

RESEARCH PAPER RP1508

Part of *Journal of Research of the National Bureau of Standards*, Volume 29,
December 1942

TEN-YEAR TESTS OF HIGH-EARLY-STRENGTH CEMENT CONCRETES

By Louis Schuman

ABSTRACT

Data on 10-year compressive strengths of concrete cylinders made from 12 commercial high-early-strength cements are given, supplementing the results up to 1 year given in Research Paper 799.¹ When cured in moist air, the concretes generally continued to gain strength between 1 and 10 years. For concretes stored in the air of the laboratory, the 10-year strengths are approximately equal to those at 28 days. Comparisons are given between strengths of concretes made in 1910, 1930, and 1941, showing that concretes made with some present-day cements may attain strengths in 1 month exceeding those for the older cements at 10 years.

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I. INTRODUCTION

Data on the properties of 12 commercial high-early-strength cements, and on mortars and concretes made from them, were published by the National Bureau of Standards in 1935.¹ The data included compressive strengths of 6- by 12-in. cylinders at ages up to 1 year; the present report supplements that of 1935 with data on strengths of concretes at the age of 10 years.

II. CEMENTS, MIXES, AND STORAGE CONDITIONS

The chemical compositions and fineness values of the cements are given in table 1. Data on other properties of the twelve cements and on the strengths of the various mortars in which they were incorporated are given in the original report. The concrete mix was 1:2.28:4.51 by weights of dry cement, sand, and gravel, respectively. The sand had a fineness modulus of 2.8. The gravel ranged from $\frac{3}{4}$ to 1 in. in size. Concretes of three *C/W* (cement:water) ratios were tested, namely 1.73, 1.50, and 1.33 by weight, corresponding to 6.5, 7.5, and 8.5 gal of water per 94-lb bag cement.

¹ L. Schuman and E. A. Pisapia, *Behavior of high-early-strength cement concretes and mortars under various temperature and humidity conditions*, J. Research NBS **14**, 723 (1935) RP799.

TABLE 1.—Chemical compositions and fineness values of cements

Cement	Chemical compositions										Fineness	
	CaO	MgO	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SO ₃	Cl	Insoluble in HCl	Loss on ignition	Free CaO ^a	Retained on No. 325 sieve	Specific surface by Wagner turbidimeter
	%	%	%	%	%	%	%	%	%	%	%	cm ² /g
1	66.2	1.1	8.3	3.1	17.0	2.4	0.0	0.2	1.7	0.4	8.5	1,990
2	66.6	1.0	6.2	1.9	20.6	2.5	.0	.5	1.1	1.6	8.3	1,910
3 ^b	65.6	2.5	4.7	3.1	20.6	1.3	.3	.5	2.4	0.3	8.8	1,770
4	65.7	2.5	5.6	2.3	19.3	2.2	.02	.6	2.1	2.7	8.7	2,030
5	64.2	3.4	7.2	2.5	18.5	2.4	.04	.2	1.8	0.6	5.3	1,760
6	62.9	2.9	7.0	2.3	20.3	2.6	.08	2.3	1.6	.1	8.4	2,050
7	65.7	1.5	6.6	2.7	19.3	2.1	.03	0.4	1.8	1.5	5.8	1,970
8	65.4	2.7	6.4	1.9	19.3	2.3	.0	.2	1.7	4.2	9.6	2,180
9	66.2	2.2	4.4	2.8	21.6	1.9	.0	.1	1.2	0.4	7.5	2,120
10	62.3	3.4	7.1	2.8	18.5	2.5	.0	.5	2.7	1.9	8.8	1,930
11	63.3	3.5	6.4	2.5	19.1	2.6	.07	.4	1.9	1.2	5.1	2,150
12	60.6	4.8	4.8	2.4	21.9	2.7	.0	.7	2.5	0.9	6.6	2,490

^a By method of Emlay, *Trans. Am. Ceram. Soc.* **17**, 720 (1915).

^b Contains a water-repellent material.

The temperatures of the materials at the time of mixing, and the conditions of storage of the test specimens during the first 24 hours after molding, were as follows:

- (1) Mixed at 70° F, stored in air at 70° F.
- (2) Mixed at 90° F, stored in air at 90° F.
- (3) Mixed at 110° F, stored in air at 110° F.
- (4) Mixed at 70° F, stored in a thermally insulated cabinet.
- (5) Mixed at 70° F, stored adiabatically (no heat loss).

No 10-year specimens were made for the adiabatic storage. After the first 24 hours, specimens from each of the other four initial conditions were treated as follows until tested:

- (1) Stored in damp room at 70° F, at relative humidity over 95 percent.
- (2) Stored in air of laboratory at 70° F.
- (3) Stored outdoors for 1 year.
- (4) Subjected to 300 cycles of freezing and thawing in approximately 15 months.

Specimens for only the first two of these storage conditions remained for 10-year tests.

III. TEN-YEAR TEST RESULTS

The compressive strengths of concretes made from each cement are given in table 2, for ages ranging from 1 day up to 10 years. Each value is the average for a set of three cylinders. The maximum deviation from the average was generally less than 10 percent. Age-strength relations for two of the cements (Nos. 7 and 11), representing typical variations, are shown in figures 1 and 2.

The concretes which were damp-cured showed continued increase in strength, in most cases, between 1 year and 10 years; such gains were of about the same magnitude as between 28 days and 1 year. In a few instances, concretes stored at 70° F during the first 24 hours showed slight decreases in strength between 1 year and 10, but in such cases the

strengths remained practically equal to those of the concretes which were initially stored at higher temperatures or were thermally insulated. Though the 1-day strengths were higher when the concretes were stored

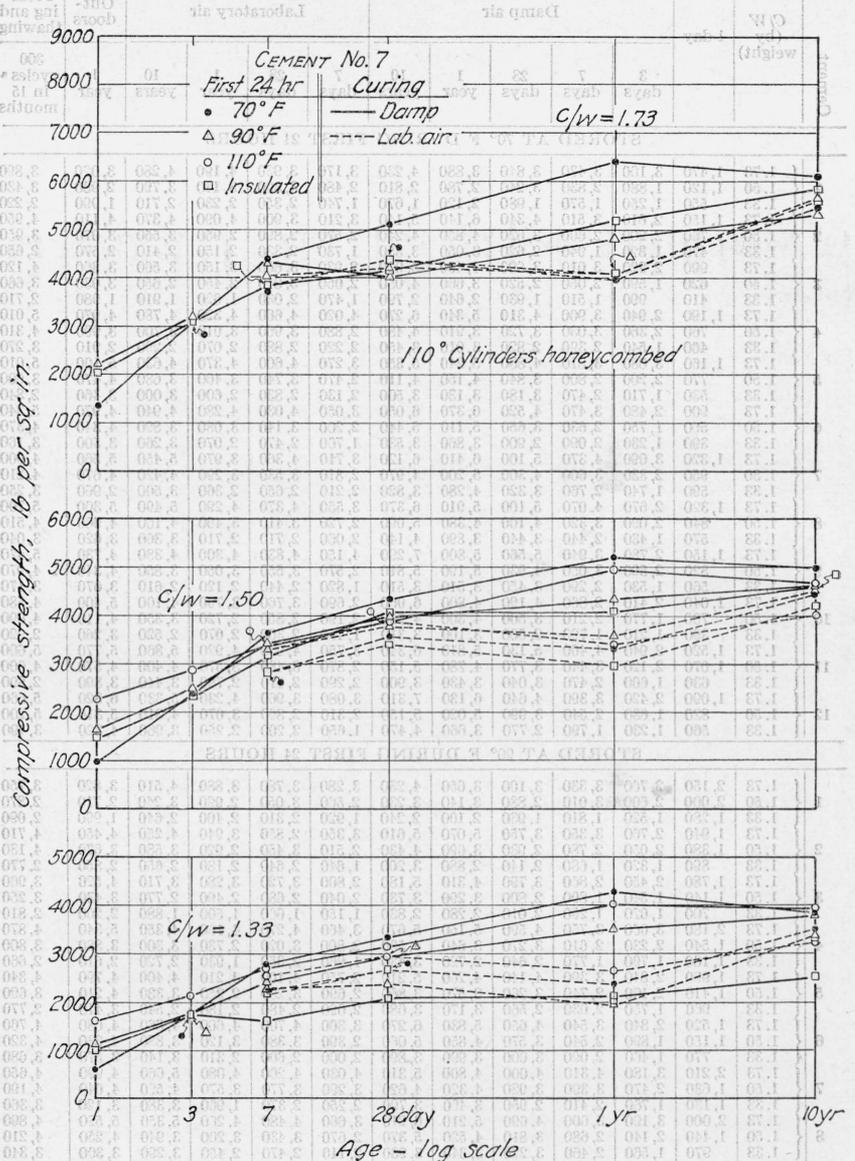


FIGURE 1.—Age-strength relations for cement 7.

at the higher temperatures during the first 24 hours, the strengths at later ages tend to equalize. There is, however, some tendency for the initially insulated concretes to have somewhat lower strengths after 3 days and up to 10 years than those under the other conditions.

* Freezing in air at 32° F., 16 hours; thawing in water at about 70° F., 3 hours.

TABLE 2.—*Compressive strengths (lb/in.²) of 6- by 12-in. concrete cylinders*

Cement	C/W (by weight)	1 day	Subsequent storage condition										Out- doors	Freez- ing and thawing
			Damp air					Laboratory air						
			3 days	7 days	28 days	1 year	10 years	7 days	28 days	1 year	10 years	1 year		
STORED AT 70° F DURING FIRST 24 HOURS														
1	1.73	1,470	3,100	3,430	3,840	3,880	4,230	3,170	3,930	4,190	4,280	3,020	3,890	
	1.50	1,120	1,880	2,830	3,240	2,780	2,810	2,480	3,390	3,140	3,790	2,930	3,430	
	1.33	550	1,250	1,570	1,980	2,120	1,670	1,740	2,350	2,230	2,710	1,990	2,220	
2	1.73	1,150	2,610	3,510	4,340	6,140	5,140	3,210	3,900	4,090	4,370	4,110	4,950	
	1.50	760	2,200	2,600	3,620	4,850	4,240	2,570	2,890	2,950	3,550	3,070	3,950	
	1.33	470	1,320	1,940	2,620	3,050	3,350	1,730	2,330	2,150	2,410	2,570	2,650	
3	1.73	990	2,220	3,010	3,690	4,490	5,020	2,930	3,660	3,150	3,560	3,860	4,120	
	1.50	620	1,590	2,050	2,520	3,660	4,050	2,050	3,010	2,450	2,650	3,030	3,660	
	1.33	410	990	1,510	1,930	2,640	2,790	1,470	2,030	1,620	1,910	1,980	2,710	
4	1.73	1,190	2,940	3,900	4,310	5,340	6,270	4,020	4,660	4,320	4,780	4,970	5,010	
	1.50	760	2,360	3,030	3,720	3,910	4,480	2,880	3,960	3,010	3,700	3,990	4,310	
	1.33	460	1,540	2,390	2,820	3,010	3,450	2,220	2,880	2,070	2,290	2,910	3,270	
5	1.73	1,160	3,080	3,810	4,880	5,240	5,350	3,270	4,600	4,370	4,630	5,100	5,010	
	1.50	770	2,200	2,800	3,840	4,150	4,110	2,470	3,740	3,400	3,680	4,470	3,600	
	1.33	530	1,710	2,470	3,180	3,130	3,500	2,130	2,830	2,600	3,000	3,460	2,840	
6	1.73	900	2,480	3,470	4,520	6,370	6,050	3,050	4,030	4,280	4,940	4,970	5,340	
	1.50	560	1,750	2,630	3,650	5,110	5,440	2,200	3,140	3,080	3,890	4,340	4,370	
	1.33	390	1,230	2,090	2,920	3,860	3,530	1,760	2,470	2,070	3,260	3,500	3,160	
7	1.73	1,320	3,090	4,370	5,100	6,410	6,120	3,710	4,360	3,970	5,450	5,560	4,900	
	1.50	950	2,330	3,600	4,300	5,200	4,970	2,810	3,530	3,290	4,420	4,670	4,210	
	1.33	590	1,740	2,760	3,320	4,280	3,820	2,210	2,650	2,360	3,500	2,960	3,250	
8	1.73	1,320	2,670	4,070	5,100	5,910	6,370	3,550	4,370	4,290	5,490	5,300	5,700	
	1.50	840	2,090	3,320	4,100	4,380	5,090	2,720	3,410	3,490	4,160	4,960	4,510	
	1.33	570	1,430	2,440	3,440	3,890	4,140	2,060	2,710	2,710	3,360	3,620	3,040	
9	1.73	1,150	2,780	3,940	5,560	5,800	7,290	4,150	4,830	4,300	4,380	4,730	5,470	
	1.50	820	2,590	3,050	4,930	5,190	5,810	2,570	3,550	3,050	3,850	4,340	4,970	
	1.33	560	1,530	2,290	3,450	3,510	3,510	1,820	2,440	2,120	2,610	3,670	3,170	
10	1.73	1,040	2,410	2,860	4,190	4,800	6,060	2,690	3,760	3,790	4,100	5,400	4,580	
	1.50	700	1,770	2,210	3,500	4,300	4,700	2,190	2,850	2,720	3,350	4,110	4,090	
	1.33	390	1,210	1,790	2,500	3,100	3,310	1,490	2,300	2,070	2,520	3,260	2,920	
11	1.73	1,520	2,940	4,400	5,130	5,810	6,340	3,750	4,920	4,920	5,860	5,770	5,600	
	1.50	1,070	2,120	3,440	3,770	4,780	5,150	2,870	3,480	3,570	4,400	4,570	4,600	
	1.33	630	1,600	2,470	3,040	3,430	3,900	2,290	2,670	2,790	3,440	3,890	2,990	
12	1.73	1,090	2,420	3,390	4,640	6,130	7,310	3,080	3,960	4,230	5,330	6,320	5,660	
	1.50	820	1,680	2,540	3,990	5,020	5,150	2,310	2,890	3,070	4,310	5,310	5,200	
	1.33	560	1,230	1,790	2,770	3,660	4,470	1,650	2,200	2,250	3,960	4,320	3,490	
STORED AT 90° F DURING FIRST 24 HOURS														
1	1.73	2,150	2,760	3,330	3,100	3,650	4,230	3,280	3,780	3,880	4,510	3,820	3,750	
	1.50	2,000	2,600	3,010	2,880	3,140	3,230	2,560	3,050	2,990	3,240	2,710	2,870	
	1.33	1,280	1,520	1,810	1,930	2,100	2,240	1,920	2,310	2,400	2,640	1,990	2,090	
2	1.73	1,940	2,760	3,350	3,750	5,070	5,610	3,350	2,850	3,940	4,250	4,450	4,710	
	1.50	1,380	2,050	2,780	2,930	3,690	4,430	2,510	3,450	2,920	3,580	3,670	4,130	
	1.33	890	1,320	1,680	2,140	2,880	3,200	1,640	2,640	2,180	2,650	2,850	2,770	
3	1.73	1,780	2,450	2,860	3,790	4,310	5,180	2,800	3,720	3,280	3,710	4,520	3,960	
	1.50	1,140	1,540	1,890	2,800	3,290	3,730	2,040	2,680	2,490	2,770	3,430	3,250	
	1.33	700	1,020	1,290	2,100	2,280	2,830	1,150	1,660	1,500	1,880	2,200	2,810	
4	1.73	2,180	3,060	3,750	4,590	5,150	5,670	3,460	4,270	4,160	4,350	5,340	4,870	
	1.50	1,540	2,230	2,610	3,270	3,640	4,530	2,800	3,020	2,730	3,300	3,880	3,800	
	1.33	1,100	1,790	1,770	2,640	2,720	3,430	1,960	2,350	1,930	2,720	2,610	2,660	
5	1.73	1,990	2,840	3,390	4,140	4,260	5,210	2,750	4,160	4,210	4,400	4,790	4,340	
	1.50	1,410	2,100	2,740	3,260	3,570	3,860	2,690	3,230	2,950	3,330	4,210	3,690	
	1.33	960	1,750	2,030	2,560	3,170	3,080	2,090	2,480	2,180	2,540	3,410	2,770	
6	1.73	1,520	2,840	3,540	4,650	5,830	6,270	3,300	4,700	4,600	4,860	4,680	4,760	
	1.50	1,150	1,890	2,540	3,570	4,850	5,060	2,390	3,380	3,120	3,880	4,330	4,320	
	1.33	770	1,460	2,090	3,000	3,990	3,890	2,000	2,600	2,310	3,140	3,570	3,680	
7	1.73	2,210	3,180	4,310	4,900	4,800	5,310	4,030	4,200	4,080	5,660	4,990	4,650	
	1.50	1,630	2,470	3,390	3,220	4,320	4,620	3,290	3,770	3,570	4,550	4,640	4,190	
	1.33	1,130	1,760	2,410	2,950	3,490	3,790	2,250	2,370	1,960	3,380	3,120	3,360	
8	1.73	2,000	3,190	3,600	4,950	5,210	6,210	3,660	4,480	4,260	5,350	5,520	4,890	
	1.50	1,440	2,140	2,680	3,810	4,520	5,370	2,670	3,430	3,200	3,940	4,250	4,210	
	1.33	970	1,560	2,460	3,220	3,340	3,930	2,110	2,470	2,450	3,290	3,300	3,340	
9	1.73	2,430	3,560	4,100	4,840	6,000	6,120	3,880	4,850	4,120	4,940	6,100	5,380	
	1.50	1,570	2,310	2,920	3,880	4,010	4,610	2,830	3,350	3,000	3,910	4,570	4,350	
	1.33	1,060	1,610	2,260	2,700	3,400	3,560	2,030	2,600	2,020	2,600	3,540	3,050	
10	1.73	1,590	2,160	3,050	3,670	5,170	5,680	2,890	3,650	3,790	4,510	4,840	4,230	
	1.50	1,240	1,800	2,140	2,990	4,040	4,560	1,970	2,710	2,810	3,410	4,100	3,830	
	1.33	710	1,160	1,330	2,430	2,990	3,240	1,430	1,980	2,010	2,330	2,990	3,140	
11	1.73	2,230	3,610	3,750	5,300	5,980	6,560	3,930	4,910	4,790	5,510	5,390	5,510	
	1.50	1,560	2,360	3,070	3,980	5,050	5,050	2,900	3,760	3,370	4,390	4,580	4,420	
	1.33	890	1,440	2,220	2,620	3,450	3,570	1,950	2,730	2,580	3,400	3,650	3,060	
12	1.73	1,810	2,070	3,060	4,670	6,240	6,770	3,320	4,000	4,260	5,510	6,020	5,260	
	1.50	1,160	1,890	2,350	3,020	4,700	5,200	2,120	2,890	3,170	4,120	4,640	4,530	
	1.33	760	1,200	1,670	2,460	3,480	3,890	1,480	2,430	2,230	3,300	3,540	3,660	

^a Freezing in air at 5° to 20° F, 16 hours; thawing in water at about 70° F, 8 hours.

TABLE 2.—Compressive strengths (lb/in.²) of 6- by 12-in. concrete cylinders—Continued

Cement	C/W (by weight)	Subsequent storage condition											
		1 day	Damp air					Laboratory air				Out- doors	Freez- ing and thawing
			3 days	7 days	28 days	1 year	10 years	7 days	28 days	1 year	10 years		
STORED AT 110° F DURING FIRST 24 HOURS													
1	b1.73	1,620	2,080	2,350	2,350	3,420	2,920	2,170	2,430	3,050	3,190	3,380	3,460
	1.50	1,780	2,190	2,680	3,100	3,550	3,220	2,310	2,910	2,960	3,210	3,540	3,490
2	1.33	1,410	1,800	2,090	2,200	2,630	2,490	1,980	2,290	2,140	2,460	2,430	2,580
	1.73	2,330	2,980	2,980	3,020	4,890	5,270	3,320	3,660	3,890	4,320	4,040	4,450
3	1.50	1,610	2,110	2,550	2,670	4,100	4,200	2,440	3,140	2,690	3,730	3,520	3,770
	1.33	1,480	1,630	1,960	2,120	3,540	3,350	2,060	2,220	2,180	2,890	2,910	2,960
4	1.73	2,470	3,010	3,360	3,520	4,610	5,170	3,490	4,160	4,080	4,460	4,570	4,810
	1.50	1,650	2,440	2,630	2,710	3,750	4,410	2,420	2,810	2,940	3,220	3,740	3,610
5	1.33	1,250	1,550	1,910	2,080	2,640	3,280	1,710	2,220	2,060	2,470	2,550	3,100
	1.73	2,360	2,490	3,070	4,390	4,380	5,800	3,540	4,090	3,830	4,460	5,760	3,930
6	1.50	1,900	2,290	2,540	3,420	3,980	4,520	2,720	3,680	3,250	3,290	4,120	3,870
	1.33	1,430	1,810	2,150	2,330	3,170	3,040	2,020	2,920	2,320	2,850	3,480	3,340
7	1.73	2,300	2,850	2,720	3,530	3,760	4,570	2,620	3,580	3,380	3,610	3,500	3,420
	1.50	1,660	2,130	2,430	3,010	3,520	4,280	2,560	3,010	3,120	3,360	4,020	3,570
8	1.33	1,240	1,560	1,900	2,480	2,980	3,480	1,740	2,410	2,410	2,760	3,760	3,050
	1.73	1,640	1,530	2,240	3,070	3,460	4,100	3,170	2,910	2,840	4,110	4,390	3,250
9	1.50	1,740	2,280	2,700	3,390	4,650	5,120	2,600	3,480	3,040	4,020	4,190	4,200
	1.33	1,250	1,840	2,170	3,030	4,250	4,600	2,120	2,610	2,320	3,110	3,630	3,780
10	b1.73	1,690	2,490	2,580	2,740	3,070	3,680	2,410	4,140	3,740	4,990	3,320	3,020
	1.50	2,240	2,850	3,360	3,840	4,970	4,780	3,260	3,870	3,790	4,000	4,390	3,860
11	1.33	1,600	2,120	2,690	3,140	4,010	3,930	2,530	2,930	2,650	3,270	3,480	3,420
	1.73	2,010	1,650	2,560	3,580	4,650	4,120	3,220	3,300	3,430	5,080	5,080	3,160
12	1.50	1,970	2,170	3,010	3,760	4,470	4,980	3,050	3,730	3,710	4,600	4,680	4,180
	1.33	1,460	1,960	2,230	3,160	3,740	4,090	2,380	2,780	3,000	3,580	3,830	3,390
13	1.73	2,680	3,680	4,010	4,980	5,330	6,580	3,880	4,930	4,710	5,290	6,140	5,320
	1.50	2,290	2,840	3,500	3,650	4,580	4,890	3,500	3,910	3,750	4,380	5,840	4,550
14	1.33	1,620	2,320	2,750	3,400	4,060	4,020	2,880	3,220	2,830	3,220	4,130	3,220
	1.73	1,760	2,060	2,690	3,180	3,960	5,300	2,770	3,220	3,600	4,590	4,490	3,700
15	1.50	1,650	1,770	2,170	2,560	3,330	4,200	2,140	2,730	3,210	3,120	4,110	3,470
	1.33	1,020	1,370	1,610	2,070	2,770	3,510	1,440	2,020	2,190	2,560	3,240	2,330
16	1.73	2,900	3,160	3,870	4,940	5,520	6,360	3,980	4,730	4,350	6,030	5,470	3,910
	1.50	2,080	2,670	3,340	3,900	4,760	5,060	3,770	3,670	3,820	4,300	4,290	4,230
17	1.33	1,520	2,100	2,420	3,180	3,540	3,850	2,380	2,940	2,810	3,620	3,600	3,450
	1.73	1,830	1,600	1,940	2,470	4,340	4,780	2,110	2,690	2,560	4,530	3,560	3,200
18	1.50	1,560	2,100	2,310	3,570	5,180	5,580	2,570	3,210	3,590	4,590	5,450	4,480
	1.33	1,030	1,470	1,880	2,890	4,070	4,670	2,020	2,560	2,790	3,500	4,430	3,680
INSULATED DURING FIRST 24 HOURS													
19	1.73	2,380	2,880	3,140	3,480	3,500	4,260	3,120	3,890	3,820	4,210	3,420	3,790
	1.50	1,800	2,100	2,430	2,660	2,720	3,200	2,550	3,890	2,930	3,630	2,420	3,320
20	1.33	1,070	1,490	1,510	1,970	2,090	2,130	1,740	2,100	2,180	2,440	1,830	2,150
	1.73	1,690	2,600	3,160	3,470	4,430	5,380	3,050	3,620	3,780	4,160	4,170	4,210
21	1.50	1,260	2,070	2,120	2,890	3,140	4,020	2,080	2,510	2,420	3,170	3,520	3,380
	1.33	820	1,430	1,730	1,930	2,340	2,930	1,470	1,770	1,600	2,650	2,340	2,530
22	1.73	1,270	1,990	2,430	3,020	4,140	4,830	2,670	3,060	2,670	3,590	3,860	4,210
	1.50	830	1,400	1,540	2,130	3,040	4,040	1,640	1,980	1,750	2,540	2,870	3,540
23	1.33	480	860	1,140	1,610	2,160	2,720	1,030	1,650	1,190	1,810	2,090	2,570
	1.73	1,150	3,010	3,280	3,700	4,270	5,340	3,180	3,850	3,730	4,160	4,510	4,450
24	1.50	1,180	2,080	2,590	3,230	3,560	4,440	2,640	2,780	2,560	3,440	4,010	3,680
	1.33	870	1,610	1,860	2,580	2,760	3,370	2,080	2,510	1,800	2,380	2,660	2,820
25	1.73	1,600	2,790	2,910	3,590	4,240	4,660	3,480	3,690	3,620	4,300	5,090	4,510
	1.50	1,280	2,020	2,760	3,050	3,300	3,720	2,430	3,200	2,740	3,330	4,030	3,820
26	1.33	830	1,670	2,200	2,480	2,690	3,040	1,880	2,550	2,080	2,700	3,320	2,710
	1.73	1,350	2,460	3,030	3,590	4,990	5,840	2,930	3,580	3,530	4,810	4,680	4,990
27	1.50	1,000	1,950	2,420	3,400	3,890	4,790	2,300	2,810	2,530	3,930	4,160	4,130
	1.33	640	1,140	1,910	2,600	3,000	3,440	1,650	2,070	2,050	2,870	3,000	3,090
28	1.73	2,040	3,100	3,850	4,160	5,180	5,850	3,800	4,370	4,050	5,610	6,650	4,960
	1.50	1,470	2,300	3,150	4,000	4,080	4,610	2,790	3,380	3,940	4,210	4,440	3,360
29	1.33	1,020	1,730	1,600	2,070	2,120	2,510	1,180	2,660	2,030	3,300	3,230	3,180
	1.73	1,870	2,670	3,450	3,840	4,820	5,810	3,150	4,460	3,840	5,330	5,600	4,810
30	1.50	1,270	2,050	3,340	3,820	3,720	4,740	2,120	2,650	3,540	4,130	4,350	3,900
	1.33	910	1,710	2,290	3,170	4,290	3,860	1,950	2,710	2,350	3,300	3,800	2,470
31	1.73	2,120	3,350	3,640	4,210	4,290	5,970	3,720	4,350	3,320	5,050	5,460	5,390
	1.50	1,030	2,070	3,130	3,800	4,480	5,240	2,240	2,440	2,960	3,780	4,420	4,620
32	1.33	660	1,420	2,110	2,970	3,370	3,240	1,750	2,430	1,730	2,670	3,090	3,350
	1.73	1,420	2,920	2,810	2,930	4,280	5,300	2,140	2,600	3,150	3,880	4,420	4,450
33	1.50	940	1,560	1,870	2,530	3,460	4,240	1,770	2,620	2,240	3,010	3,370	3,030
	1.33	660	1,110	1,340	2,250	2,610	3,200	1,370	1,750	1,680	2,080	2,660	2,260
34	1.73	1,930	2,850	3,590	4,210	4,590	5,800	3,610	3,950	3,670	4,860	4,770	5,110
	1.50	1,250	1,930	2,770	3,520	4,090	4,750	2,740	3,090	2,970	3,790	3,940	4,130
35	1.33	700	1,280	1,920	2,460	2,610	3,360	1,170	2,670	2,140	2,900	3,050	3,120
	1.73	1,310	2,130	2,960	4,240	5,460	6,560	2,450	3,850	3,890	5,120	4,860	5,040
36	1.50	940	1,520	2,200	3,340	4,320	5,280	1,920	3,080	3,200	4,160	4,170	4,000
	1.33	580	1,140	1,650	2,910	3,430	3,870	1,410	1,740	1,930	3,480	3,350	3,280

^a Freezing in air at 5° to 20° F, 16 hours; thawing in water at about 70° F, 8 hours.

^b Cylinders for this cement, made at 110° F, C/W=1.73, were honeycombed.

The concretes in laboratory air storage also show a slight gain in strength between 1 year and 10, but this gain is often just sufficient to compensate for the frequently noted slight decrease in strength between

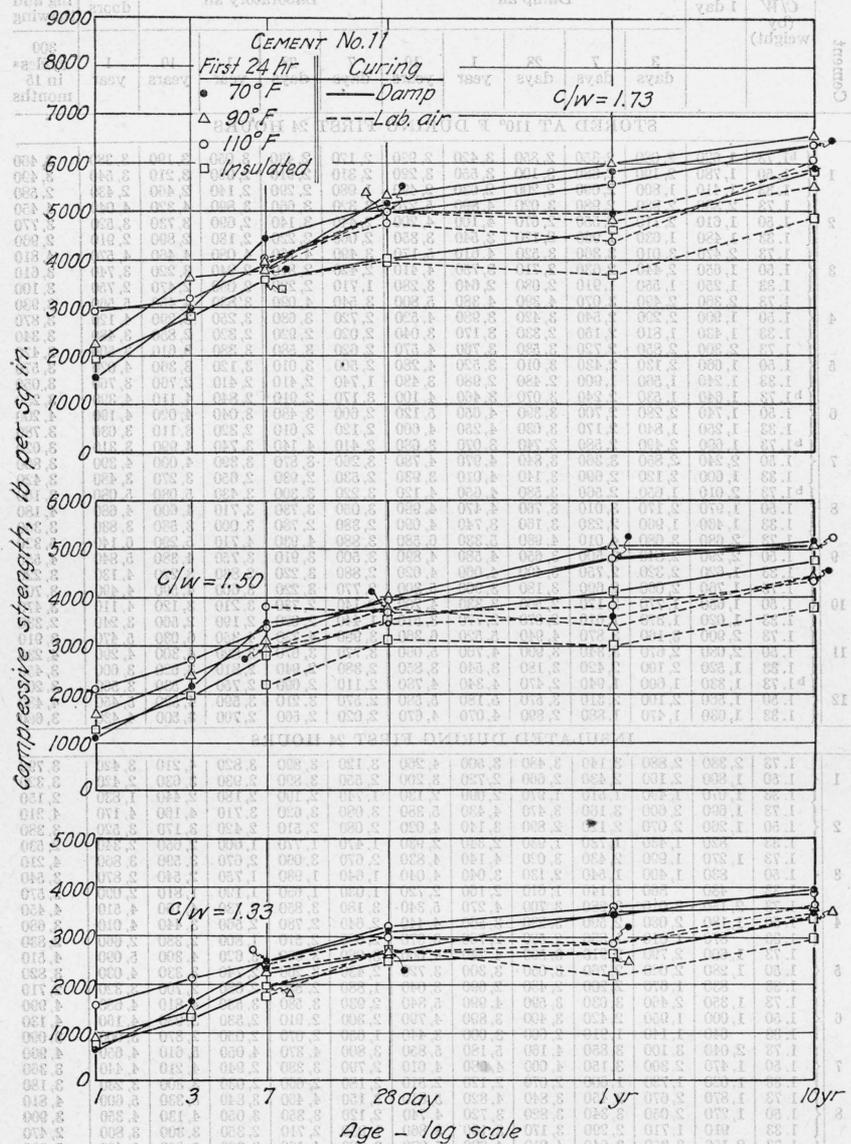


FIGURE 2.—Age-strength relations for cement 11.

28 days and 1 year, so that generally the air-stored concretes are appreciably lower in strength at 10 years than those damp-cured.

It is of some interest to compare the strengths of the concretes of this investigation with those obtained by Withey² for water-cured concretes

² M. O. Withey, *Some long-time tests of concrete*, Proc. Am. Concrete Inst. **27**, 547 (1931).

made in 1910, and those of the PCA 1926 series cited by him. Such a comparison is made in table 3.

In order to make this comparison on an equal C/W basis, it was necessary to interpolate the strength values for a C/W of 1.60 between those for $C/W=1.73$ and $C/W=1.50$. The average strengths, for the twelve cements, for the 70° F initial, damp-cured concretes, were used. In addition, some as yet unpublished values recently obtained at this Bureau for various types of cement made in 1941 are included.

TABLE 3.—Compressive strengths of 1:6 concretes (lb/in.²)

Age when tested				Source of data	C/W (by weight)
1 day	1 mo	1 yr	10 yr		
-----	2,000	3,200	4,200	Withey, series A, 1910 ^a -----	1.60
-----	3,000	5,000	-----	PCA, 1926-----	1.60
970	4,100	5,000	5,300	NBS 1929-32, 12 high-early-strength cements-----	^b 1.60
-----	4,600	5,900	-----	NBS 1941, 5 normal cements-----	1.66
-----	5,700	5,700	-----	NBS 1941, 3 high-early-strength cements-----	1.66
1,060	4,250	6,300	-----	NBS 1941, 4 moderate-heat cements-----	1.66

^a 6- by 18-in. cylinders.

^b Interpolated from values for $C/W=1.73$ and 1.50.

It is seen that the more recent cements (1941), even of the moderate-heat type, attain strengths in 1 month about equal to those for the 1910 cement at 10 years. Similarly, the high-early-strength cements of 1941 gave strengths at 1 month exceeding those of the 1929-32 cements of this type at 10 years. The 1941 high-early-strength cements also showed appreciably higher 3- and 7-day strengths than those for the 1929-32 cements (data not shown), though the 1-day strengths were not appreciably greater.

WASHINGTON, October 9, 1942.