr water / 28 day water	10 yr air / 28 day water
CEMENT P							
X	N−1	1.1	1.5	X−1	N−1	1.2	1.8
X	N	1.0	1.6	X−1	N	1.0	1.6
X	N+1	1.1	1.7	X−1	N+1	1.0	1.6
				Y	N	1.1	1.8
CEMENT PM							
X	N−1	1.3	1.8	X−1	N−1	1.4	1.8
X	N	1.3	1.8	X−1	N	1.3	2.0
X	N+1	1.4	1.9	X−1	N+1	1.5	2.1
				Y	N	1.7	1.4
CEMENT PL							
X	N−1	1.3	2.8	X−1	N−1	1.4	2.7
X	N	1.4	2.7	X−1	N	1.5	2.8
X	N+1	1.3	2.8	X−1	N+1	1.5	2.9
				Y	N	1.7	2.3
CEMENT N							
X	N−1	3.4	2.1	X−1	N−1	3.1	2.4
X	N	4.0	2.3	X−1	N	3.4	2.3
X	N+1	4.3	2.2	X−1	N+1	3.6	2.1
				Y	N	3.2	1.8
CEMENT S							
X	N−1	2.6	1.8	X−1	N−1	2.4	1.8
X	N	2.8	1.8	X−1	N	2.7	1.8
X	N+1	3.0	1.6	X−1	N+1	2.5	1.7
				Y	N	3.6	1.2

[a] N=Mortar of normal flow; N−1=1 percent less water than that required for normal flow, N+1=1 percent more water than that required for normal flow.

2. LENGTH MEASUREMENTS

The results of the length measurements on the bars made of mortar X of normal consistency that were stored in water for 10 years are presented in figure 2. The percentage increase in length is plotted against the percentage of magnesia in the cement. There appears to be a definite trend of greater expansions with mortars made of cements of higher magnesia content. Although the mortar bars made from cements having less than 4 percent of magnesia, all had linear expansions of less than 0.04 percent in 10 years, and those made from four of the cements having a high magnesia content had linear expansions of from 0.265 to 0.808 percent; nevertheless, mortars made from three of the cements having a high magnesia content expanded only from 0.05 to 0.09 percent.

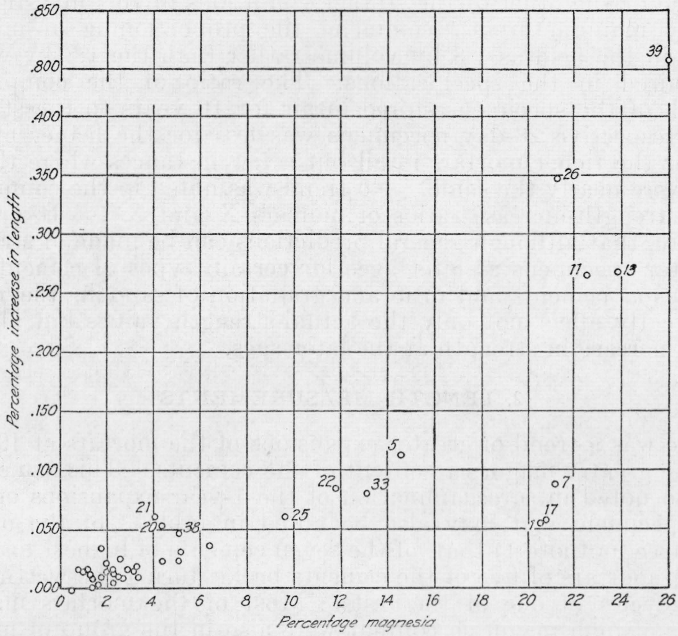

FIGURE 2.—*Relation between the magnesia content of the cement and the percentage increase in length in 10 years of water storage of 1- by 1- by 8-inch bars made of 1:3, by weight, cement to standard (20–30) sand mortar of normal flow.*

IV. DISCUSSION

1. COMPRESSIVE STRENGTH

It is impracticable to require specification strength tests at periods greater than 28 days. However, the 28-day results are not indicative of the strengths that may be expected, unless something is known of the composition of the cement. Consideration should also be given, especially with the low-strength cements, to the conditions under which the mortar is to be used. For example, many of the cements which were originally classified as portland cement-hydrated lime mixtures had relatively low compressive strengths even after 10 years of water storage. On the other hand, some of the natural cements had low compressive strengths after 10 years of air storage. It is realized that the storage conditions of this investigation are not the same as those under which the mortars are used, but cognizance should be taken of the fact that some of the cements do not have a great increase in compressive strength after 28 days under certain storage conditions. Hence, in a general specification for masonry cement, the 28-day strength requirements should be set sufficiently high, and too much dependence should not be placed on subsequently expected strength increases. Many of the mortars made of these cements had decreases in strength values between 1 and 10 years with one or the other of the storage conditions of this investigation.

Many manufacturers recommend the proportioning of masonry mortar in the field as 1:3 by volume rather than the 1:3 by weight, as required in the specifications. The ratio of the compressive strength of the specimens stored in air for 10 years to the strength of the respective 28-day specimens was less for the leaner mortars than for the richer mortars in all but a few instances where the two ratios were nearly the same. No trend was noted in the comparison of the strength-increase ratios of mortars X and X-1. It appears, therefore, that although general predictions can be made of strengths of mortar specimens at later ages for certain types of cement, such variables as cement-sand ratio and gradation of sand in the mortar may greatly affect not only the actual-strength values but also the rate of increase in strength at the later ages.

2. LENGTH MEASUREMENTS

There was a trend of greater expansions of the mortars at 10 years with the greater magnesia content of the cements. This same trend was also noted in a reexamination of the 1-year expansions of these same specimens. It may also be noted in table 3 of the original report (see footnote 1) that, of the seven cements of highest magnesia content, mortars of five of the cements broke during the wetting and drying cycles of one of the tests. Most of the mortars made of cements of high magnesia content were also in the group of mortars failing in 10 or less cycles of freezing and thawing.

The presence of unhydrated, or free, magnesia in cementitious materials has long been recognized as an element contributing to unsoundness because of the expansion concomitant with the hydration of the oxide to the hydroxide form. As a safeguard, portland cement specifications limit the total magnesia, although the magnesia, as determined by chemical analysis, may not all be the unhydrated MgO. The autoclave expansion test has also been developed as a further safeguard of soundness.

Masonry cements are sometimes made by the addition of either slag, hydrated dolomitic lime, or finely ground dolomitic limestone to a portland cement or other material for purposes of plasticizing or diluting the cement. Accordingly, in many cases the magnesium compounds may not be of the unhydrated form, e. g., some may be in the form of carbonate from the limestone, and some may be completely hydrated, since completely hydrated limes are now available. Therefore, inasmuch as the character of the magnesium compound is significant, it would be unfair, with masonry cements, to limit the percentage of total "MgO" content as determined by chemical analysis.

In this investigation, mortars of four of the seven cements of high "MgO" content expanded considerably more than the other three of this group, indicating that the total "MgO" content, as determined by chemical analysis, is not a criterion of expansion.

The determination of the free, or unhydrated, magnesia in mixtures such as masonry cements would be impractical, if not impossible, and it therefore appears that the only method to safeguard against excessive expansions would be the adoption of an autoclave expansion test such as is required in portland cement specifications.

V. SUMMARY OF RESULTS

The compressive strengths of 1:3 masonry cement to standard sand mortars varied from less than 200 to more than 6,000 lb/in.^{2} at 10 years. The mortars made of cements originally classified as largely portland, portland-plus-unknown additions, and portland-lime mixes had greater compressive strength after 10 years of air storage than after 10 years of water storage; the mortars of these types of cement had very little increase or a slight decrease in compressive strength between the period of 1 and 10 years of water storage but had appreciable strength increases in air storage for the same period. The mortars made of cements originally classified as natural cements or largely slag cements had greater compressive strength after water storage than after air storage for 10 years; the mortars of these cements had appreciable compressive-strength increases in water storage between the 1- and 10-year periods. The mortars made of the natural cements increased only slightly in compressive strength, whereas those made of the slag cements decreased slightly between the 1- and 10-year periods of air storage.

Mortars made of the graded sand maintained a higher compressive strength than mortars made with the standard (20–30) sand with most of the cements at the 10-year test period. At 10 years the leaner mortar Y had greater strength increase with water storage and smaller increase with air storage than the standard 1:3 mortar compared with the respective 28-day compressive-strength values. The percentage of water used in preparing the mortars did not alter to a great extent the ratio of the compressive-strength increases between 28 days and 10 years The necessity for an adequate 28-day compressive-strength requirement was discussed.

The linear expansion of mortar specimens in 10 years varied from 0 to 0.808 percent. There was a definite trend of greater expansion with greater magnesia content of the cement. All mortar specimens made of cements having less than 4 percent of magnesia had linear expansions of less than 0.04 percent during 10 years of water storage. Conversely, mortars made of four of seven of the cements with the highest magnesia contents had expansions greater than 0.25 percent.

WASHINGTON, March 27, 1943.

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5. 00 to 10. 00	. 01	12

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[Continued on p. 4 of cover]

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Range of x	Interval between successive arguments
0 to 7	0.001
7 to 50	.01
50 to 300	.1
300 to 2,000	1
2,000 to 10,000	10

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