EARLY STRENGTH TEST FOR QUALITY CONTROL OF CONCRETE

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The time-honored approach to ensure quality of concrete is to take samples at the job site, to mold test cylinders, and then to cure the cylinders under standard conditions for 28 days before testing. The procedure is convenient, the test is simple, and the equipment is dependable. The disadvantage of the 28-day curing is the delay time that neither leads to the early correction of a material problem nor facilitates the prompt removal of defective concrete. Several researchers have demonstrated the feasibility of 24-hour tests to ensure quality control of concrete. Most early tests have been accelerated strength tests employing hot air, steam, or water for curing. The higher temperatures require special equipment, make the specimens difficult to handle, and introduce special problems when air-entraining agents and other additives are used. The merits of a simple 24-hour, 100 F (37.8 C) hot-water curing and testing procedure are described. Results achieved with the procedure are presented and analyzed. It is concluded that a hot-water curing temperature of 100 F (37.8 C) is adequate. The temperature is low enough to be completely safe for personnel involved and to permit careful handling of test specimens. The equipment required is simple and inexpensive.

•THE principal aspects of early strength testing of portland cement concrete are curing time, curing temperature, and experimental procedure. A curing time of 24 hours has considerable merit because it is convenient and leads to prompt results. The curing temperature is much more arbitrary. Initial tests were run to observe the effects of curing temperature on the level and reliability of 24-hour compressive strength.

TESTS PERFORMED

The study of curing temperatures was made by comparing results obtained from curing similar batches of concrete in different water temperatures. The strength correlations were achieved by curing and testing various grades of concrete by both the 28-day standard procedure and the accelerated hot-water procedure.

The concrete mix design used is given in Table 1. Tests were conducted by using hot-water curing temperatures of 90, 110, 130, and 150 F (32.2, 43.3, 54.4, and 65.6 C). Three 6-in.-diameter (15.2-cm) cylinders were molded from various batches of concrete and cured for 24 hours before testing. The 24-hour strength versus the curing temperature is shown in Figure 1. From the same batches of concrete, three additional cylinders were cast, cured for 28 days in a moist room, and then tested.

ANALYSIS OF RESULTS

The average compressive strengths of the cylinders cured at 90, 110, 130 and 150 F (32.2, 43.3, 54.4, and 65.6 C) were 1,879, 2,822, 2,990, and 3,107 psi (13, 19.5, 20.6, and 21.4 MPa) repectively. The results are shown in Figure 2.

Table 1. Concrete mix design.

Mix Designation	Water (lb/yd³)	Cement Factor (sacks/yd³)	Water-Cement Ratio (by weight)	Sand (lb/yd³)	Coarse Aggregate (lb/yd³)
A	325	7.30	0.488	1,320	1,710
B	325	7.27	0.477	1,200	1,820
C	325	6.08	0.570	1,310	1,800
D	325	5.20	0.667	1,400	1,770
E	325	4.53	0.766	1,490	1,740

Note: 1 lb/yd³ = 0.593 kg/m³.

Figure 1. Twenty-four-hour strength versus curing temperature.

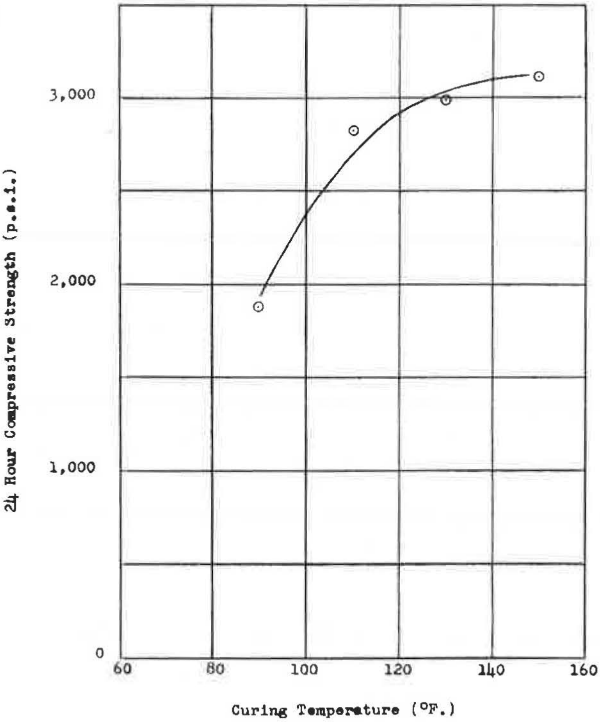
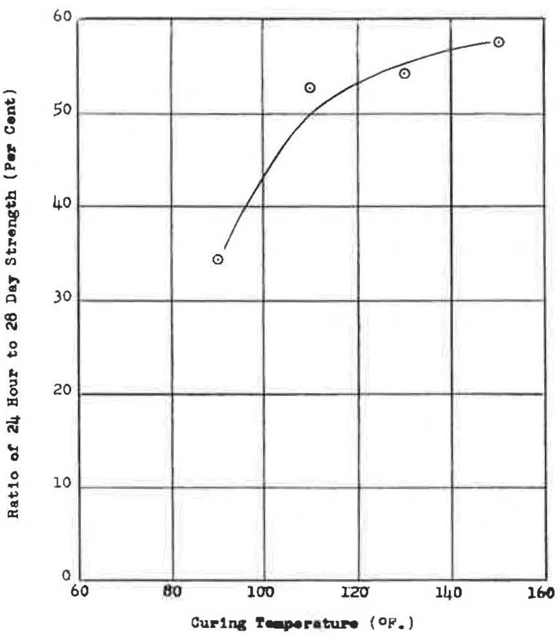


Figure 2. Percentage of strength gained in 24 hours versus curing temperature.



The tests demonstrate a substantial strength gain in 24 hours at a temperature as low as 100 F (37.8 C). Since these results were sufficiently interesting, we performed additional hot-water curing tests at 100 F (37.8 C). The 100 F (37.8 C) temperature is low enough to be regarded as a normal rather than an elevated temperature for accelerated curing. The merits of avoiding excessive temperatures are numerous and readily apparent. Since there is no threat to the safety of technicians, they are able to handle the specimens with care. When abnormal temperatures are not used, questions about thermal shock, the expansion of entrained air, and artificial changes in the hardening process do not arise. The equipment should add neither excessive heat nor humidity to the testing laboratory.

PROPOSED EARLY STRENGTH TEST

Procedure

The description of the procedure followed in conducting the early strength tests is recommended for further tests leading to the eventual adoption of standard specifications.

When mixing was completed, the properties of the plastic concrete were determined in accordance with ASTM specifications. Six standard 6 by 12-in. (15.2 by 30-cm) cylinders were prepared in cast-iron molds by following the procedure of ASTM C 192. The molds were capped with ½-in.-thick (1.27-cm) steel plates. They were turned on their sides and tapped several times at each end.

Fifteen min after the molding began, three cylinders were placed in the hot-water bath and three were placed in a moist room, where a standard temperature of 73.4 ± 3 F (23 C) was maintained. The cylinders placed in the hot-water bath were cured for 23½ hours. They were then removed, stripped, and tested at 24 hours according to ASTM C 39. The cylinders placed in the moist room were cured for 28 days and then removed, stripped, and tested in accordance with ASTM C 39.

The procedure produced cylinders with very good ends; no capping was needed.

Equipment

Perhaps the only equipment of interest is the hot-water bath, which is shown in Figure 3. The bath was simply constructed in our shop. The base to support the tank was constructed of 2 by 2 by ¼-in. (5.1 by 5.1 by 0.6-cm) steel angles. The tank was made of 0.13-in. (0.32-cm) steel plates welded together along their edges. The top was fitted with a wooden lid. The 16-ft^3 (0.45-m^3) tank is large enough to hold 14 cylinders. Circulation of the water is provided by a small electric impeller. Heat is supplied by a 6-in. (15.2-cm) ring gas burner. A solonoid valve is activated by a metallic expansion thermometer. The tank and its lid were insulated because the testing program included curing temperatures as high as 150 F (65.6 C). The tank was large enough for the tests conducted and provided temperature control for the water. Tanks of other sizes and shapes should perform equally well.

Additional equipment for producing and testing concrete conformed to ASTM C 31-66, C 39-66, C 143-66, C 192-62, and C 192-65. The cast-iron cylinder molds were fitted with ½-in. (1.3-cm) plates that could easily be swung into position and clamped. The end plates led to cylinders with good ends and eliminated the need for capping.

EARLY STRENGTH TEST EXPERIMENTS

Testing Program

Tests were performed to observe the merits of the 24-hour, 100 F (37.8 C) hot-water

Figure 3. Hot-water bath.

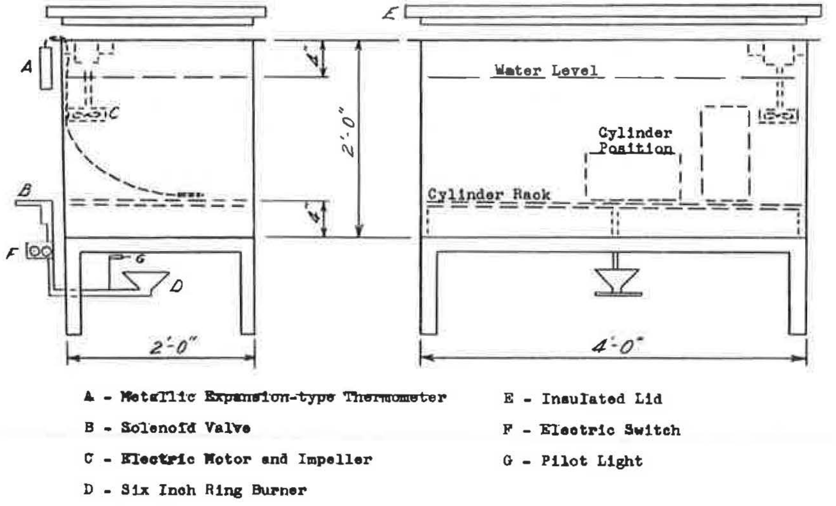


Figure 4. Twenty-four-hour strength versus 28-day strength.

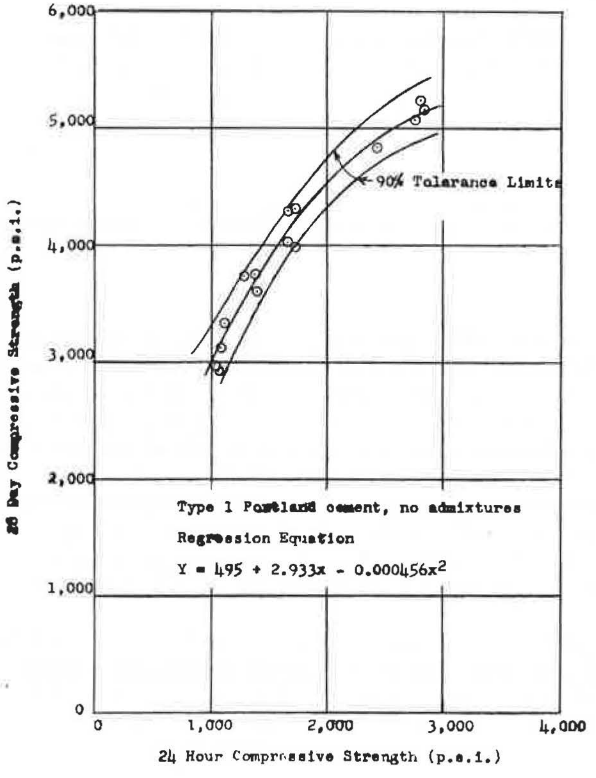


Figure 5. Compressive strength versus water-cement ratio.

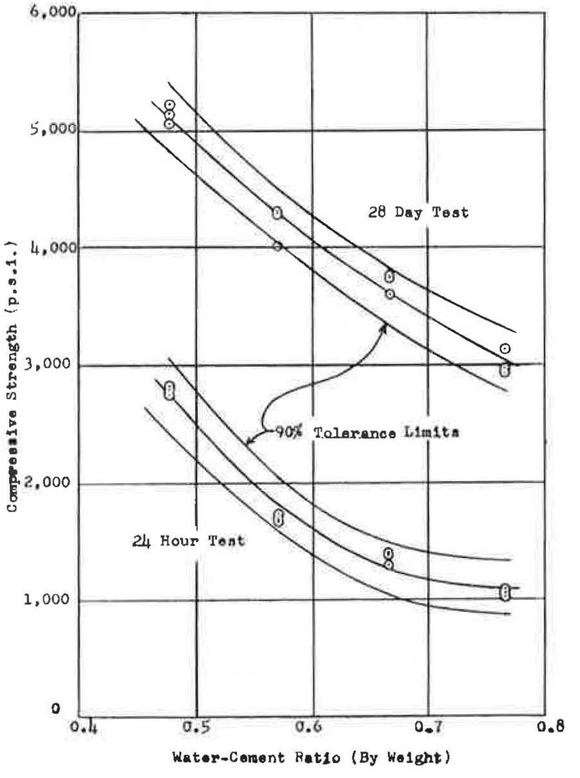


Figure 6. Effect of admixtures on strength correlation.

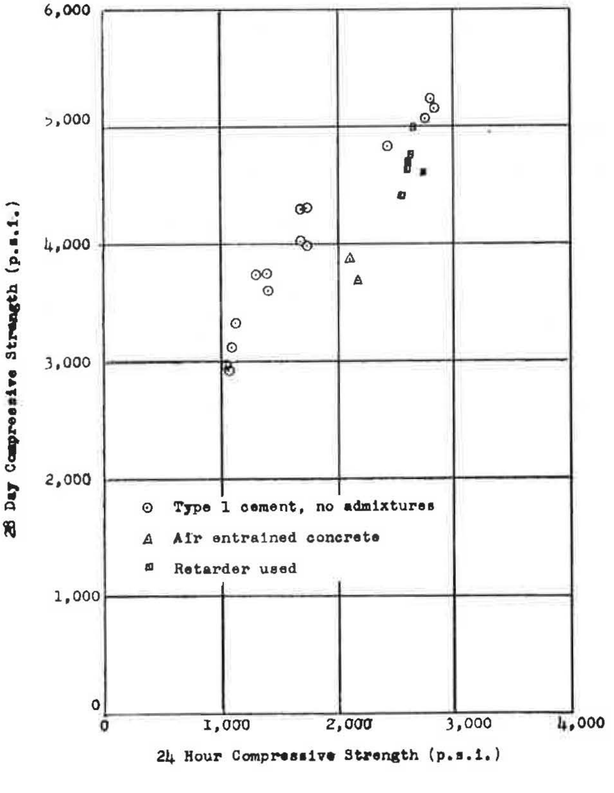


Figure 7. Effect of retarder on correlation between strength and water-cement ratio.

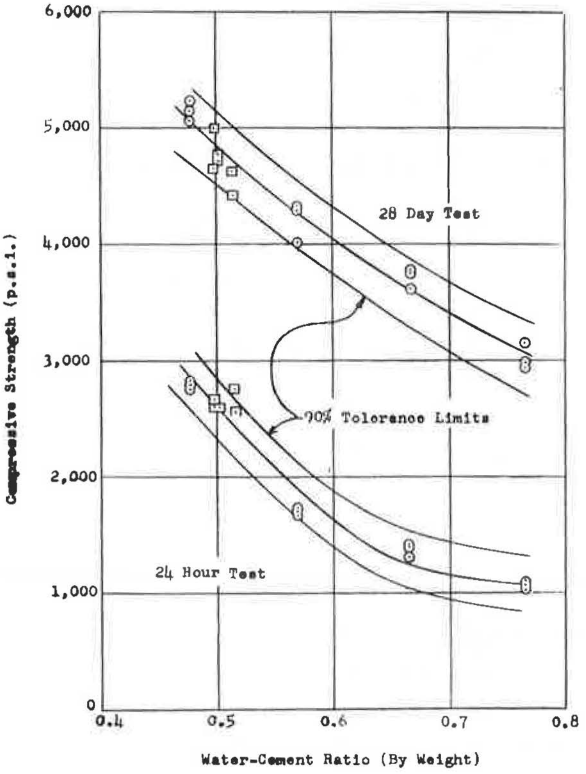


Table 2. Statistical analysis of results for each mix.

Mix Design	Test	Average Compressive Strength (psi)	Standard Deviation (psi)	Coefficient of Variation	Limits of Uncertainty[a] (psi)
B	24-hour	2,796.7	112.0	4.004	±73.9
B	28-day	5,147.6	170.4	3.310	±112.5
C	24-hour	1,691.4	78.8	4.658	±52.0
C	28-day	4,205.2	176.7	4.201	±116.6
D	24-hour	1,357.3	65.5	4.825	±43.2
D	28-day	3,701.0	121.1	3.272	±79.9
E	24-hour	1,058.0	31.9	3.015	±21.1
E	28-day	3,006.0	179.2	5.961	±118.3

Note: 1 psi = 6.9 kPa.

[a]P = 0.9.

curing. They were planned to determine (a) the correlation between the 24-hour test and the standard 28-day test (Figure 4) and (b) the correlation between 24-hour and 28-day compressive strength and the water-cement ratio (Figure 5).

Ninety standard cylinders were molded from the mixes without admixtures (Table 1). Thirty-six cylinders were prepared with a commercial retarder-densifier additive, and 12 were prepared with a commercial air-entraining agent. Figure 6 shows the effect of a retarder and an air-entraining agent on strength correlation, and Figure 7 shows the effect of a retarder on the correlation between strength and the water-cement ratio. The air content ranged between 6 and 7.5 percent. The procedure described previously was followed.

Analysis of Test Results

The compressive strength of each cylinder, the average strength, the standard deviations, and the coefficients of variation are given elsewhere (13). Table 2 gives the average compressive strengths, standard deviations, coefficients of variation, and limits of uncertainty obtained for each mix used. As the average 28-day strength increased from 3,006 to 5,148 psi (20.7 to 35.5 MPa), the strength gained in the 24 hours increased from 35 to 54 percent of the 28-day strength. It is noteworthy that the coefficients of variation (ratio of standard deviation to compressive strength) of the 24-hour strengths and 28-day strengths were much alike. The average values were 4.13 and 4.19 percent respectively.

CONCLUSIONS AND RECOMMENDATIONS

This experimental study leads to the following conclusions:

1. Twenty-four-hour compressive strengths can be used to predict 28-day strengths with good precision;
2. A hot-water curing temperature of 100 F (37.8 C) is adequate for a 24-hour early strength test; and
3. Test specimens of good quality can be produced with cast-iron molds equipped with steel end plates.

Based on the experiments described and additional research performed at the University of Delaware, we recommend the following:

1. A broadly based testing program leading to the development of an early strength test for concrete,
2. The use of hot-water curing,
3. A curing temperature low enough to ensure the careful handling of test specimens and the safety of the technicians involved, and
4. The eventual elimination of the 28-day test as a basis for design and quality control of concrete.

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