INFLUENCE OF VARIOUS CURING METHODS ON STRENGTH AND ABRASIVE WEAR RESISTANCE OF A PORTLAND CEMENT CONCRETE

Progress Report

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SYNOPSIS

The curing of concrete pavements by covering with burlap, kept wet for 3 days, is a widely used method. The war has created a shortage of burlap, and interest has become focused upon other methods of curing. An investigation under progress of several curing procedures includes three curing compounds applied as liquids but which, upon evaporation of the solvent, form thin membranes, and also includes the surface application of calcium chloride as well as calcium chloride added as an admixture to the concrete.

The use of damp burlap for 18 hr., with calcium chloride used either integrally in the concrete or spread on the surface of the concrete upon removal of the burlap, resulted in 28-day flexural strengths of the same order as obtained with the 3-day wet burlap method. The application of calcium chloride on the surface of the concrete as soon as the bleeding water disappeared resulted in strengths some 7 per cent lower than those obtained by the procedures requiring burlap. The 28-day flexural strengths obtained by the use of three liquid curing compounds were 17 to 19 per cent lower than those obtained with the 3-day burlap curing procedure. Flexural strengths obtained with continuous damp laboratory curing for 28 days, were higher than obtained by any of the other procedures described. Strengths of specimens exposed to laboratory air were lower than obtained when curing by any of the other methods. For the 28-day compressive strengths the results were in the same general order as the 28-day flexural strengths.

In tests of the resistance to abrasion of the top (cured) surface of the specimens, good wear resistance resulted on all specimens treated with calcium chloride. The specimens with the 3 surface coatings showed relatively lower resistance to abrasion and a significant variation between different coatings.

Inasmuch as it is not practicable to secure optimum curing conditions of 100 per cent moist atmosphere and a limited temperature range for most structural and roadway concretes, the use of wet burlap covering has become quite general. Nevertheless it is well recognized that inadequate supervision, or restricted water supply in the field may introduce difficulties which often impair the effectiveness of wet burlap curing. Therefore other curing methods have been developed which may have advantages, especially under these conditions. Membrane coatings of various types are applied to exposed concrete surfaces to retard the evaporation of the mixing water. Calcium chloride has been used integrally to reduce moisture loss and accelerate the hydration of the cement and, as a surface treatment, to form a moisture film on the concrete, thus controlling evaporation of internal moisture.

Jackson and Kellerman[1] have shown that preliminary wet burlap treatment will substantially improve the efficiency of subsequent surface coatings of the sprayed membrane type. Nevertheless the scarcity of burlap during the emergency has increased the use of curing membranes on concrete immediately after disappearance of the bleeding water. Recognizing the influence that these emergency curing procedures may have on the post-war practice it was considered of value to make a study of the more common curing methods in use and include some variations for purposes of comparison. In this progress

[1] "Tests on Concrete Curing Materials," *Public Roads*, June, 1939.

report, comparative strength and wear tests are reported for concretes cast and maintained at 70°F and a relative humidity of 50–60 per cent. The abrasion tests were included because of their importance for concretes used for pavements and floors. Similar tests are being made on concretes cast and maintained at 100°F at a relative humidity of 25–35 per cent, and on concretes cast and maintained under field conditions.

MATERIALS AND TEST METHODS

The cement used in these tests was obtained from a local warehouse and conformed to A.S.T.M. specification (C-150-42) for Type I cement. A standard brand of flake calcium chloride was obtained from one source. Samples of three brands of curing liquids, available on the local market were obtained in sealed cans. Tests for water retentivity of the curing liquids were made at 99 to 101°F. and 28 to 32 per cent relative humidity using essentially the A.S.T.M. method C-156-44T. The results of the moisture retention tests (per cent water retained) using specimens with sprayed membranes A B & C and uncoated control specimens, were respectively 82, 87, 85 and 68 as computed on the basis of the weight of water in the specimen at the time of molding, and 90, 94, 93 and 78 on the basis of the weight of water in the specimen at the time the coatings were applied. Potomac River sand of gradation conforming to Federal Specification SS-A-281a was used with crushed limestone coarse aggregate from Martinsburg, West Virginia. This was used in two sizes (1½-in. and ¾-in.) and had a bulk specific gravity of 2.72 and an absorption of 0.2 per cent. The aggregates were combined with the cement to obtain a workable mix, proportioned 1:2.49:3.12 by weight, having a nominal cement factor of 6 bags per cubic yard and W/C of 0.54 by weight or 6 gal. per bag of cement. The slump was maintained at approximately 3 in.

Concrete prisms 6 by 6 by 20 in. were made in accordance with A.S.T.M. method of test C 39-44 except that the specimens were kept in the molds 3 days in a room maintained at 70°F and 50 to 60 per cent relative humidity. The specimens were then removed from the molds and those to be tested at 7 and 28 days were kept in the same room with all faces exposed to drying. Strength tests were made according to A.S.T.M. standard method C 78-44 except that the finished surfaces of the specimens for the flexure tests (18-in. span, 3rd point loading) were placed at the bottom in tension, instead of on the side. The various methods of curing are identified and described in Table 1. One specimen for each of the various curing methods was fabricated during the same day. This procedure was intended to eliminate the effect of variable conditions from day to day on properties of specimens made for test at a given age. How-

TABLE 1
CURING METHODS

Identification	Description
A, B, C	*Membrane curing compounds.* The liquids were applied with a hand operated spray gun at the covering rate of 200 sq. ft. per gal. after the surface water had disappeared. This was 4 to 5 hr. after molding, in this series of tests.
D	*Surface calcium chloride.* Flake calcium chloride was spread uniformly over the top surfaces of the specimens, at the rate of 2 lb. per sq. yd. after the surface water had disappeared.
E	*Integral calcium chloride.* 2 per cent calcium chloride by weight of the cement was dissolved in the mixing water of the concrete. Wet burlap in two layers was spread over the top surfaces of the specimens for 18 hr. and then removed. This method conformed to A.S.T.M. C82-38.
F	*Integral and surface calcium chloride.* Flake calcium chloride (1½ per cent) was dissolved in the mixing water and flake calcium chloride was spread uniformly on the surface at a rate of 1½ lb. per sq. yd. when the surface water had disappeared; i.e., 2½ to 3 hr. after molding.
G	Two layers of burlap were kept damp for 12–15 hr. and then maintained soaking wet until the specimens were 3 days old, at which time the burlap was removed.
H	*Burlap and surface calcium chloride.* Damp and wet burlap were continuously applied until the specimens were 18 hr. old when the burlap was removed and calcium chloride applied uniformly to the surface at rate of 2 lb. per sq. yd. This method conformed to A.S.T.M. C83-38.
I	*Laboratory air curing.* The specimens were tested in the laboratory air-dried condition.
J	*Laboratory air curing.* Identical with method I except that the specimens were submerged in tap water as follows: For test at age 3 days—6 hr. before time for test. For test at age 7 days—24 hr. before time for test. For test at age 28 days—73 hr. before time for test.
K	*Continuous damp cured specimens.* These specimens were removed from the steel molds at age of 24 hr. and stored continuously in moist room until test.

Note: All specimens, except for curing method K, were removed from the molds at 3 days. Specimens for 7 and 28 day test were then allowed to dry in air at 70°F and relative humidity of 55 to 60 per cent until time of test.

ever, no compensation was included in the procedure for batch to batch variations in specimens for test at different ages. Tests were made at ages of 3, 7 and 28 days. Except for curing method J (air-curing), the tests of of the specimens were made at their existing moisture contents after storage. This may have resulted in different moisture contents of the specimens at time of test and may have had an effect on the results. The damp-cured specimens were kept in the moist room continuously after the first 24 hours and were tested immediately upon removal.

The tests for abrasive resistance were made on the cured faces of 2-in. cubes cut from the

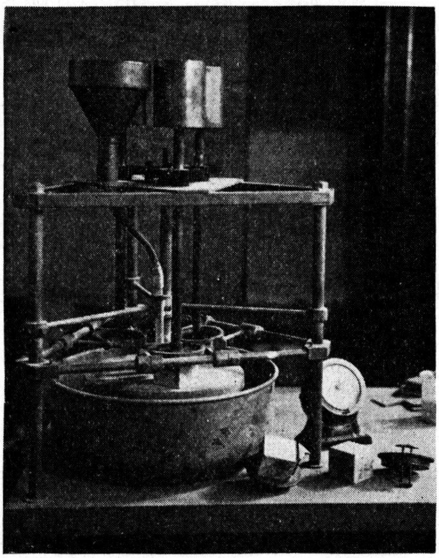

Figure 1. Wear Testing Apparatus Showing One Specimen in Position for Testing and Two Removed.

beam ends remaining from the strength tests. Tests were made on three specimens for each curing method at age of 28 days, using the apparatus described by Kessler,[2] which is illustrated in Figure 1. By this method, one face of each of three specimens is applied to a rotating disc and an aluminum oxide abrading agent supplied.

In this series of tests the suggestions of Swayze[3] were followed with respect to methods which required the use of burlap (E, G and H). He states in part: "By preventing evaporation from the fresh concrete surface after water from bleeding is removed, but withholding curing water until the concrete is nearing its maximum temperature, the later thermal shrinkage may be decreased and density improved by the effective use of curing water during the cooling period."

Preliminary tests were made to determine the temperature rise in a 6-bag concrete, plain and containing 2 per cent calcium chloride. This was done by the use of thermocouples cast in 6-in. by 12-in. cylinders. The results indicated that the maximum temperature of the plain concrete was attained between 12 and 15 hr. while the maximum temperature of the concrete with the integral calcium chloride was attained between 5 and 6 hr.

For this reason, after placing the concrete, the surface of those specimens cured by methods which involved the use of burlap (E, G and H) were immediately covered with two layers of damp burlap separated from the top surface of the beams by 1-in. wood strips placed around the edges of the steel molds. With the use of integral calcium chloride (method E) the burlap was damp for the first 5 to 6 hr. then wetted thoroughly and kept soaking wet for 12 additional hours, and then removed. With the 3-day wet burlap curing (method G) the burlap was kept damp for 15 hours and then maintained soaking wet until time for removal. With the burlap and surface calcium chloride curing (method H) the burlap was kept damp for 15 hr. and then kept soaking wet for 3 additional hours.

DISCUSSION OF RESULTS

The results of the compressive strength and flexural strength tests are given in Tables 2 and 3 and illustrated in Figures 2 and 3. Curing method G (3 days of wet burlap) may be used as a basis of comparison since this method is accepted as standard by most States.

The use of wet burlap for 18 hr. together with calcium chloride used integrally in the concrete or spread on the surface of the concrete upon removal of the burlap, resulted in 28-day flexural strengths of the same order as obtained with wet burlap alone applied 3 days. The use of surface calcium chloride applied as soon as the bleeding water disappeared (no

[2] "Development of Apparatus for Wear Tests of Natural Stone and Flooring Materials," A.S.T.M., Vol. 28, Part II.

[3] "Early Volume Changes in Concrete," A.C.I. Journal, April, 1942.

TABLE 2

FLEXURAL STRENGTHS OF 6-IN. BY 6-IN. BY 20-IN. CONCRETE PRISMS SUBJECTED TO VARIOUS CURING METHODS AND STORED AT 70°F AND 50-60 PER CENT RELATIVE HUMIDITY

Curing Methods (see Table 1)

	A		B		C		D		E		F		G	H		I		J		K	
	psi	A/G × 100	psi	B/G × 100	psi	C/G × 100	psi	D/G × 100	psi	E/G × 100	psi	F/G × 100	psi	psi	H/G × 100	psi	I/G × 100	psi	J/G × 100	psi	K/G × 100
3-Day Flexural Strengths																					
	320		380		390		380		470		490		420	465		325		345		370	
	365		340		380		435		540		480		400	435		305		290		385	
	305		300		325		350		470		430		380	395		270		310		310	
Av.	330	81	340	84	365	90	385	95	495	122	465	115	405	430	106	300	74	315	78	355	88
7-Day Flexural Strengths																					
	440		390		435		505		475		455		530	490		380		415		625	
	410		410		400		430		500		490		475	485		355		360		615	
	380		370		370		450		555		480		490	445		320		350		500	
Av.	410	83	390	79	400	81	460	93	510	103	475	96	495	475	96	350	71	375	76	580	117
28-Day Flexural Strengths																					
	445		420		435		505		505		525		525	495		350		360		745	
	435		415		385		480		525		465		525	525		360		350		715	
	400		410		425		450		475		460		500	525		350		370		675	
Av.	430	83	415	81	415	81	480	93	500	97	485	94	515	515	100	355	69	360	70	710	138

TABLE 3

COMPRESSIVE STRENGTHS OF 6-IN. BY 6-IN. MODIFIED CUBES OF CONCRETE SUBJECTED TO VARIOUS CURING METHODS AND STORED AT 70°F AND 50-60 PER CENT RELATIVE HUMIDITY

Curing Methods (see Table 1)

	A		B		C		D		E		F		G	H		I		J		K	
	psi	A/G × 100	psi	B/G × 100	psi	C/G × 100	psi	D/G × 100	psi	E/G × 100	psi	F/G × 100	psi	psi	H/G × 100	psi	I/G × 100	psi	J/G × 100	psi	K/G × 100
3-Day Compressive Strengths																					
	2,150		2,060		2,000		2,080		2,860		2,940		2,120	1,850		1,950		1,740		2,660	
	2,500		2,420		1,860		2,760		3,600		3,520		2,530	2,400		2,110		2,060		2,520	
	2,380		2,290		2,220		2,640		3,480		3,430		2,500	2,590		2,010		1,970		2,220	
Av.	2,340	98	2,260	95	2,030	85	2,490	105	3,310	139	3,300	139	2,380	2,280	96	2,020	85	1,920	81	2,470	104
7-Day Compressive Strengths																					
	3,820		3,260		3,640		3,550		4,150		4,430		3,750	3,600		3,140		3,150		3,580	
	3,560		3,330		3,580		3,620		4,430		4,400		3,680	3,700		3,050		2,910		3,550	
Av.	3,690	99	3,290	90	3,610	97	3,580	97	4,290	116	4,410	119	3,710	3,650	98	3,090	83	3,030	82	3,560	96
28-Day Compressive Strengths																					
	3,930		4,100		3,950		3,700		4,460		4,670		4,400	3,620		3,380		2,980			
	3,900		3,620		3,800		4,250		4,600		4,300		4,350	4,300		3,450		3,720		5,300	
	3,820		3,750		3,920		3,840		4,530		4,460		4,250	4,470		3,300		3,220		5,000	
Av.	3,880	89	3,820	88	3,890	89	3,930	90	4,530	104	4,480	103	4,350	4,130	95	3,380	78	3,310	76	5,150	118

burlap at all) resulted in flexural strengths some 7 per cent lower than those obtained by the procedure requiring burlap alone. The 28-day flexural strengths obtained by the use of the 3 liquid curing compounds were 17 to 19 per cent lower than those obtained with the 3-day burlap curing procedure. As would be expected, the flexural strengths obtained with

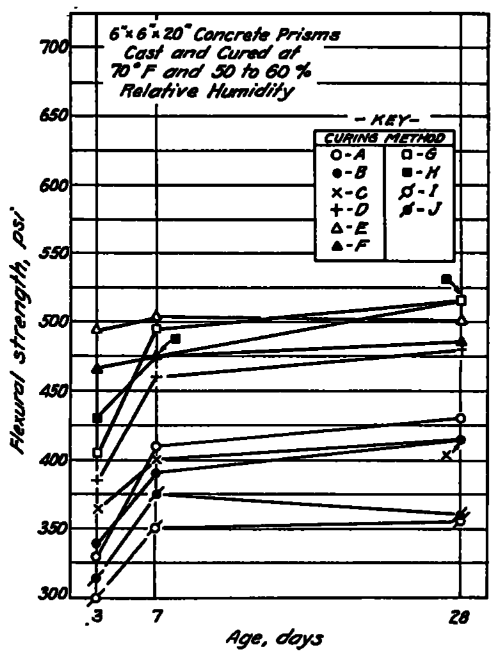

Figure 2. Flexural Strength of Concrete Resulting from Various Curing Conditions.

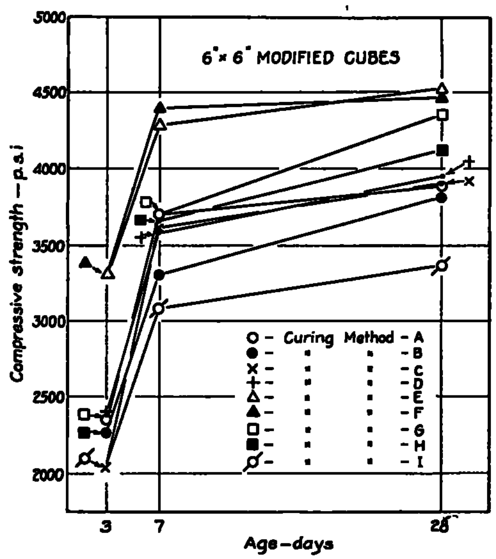

Figure 3. Compressive Strength of Concrete Resulting from Various Curing Conditions, 6 by 6 inches Modified Cubes Cured at 70°F. and 50–60 per cent Relative Humidity.

TABLE 4

ABRASIVE LOSS OF CURED SURFACES OF CONCRETE SPECIMENS TESTED AT AGE OF 28 DAYS BY KESSLER METHOD

(Loss in grams per 2-in. by 2-in. test face)

Curing Method	15 seconds			Additional 30 seconds			Additional 1 minute			Additional 2 minutes			Additional 4 minutes			Average wear in 7 min. 45 sec.
	Highest	Lowest	Av. 3 tests	Highest	Lowest	Av. 3 tests	Highest	Lowest	Av. 3 tests	Highest	Lowest	Av. 3 tests	Highest	Lowest	Av. 3 tests	
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
A	0.66	0.31	0.50	0.74	0.60	0.66	2.02	1.67	1.81	1.21	1.00	1.12	1.36	2.52	2.05	6.14
B	0.85	0.31	0.52	0.45	0.38	0.42	1.91	1.53	1.73	1.14	0.75	0.93	1.28	1.72	1.47	5.07
C	0.95	0.70	0.76	0.83	0.75	0.78	1.74	1.54	1.66	1.05	0.78	0.88	1.30	1.16	1.23	5.30
D	0.30	0.25	0.27	0.32	0.23	0.27	1.25	1.12	1.18	0.75	0.63	0.68	1.23	0.98	1.10	3.50
E	0.32	0.30	0.31	0.38	0.34	0.36	1.30	1.19	1.26	0.78	0.70	0.73	1.16	1.03	1.08	3.74
F	0.18	0.17	0.17	0.22	0.20	0.21	1.18	1.14	1.16	0.50	0.44	0.47	0.95	0.82	0.89	2.90
G	0.40	0.31	0.35	0.52	0.38	0.44	1.41	1.26	1.33	0.81	0.67	0.74	1.01	1.00	1.01	3.87
H	0.24	0.18	0.22	0.29	0.24	0.27	1.13	0.98	1.05	0.67	0.52	0.58	0.99	0.84	0.90	3.02
I	0.73	0.31	0.52	0.71	0.41	0.60	2.02	1.94	1.97	1.19	1.09	1.15	1.52	1.38	1.47	5.71
J	0.34	0.34	0.34	0.63	0.43	0.56	1.73	1.52	1.65	1.06	0.95	1.01	1.64	1.23	1.44	5.00

continuous damp curing for 28 days were the highest of those tested and the strengths of the specimens stored in the laboratory air were the lowest.

In general the values of compressive strength for the various curing methods show the same trend as the flexural strengths.

The weight losses of 28-day old specimens when abraded for various time intervals are shown in Table 4. Figure 4 shows a comparison of these weight losses from abrasion at 1, 2 and 4 min. after the preliminary treatment of 45 sec. which was required to insure plane surfaces of all the specimens. In this figure it is shown that the total of those weight losses obtained with the surface application of calcium chloride as used in methods F, H and D, were respectively 18, 17 and 4 per cent less than the weight loss obtained for those specimens cured 3 days with wet burlap. In other words calcium chloride increased the wear resistance of the specimens tested. On the same basis the values obtained for the sprayed membranes (A, B & C) and laboratory air curing (I) were respectively 60, 34, 22 and

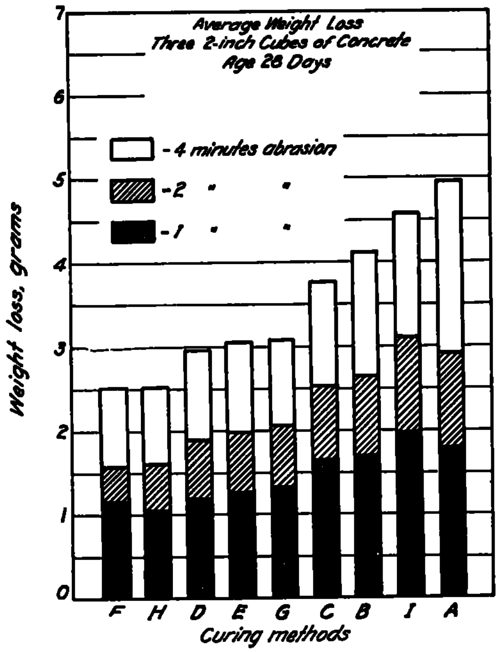

Figure 4. Comparison of Resistance to Abrasion of Concrete Surfaces Cured by Different Methods. Average Weight Loss, grams per 2-in. by 2-in. face.

49 per cent greater than the results for the wet burlap method. This represents a decrease of wear resistance. The specimens with calcium chloride curings F or H had the highest wear resistance of any of the curings tested. The weight loss for these specimens was 45 per cent less than the weight loss obtained with the laboratory air cured specimens (method I).

The depth of wear after 7 min. of abrasion, computed from the loss of weight and specific gravity of the specimens, ranged from approximately ⅛ in. for the concretes cured with surface and integral calcium chloride to approximately ¼ in. for the concrete stored in laboratory air. From observations of the broken faces of beams from the flexure tests, it was noted that all specimens with surface calcium chloride curing were markedly darker for approximately $\frac{1}{16}$ in. below the cured surface. This may indicate a penetration of the solution into the concrete.

SUMMARY

The use of calcium chloride integrally or as a surface application resulted in strengths (flexure and compression) comparable to those obtained with 3-day wet burlap curing. The use of the 3 membrane curings resulted in lower strengths.

The abrasive resistance for all specimens cured with surface calcium chloride exceeded that obtained for specimens cured 3 days with wet burlap. The abrasive resistance of the specimens treated with the 3 surface membranes was quite variable and considerably less than that obtained with the wet burlap curing.