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THE EFFECT OF ACCELERATED AND SUBSEQUENT MOIST CURING, AND EXTENDED MOIST CURING BEFORE BOILING ON COMPRESSIVE STRENGTH OF CONCRETE

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Mineral Processing Division

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SUMMARY OF RESULTS

This report concerns an investigation of the compressive strength of concrete after accelerated and subsequent moist curing, and extended moist curing before boiling.

The compressive strength of 6 x 12-in. concrete cylinders subjected to accelerated curing followed by standard moist curing for 27 days are significantly lower than the strength of corresponding cylinders subjected to standard moist curing for 28 days.

The extension of moist curing period from 24 hours to 72 hours before boiling does not significantly increase the compressive strength of test cylinders.

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INTRODUCTION

Since 1963 the Construction Materials Section of the Mineral Processing Division has been engaged in the development of an accelerated test method for estimating the potential strength of concrete. The findings of this research work have been reported in departmental publications (1-3).

Briefly, the accelerated test method consists of curing 6 x 12-in. test cylinders for 24 hours under standard* conditions, followed by boiling in water for 3½ hours and measuring compressive strength one hour later.

A number of organizations in Canada have adopted this test method as one of the routine control methods of estimating strength of concrete for their field jobs. However, additional information has been requested by some organizations using this method:

(a) Compressive strength of 6 x 12-in. test cylinders after accelerated curing and subsequent moist curing for 27 days to see if the strengths obtained are comparable to those obtained after 28 days of moist curing under standard* conditions.

(b) Compressive strength of 6 x 12-in. cylinders after accelerated curing but having a delay time of 72 hours instead of 24 hours, thus increasing the total curing cycle from 28½ hours to 76½ hours. This information was needed to see if test cylinders cast on a Friday can be left in a moist curing room until the following Monday before accelerated curing.

This brief investigation was therefore undertaken to obtain the required information. It was carried out at the request of Professor J. Houde, Ecole Polytechnique, Montreal, P.Q., and Mr. G. Spratt, Spratt and Associates, Vancouver, B.C.

SCOPE OF INVESTIGATION

In order to obtain the required information, four 2-cu-ft concrete mixes were made with water/cement ratio (by weight) varying from 0.58 to 0.49. Nine 6 x 12-in. cylinders were cast from each of the four concrete mixes. All specimens were tested for compressive strength after standard and/or accelerated curing.

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* 73.2±3°F and 100% relative humidity.

MATERIALS USED

Normal portland cement from Canada Cement Company Limited, Hull, P.Q., was used. The physical properties and chemical analyses of the cement are given in Table 1.

The coarse aggregate used was crushed limestone having a maximum size of 1 inch. Local natural sand was used as the fine aggregate. To keep the grading uniform for each mix, the sand was separated into different size fractions and then recombined to a specific grading.

The gradings and physical properties of both coarse and fine aggregates are given in Tables 2 and 3.

TABLE 1

Physical Properties and Chemical Analyses of Normal Portland Cement*

Description of Test		
Physical Test - (General)		
Time of Set (Vicat Needle): Initial	190	min
Final	305	min
Fineness, No. 200 (passing)	96.2	%
Soundness - Autoclave	0.18	%
Physical Tests - Mortar Strength (2-in. cubes)		
3-day	2780	psi
7-day	3620	psi
28-day	5000	psi
Chemical Analyses		
Insoluble Residue	0.32	%
Silicon Dioxide (SiO_2)	20.9	%
Aluminum Oxide (Al_2O_3)	5.7	%
Ferric Oxide (Fe_2O_3)	2.5	%
Calcium Oxide (CaO) (Total)	62.8	%
Magnesium Oxide (MgO)	3.0	%
Sulphur Trioxide (SO_3)	2.8	%
Loss on Ignition	1.1	%
Others	0.88	%
Total	100.00	%

* Test data on cement supplied by Canada Cement Company Limited, Hull, P.Q.

TABLE 2

Grading of Aggregates

Coarse Aggregate		Fine Aggregate	
Sieve Size	Cumulative percentage retained	Sieve Size	Cumulative percentage retained
		No. 4	0
3/4-in.	33.3	No. 8	10.0
		No. 16	32.5
3/8-in.	66.6	No. 30	57.5
		No. 50	80.0
No. 4	100.0	No.100	94.0
		Pan	100.0

TABLE 3

Physical Properties of Coarse and Fine Aggregates

	Crushed Limestone	Natural Sand
Specific Gravity	2.68	2.70
Absorption, %	0.40	0.50

MIX DESIGN DATA

Mix design data for the concretes are given in Table 4. The graded room-dry coarse and fine aggregates were weighed and immersed in water for 24 hours before use. At the end of the soaking period, the excess water was decanted and the amount of water held by the wet aggregate was determined by weighing.

Darex air-entraining agent was used in all the mixes.

CONCRETE MIXES

Four 2-cu-ft concrete mixes were prepared and test specimens were cast in the Mines Branch laboratory at Ottawa. A laboratory counter-current concrete mixer was used for preparing the concrete batches.

Properties of Fresh Concrete

The properties of fresh concretes, i.e. temperature, slump, unit weight and air content, are given in Table 5.

Preparation and Testing of Test Specimens

Nine 6 x 12-in. test cylinders were cast from each concrete mix. The test cylinders were prepared by filling 6 x 12-in. steel moulds in two approximately equal layers. Each layer was compacted with a 1 1/8-in.-diameter internal vibrator, inserted once for from 4 to 6 seconds.

From each concrete mix, six of the moulded specimens selected at random were fitted with machined steel caps; the remaining three cylinders were covered only with glass plates. Following this, all the moulded specimens were covered with water-saturated burlap and left in the casting room for 24 hours. At the end of this period, the nine test specimens cast from mix no. 511 and no. 512 were treated as follows:

(i) Three of the specimens together with their moulds and caps were placed in an accelerated-curing tank maintained at 210°F for 3½ hours. At the end of this period they were removed from the tank, demoulded, cooled, capped and tested in compression at an age of 28½ hours.

(ii) Three of the specimens, together with their moulds and caps, were placed in an accelerated-curing tank maintained at 210° F, for 3½ hours. At the end of this period they were removed from the tank, demoulded and transferred to a standard moist-curing room for testing at 28 days.

(iii) The remaining three specimens without caps were demoulded and transferred immediately to the standard moist curing room for testing at 28 days.

TABLE 4

Mix Design Data

Mix No	Date of Mixing	W/C* Ratio	Mix Proportions, lb/cu yd				A/C*** Ratio
			Free Water	Cement	Aggregate, SSD**		
					Coarse	Fine	
511	Jan. 6, 1969	0.51	283	560	1742	1399	5.62
512	Jan. 6, 1969	0.50	281	560	1738	1395	5.59
513	Feb. 18, 1969	0.49	276	565	1755	1410	5.62
514	Feb. 24, 1969	0.58	265	460	1737	1502	7.04

* W/C: water-cement ratio by weight, free water to cement.
** SSD: aggregate in a saturated, surface-dry condition.
*** A/C: aggregate-cement ratio by weight.

TABLE 5

Properties of Fresh Concrete

Mix No.	Date of Mixing	W/C Ratio	Properties of Fresh Concrete			
			Temp, °F	Slump, in.	Unit Weight, lb/cu ft	Air Content, per cent
511	Jan. 6, 1969	0.51	70	2.0	147.6	4.0
512	Jan. 6, 1969	0.50	72	2.0	147.2	4.6
513	Feb. 18, 1969	0.49	70	2.0	148.4	4.0
514	Feb. 24, 1969	0.58	70	1.75	146.8	4.4

The nine cylinder specimens cast from mix nos. 513 and 514 were disposed of as follows:

(i) Three of the specimens together with their moulds and caps were placed in an accelerated-curing tank maintained at 210°F for 3½ hours. At the end of this period, they were removed from the tank, demoulded, cooled, capped and tested in compression at an age of 28½ hours.

(ii) Three of the specimens together with their moulds and caps were transferred to a moist curing room for a period of 48 hours. At the end of 72 hours from the time of casting these cylinders were transferred to an accelerated-curing tank maintained at 210°F for 3½ hours. At the end of this period, they were removed from the tank, demoulded, cooled, capped and tested in compression at the age of 76½ hours.

(iii) The remaining three specimens without caps were demoulded and transferred immediately to a moist-curing room for testing at 28 days.

All testing was carried out in accordance with the ASTM Standard Method, C 39-64, in a 600,000-lb-capacity Amsler testing machine. The test results are shown in Tables 6 and 7.

DISCUSSION

The compressive strength test results for mix nos. 511-512 (Table 2) after various curing regimes indicate that once the test specimens have been accelerated-cured using the modified boiling method, these should not be moist-cured again. Any further moist curing tends to lower the measured 28-day strength. This falls in line with the generally well-known principle that if concrete specimens are subjected to curing at elevated temperatures the ultimate strength of concrete is lowered. In the test results under discussion, accelerated curing and subsequent moist curing lowers the compressive strength of 6 x 12-in. cylinders by 21.2* per cent.

Research work (1) carried out at the Mines Branch in 1964 had indicated that little strength was gained by extending the moist-curing period

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* Strength loss for mix no. 511 = 26.9%; strength loss for mix no. 512 = 15.6%; Average strength loss = 21.2%.

TABLE 6

Compressive-Strength Test Results for Mix Nos. 511-512

Mix No.	W/C Ratio	Compressive Strength, psi		
		Accelerated Cured		Standard Moist-Cured
		Moist-cured = 24 hr Accelerated-cured = 3½ hr Tested at = 28½ hr	Moist-cured = 24 hr Accelerated-cured = 3½ hr Moist-cured = 27 days Tested at = 28 days and 3½ hr	28 days
511	0.51	2100 2165 2175 Av.= 2145	3615 3735 3960 Av. = 3770	5210 5185 5080 Av. = 5160
512	0.50	2465 2370 2205 Av. = 2345	4145 4385 4195 Av. = 4240	5040 4935 5080 Av. = 5020

TABLE 7

Compressive-Strength Test Results for Mix Nos. 513-514

Mix No.	W/C Ratio	Compressive Strength, psi			
		Accelerated Cured		Standard Moist-Cured	
		Moist-cured = 24 hr Accelerated-cured = 3½ hr Tested at 28½ hr	Moist-cured = 72 hr Accelerated-cured = 3½ hr Tested at 76½ hr	76½ hr	28 days
513	0.49	2450 2300 2570 Av. = 2420	2920 2775 2865 Av. = 2855		5580 5420 5440 Av. = 5480
514	0.58	1835 1715 1770 Av. = 1805	2340 2320 2335 Av. = 2330	2190 2180 2190 Av. = 2185	

before boiling from 22 hours to 27 hours. The results of the present investigation tend to confirm this. By extending the moist-curing time from 24 hours to 72 hours, before boiling, the compressive strength of accelerated cured specimens exceeds by only 145 psi the strength of the companion test cylinders which had been moist cured for 76 hours (mix no. 514). For mix no. 513, no such data were available; however, in this case the accelerated strength for a 28½-hr curing cycle was 43 per cent of the corresponding 28-day strength as compared to only 52 per cent for the 76-hr cycle. This once again emphasizes that little is gained by extending the moist curing period from 24 hours to 72 hours. Thus, when test specimens are cast on a Friday, it is advisable to subject them to accelerated curing the following day rather than wait for two more days. The disadvantages of overtime are offset by early availability of test results. However, if weekend overtime is to be avoided at all costs, then it would be advisable to determine the compressive strength of 6 x 12-in. cylinders which had been moist-cured for three days, rather than use an accelerated strength test after 72 hours.

CONCLUSIONS

1. The compressive strength of 6 x 12-in. concrete cylinders subjected to accelerated curing and subsequent standard moist curing for 27 days are significantly lower than the strengths of corresponding cylinders subjected to standard moist curing for 28 days.

2. The extension of the moist curing period from 24 hours to 72 hours before accelerated curing does not significantly increase the compressive strength of test cylinders.

REFERENCES

1. V. M. Malhotra, N. G. Zoldners and R. Lapinas, "Accelerated Test for Determining the 28-day Compressive Strength of Concrete", Canadian Mines Branch Research Report R-134 (1964).

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3. V. M. Malhotra, "The Past, Present and Future of Accelerated Strength Testing of Concrete", Canada Mines Branch Internal Report MPI 68-35, (September, 1968).

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