ACCELERATED METHODS OF ESTIMATING THE STRENGTH OF CONCRETE

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This paper gives the results of an experimental investigation to develop equations for estimating the potential strength of concrete by using the accelerated-curing methods recommended by the American Society for Testing and Materials. Cylinders made from 21 different batches of concrete were tested. Ranges of variables included in this investigation were types of cements (1, 2, and K); types of molds (steel, plastic, and cardboard); water-cement ratios (by weight), 0.41 to 0.72; aggregate-cement ratios (by weight), 2.5 to 4.1; maximum size of coarse aggregate, 1 in. (25.4 mm); and the 28-day compressive strengths, 3,400 to 6,800 psi (23 500 to 46 900 kPa). An equation and correlation curves are presented for the locally used materials and mixes relating the strength of types 1, 2, and K cement concretes obtained in the accelerated-curing methods and the 28-day strength obtained with standard-curing conditions. Based on the results from this investigation and those of other investigators from various parts of the world, an equation applicable universally with reasonable accuracy is presented for estimating the potential strength of concrete by using accelerated-curing methods. Equations based on maturity concept are also presented to predict the strength of concrete when the water-cement ratio, duration, and temperature of curing are known. The results of this investigation are compared and analyzed in relation to published works.

•CONCRETE testing in the last 50 years has remained consistently the same; however, the methods of production and placement have changed quite considerably. Developments such as high-capacity ready-mix concrete plants, transit-mixer trucks, prefabricated forms, power vibrators and finishing equipment, conveyors, and concrete pumps have enabled contractors to place and finish huge quantities of concrete, as much as 120 to 400 yd^3 (92 to 306 m^3) in an hour.

What are the consequences? Buildings, roads, and bridges could be completed before one conventional 28-day, standard-cured concrete test cylinder can be tested. A large quantity of inferior concrete could be placed in a key location of a structure and become an integral part of the structure before it could be detected. It may then be too late to remove the inferior concrete alone; thus the removal of the entire structure may be needed. The problem therefore is to reduce the time required between the placement of concrete and the determination of the strength. This can be achieved by replacing the standard 28-day moist curing (ASTM C 684-71T) with accelerated curing. The accelerated curing reduces the waiting period from 28 days to 1 or 2 days (ASTM C 192-69). This alone is a sufficient and adequate reason for adopting accelerated-curing procedures.

Earlier research of accelerated curing has helped to develop three main requirements (2) for an acceptable test method: (a) The test must be reproducible, (b) the test must produce accelerated concrete strengths that can be easily related to a reference strength level (probably the 28-day standard-cured strength), and (c) the accelerated strength must be a high percentage of the reference strength to ensure that the test will be efficient. Recognizing the need for rapid test results, ASTM has adopted three accelerated-curing procedures (ASTM C 192-69): the warm-water curing method, the boiling-water curing method, and the autogenous curing method.

The detailed accelerated-curing procedures are to be followed nationwide; however, the correlation curves and the relationships for predicting the 28-day compression strength of concrete will largely depend on the locally used materials and mixes.

In that type K expansive cement is the cement of the future (3), there is a need for developing relationships for predicting the 28-day strength of this shrinkage-compensating concrete by using accelerated-curing methods.

SPECIFIC AIMS

The specific aim of this research is to develop correlation curves for the locally used materials, mixes, and methods relating the strength of portland cement concrete obtained in the accelerated-curing methods and the 28-day strength obtained with standard-curing procedures.

The correlation between the compressive strength obtained from the accelerated method and from the 28-day standard-curing method will also be developed for the type K, expansive cement concrete.

EARLIER RESEARCH

Theoretical Basis

Concrete Hardening, The Curing Process

There are four distinct periods in the hardening or hydration process. The first period occurs when cement and water are brought into contact. It is a period of rapid dissolution and exothermic chemical reactions lasting about 5 min. The rate of reactions then subsides to a low level, and the second period, one of dormancy or plasticity, lasts 40 to 120 min (depending on the cement characteristics). The third period, one of rapid chemical reactions, then begins, usually lasting 3 to 6 hours, during which the concrete loses its plasticity and sets. Final set commonly occurs by the sixth hour after the cement first comes in contact with water. At that time approximately 85 percent of the hydration process is still remaining (2). After final set, the fourth period begins, one in which the chemical reactions continue at a diminishing rate until the conditions necessary for the reactions to continue are no longer present.

When hydration occurs at a rapid pace, there is rapid hardening and rapid gain of strength. Hydration, being an exothermal chemical reaction, gives off heat, and, if heat is applied externally, hydration will accelerate. When the rate of heat evolution is measured at normal temperature and at an elevated temperature (applying heat), it can be seen that the heat evolution at elevated temperatures is greater than at normal temperatures (4) (Figure 1). This implies that the hydration process is accelerated and that the strength gain due to elevated temperatures is also accelerated.

Maturity Concept

The compressive strength of concrete increases with time; the temperature at which it is cured also has a major influence. Previous research has shown the most accepted datum temperature to be between 10 and 14 F (-12.2 and -10 C). It is at this temperature and above that hydration and hardening begin. The maturity concept is based on this datum temperature, where

$$\text{Maturity (M)} = \text{curing time (hours)} \times \text{temperature of cure (deg F)} - 14 \qquad (1)$$

Figure 1. Rate of heat evolution versus time.

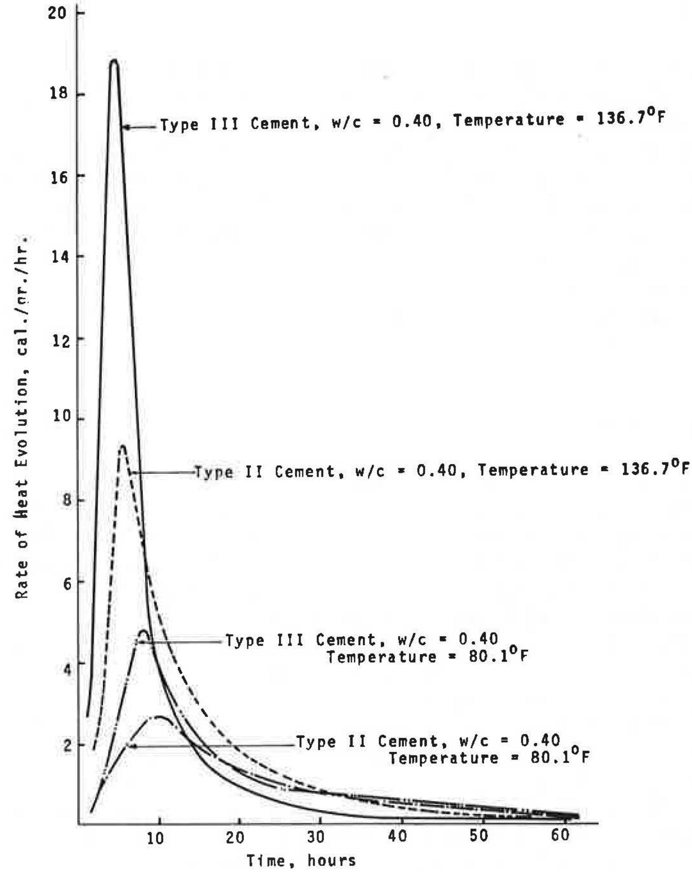
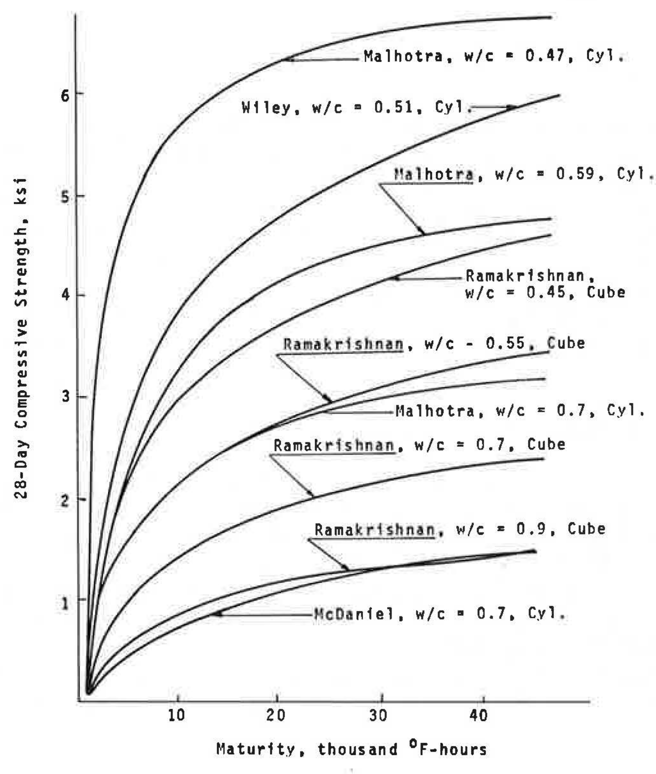


Figure 2. Twenty-eight-day strength versus maturity.



The units of maturity are deg F hours (deg C hours).

The strength then of a given concrete mix can be defined by a single value, maturity, all other conditions being equal. Figure 2 is based on the results of the research of McDaniel (6), Wiley (7), Malhotra and Berwanger (8), and Ramakrishnan and Li (9) and shows that the strength increase due to increasing maturity is not linear. If these same curves are plotted by using $\log_{10}$(maturity) as the independent variable on the X-axis, the curves become linear as shown in Figure 3. By using the maturity concept, it is possible to determine the strength of a given concrete without physically testing a concrete specimen.

Maturity, then, is an additional tool in determining the concrete strength, but the test data and results should not be used indiscriminately.

Findings

Previous research of boiling-water or high-temperature accelerated curing has shown a wide variety of procedures and methods. Results of research by McGhee (2), Malhotra and Berwanger (8), Smith and Chojnacki (11), Malhotra and Zoldners (12), and Vuorinen (13) are shown in Figure 4. The close grouping of these curves is quite extraordinary in spite of the fact that the testing was done in three countries and three different test methods were used. It also shows the possibility of using a general curve obtained from these curves to estimate the 28-day strength until a more accurate local curve can be developed. A local curve must be found because of differences in aggregate, sand, and cement in various regions.

The results of hot-water testing done by Malhotra (14) and McGhee (2) are shown in Figure 5. It can be seen from these curves that there is a wide range of results. It would not be possible to use an average equation to represent all the data; therefore separate equations based on specific cement types are definitely required. Figure 6 shows curves developed by McGhee (2) that compare efficiency (ratio of accelerated strength to 28-day strength) and the curing temperature. His testing and conclusions indicated that the highest efficiencies are obtained at water temperatures of 165 to 180 F (74 to 82 C).

SCOPE

This investigation consisted of two parts. In the first part the mandatory ASTM procedures for accelerated curing (ASTM C192-69) were followed. The second part consisted of minor variations of ASTM procedures necessary to time scheduling properly for testing and to improve the efficiency of the tests.

Included in the testing were 21 different batches of concrete obtained from local ready-mix plants. Ranges of variable parameters included in this investigation were water-cement ratios (by weight), 0.41 to 0.72; aggregate-cement ratios (by weight), 2.5 to 4.1; maximum size of coarse aggregate, 1 in. (25.4 mm); and the 28-day compressive strengths, 3,400 to 6,800 psi (23 500 to 46 900 kPa).

MATERIALS AND METHODS

The cements used were types 1, 2, and K portland cements. The fine aggregate used was a coarse, washed river sand found along the Cheyenne River near Hot Springs, South Dakota. The coarse aggregate used was crushed limestone from the local quarries of Rapid City, South Dakota. Concrete using type K cement was made in the laboratory. Concretes using types 1 and 2 cements were obtained from local ready-mix concrete producers, one using the central-mixer technique and the other using the transit-mixer operation.

The casting of the cylinders was done according to ASTM C192-69. Molds of steel, cardboard, and plastic were used, and both manual and mechanical methods of consoli-

Figure 3. Twenty-eight-day strength versus $\log_{10}$ (maturity).

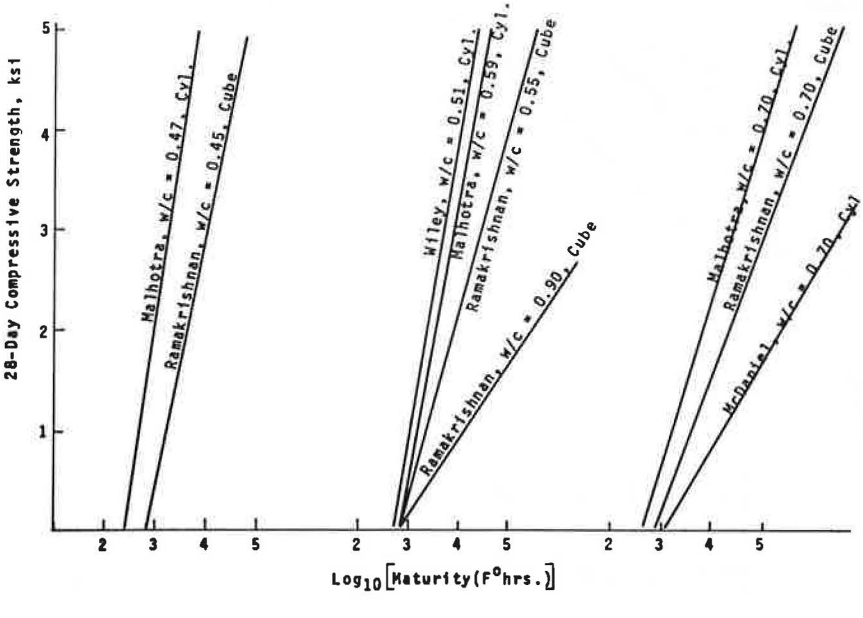


Figure 4. Twenty-eight-day versus accelerated strength at high temperatures.

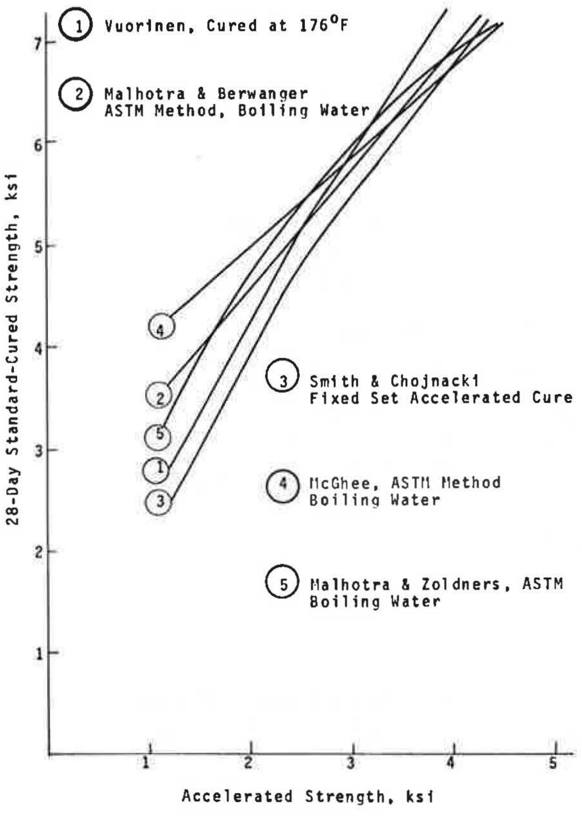


Figure 5. Twenty-eight-day versus accelerated strength at low and medium temperatures.

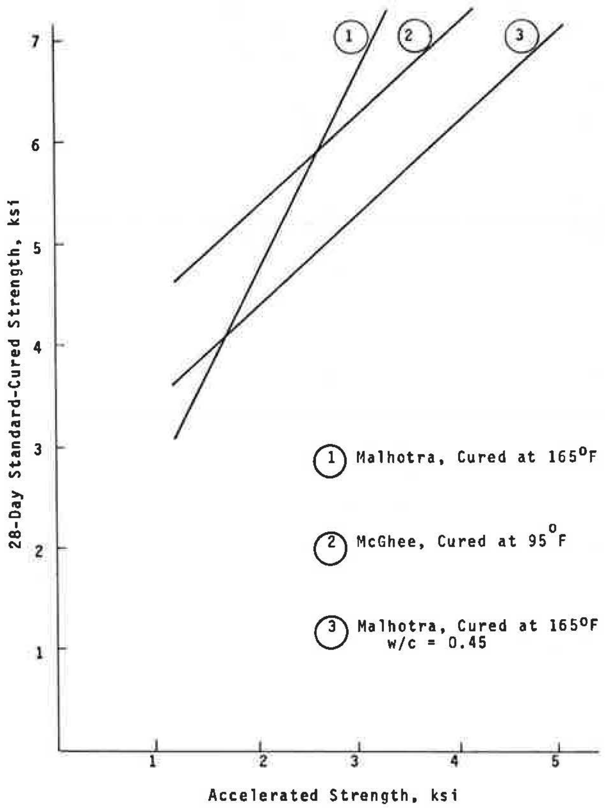
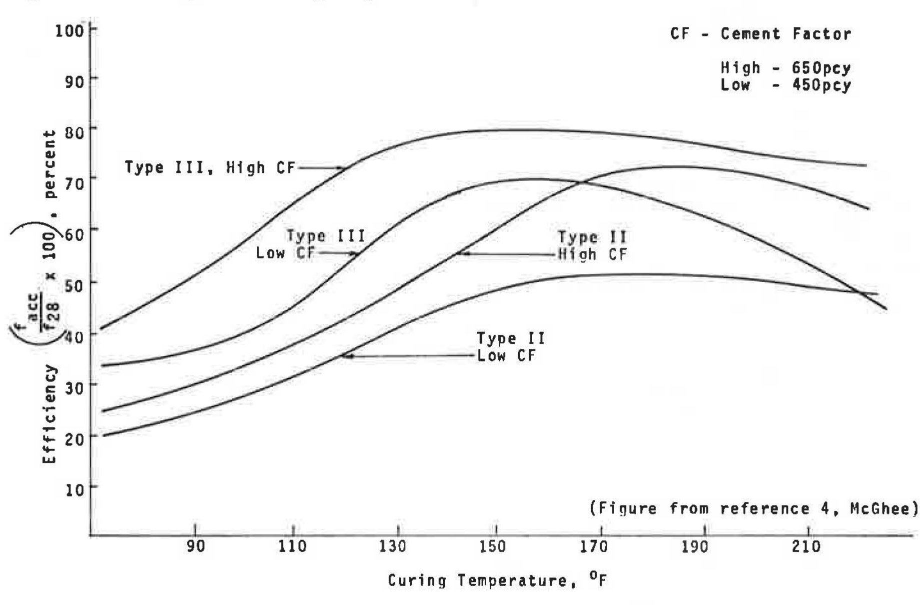


Figure 6. Efficiency versus curing temperature.



dation were used. A ½-in.-diameter (12.7-mm) rod and a 1¼-in. (31.75-mm) Stow concrete vibrator (model 71E) were used in consolidating the concrete.

The curing of the concrete cylinders was done according to ASTM procedures for standard curing (ASTM C192-69) and for accelerated curing (ASTM C684-71T). Additional accelerated-curing methods were also used, one of which was similar to the ASTM warm-water method. In this method, the curing water temperature was higher, 167 F (75 C), the duration of the cure was 1 hour longer, and the concrete was allowed to set for 2 hours before curing began. The other method was a slight variation of the ASTM boiling-water method. In this method, the cylinders were placed in the boiling water immediately after the cylinders from the hot-water test were removed. Because of this procedure, the time at which curing began in the boiling-water method was 26 hours after casting instead of the 23 hours recommended by ASTM. Therefore, the age at testing was also 3 hours later, at 31½ hours instead of 28½ hours. Table 1 gives the curing methods used and their variations.

Testing of the cylinder specimens was done according to ASTM C39-71 on a 300,000-lb (136 000-kg) capacity Tinius Olsen compression testing machine.

A minimum of nine cylinders were cast (all in the same type of mold) from each batch (three in warm or hot water, three in boiling water, and three for 28 days). Testing was also done on cylinders cast in different types of molds and from the same batch. The data obtained from these tests were used in determining regression equations.

DISCUSSION OF TEST RESULTS

The data obtained from the various test batches are given in Table 2.

Hot-Water Method

Tests 1 to 13 followed the hot-water procedure from Table 1. This method was recommended by an ASTM subcommittee and was effective July 1971. The resulting data are shown in Figure 7. By using the method of least squares (17) in determining regression equations, three equations representing different parameters were obtained and are also given in Table 3.

In the hot-water method, when all the available results with different variables are considered together, there are enough test results for a reasonable statistical analysis. There is a good correlation between the 28-day strength and the accelerated strength of concrete when the hot-water method is used. The efficiency $f_{acc}/f_{28'}$ (ratio of the accelerated strength to the 28-day strength) is greater when the hot-water method is used than when the other two methods are used. The efficiencies obtained for the hot-water, warm-water, and boiling-water methods are 51, 33, and 41 percent respectively.

Warm-Water Method

Tests 15 to 21 followed the warm-water procedure (Table 1) recommended by ASTM C684-71T. Test results are shown in Figure 8, and corresponding regression equations are given in Table 3. From Table 3 and Figure 8, one can see that the different types of cements are more sensitive to this type of cure than to the different types of molds used. This is shown by the low correlation factors obtained when results based on the use of different molds are individually analyzed. In the warm-water method, even at a comparatively low temperature of 95 F (35 C), there was a definite increase in the strength. There was also a consistent pattern in the rate of increase of strength of concrete, even though a small number of tests and a small range of strengths were used.

Among all the correlation coefficients found, the highest and lowest values occurred when this test method was used. If this method is to be used, it is imperative that the

Table 1. Curing methods used.

Procedure	Molds	Curing Medium	Curing Temperature (C)	Age Curing Begins	Duration of Cure	Age at Testing
ASTM 28-day standard	Reusable or single-use	Water	21	24 hours after casting	28 days	29 days
Hot-water	Reusable or single-use	Water	75	2 hours after casting	24 ± ½ hours	28 ± ¼ hours
ASTM warm-water	Reusable or single-use	Water	35	Immediately after casting	23½ ± ½ hours	24 ± ¼ hours
Boiling-water	Reusable or single-use	Water	93[a]	26 hours after casting	3½ ± 1/12 hours	31½ ± ¼ hours
ASTM boiling-water	Reusable or single-use	Water	93[a]	23 hours after casting	3½ ± 1/12 hours	28½ ± ¼ hours

[a]Test elevation = 3,230 ft (985 m).

Table 2. Test data.

Test No.	Type of Cement	Avg Strength Results (psi)								
		Steel Molds			Plastic Molds			Paper Molds		
		H-W	B-W	28-D	H-W	B-W	28-D	H-W	B-W	28-D
1	1	2,118	1,681	3,657						
2	1	2,192	1,630	3,498						
3	1	1,620	1,691	4,233						
4	1	1,630	1,750	4,292						
5	1		1,375	3,545		1,435	3,637			
6	1	3,682		5,237	3,554		4,977			
7	K	4,424	2,980	6,783		2,642				
8	1	1,896	1,753	3,896						
9	1	1,940	1,970	4,565						
10	K	4,346	2,567	6,443						
11	1	1,655	1,482	4,197						
12	1		1,687	3,836					1,599	3,538
13	1	1,939		4,244				1,189		4,069
14	1								2,167	4,721
15	1	1,416	1,802	4,234				1,308	1,611	4,054
16	K	1,198	1,747	4,900						4,638
17	1	1,490	1,610	4,200						
18	2	1,323	1,984	5,662		2,099	6,054			
19	K		2,120	5,860		2,064	5,736			
20	1	2,307		4,853	2,091		4,798	2,004		4,636
21	K	1,652	2,617	5,497				1,544	2,424	5,048

Note: H-W = hot-water, B-W = boiling-water, and 28-D = 28-day. 1 psi = 6.9 kPa.

Figure 7. Twenty-eight-day versus accelerated-strength results from the hot-water method.

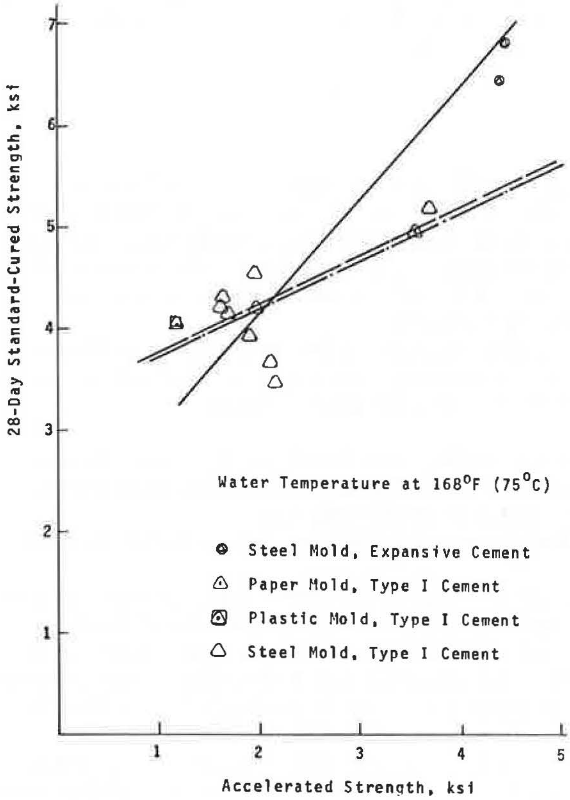


Table 3. Correlation equations.

Method	Test Parameters: Cement	Molds	No. of Tests	Equations	Correlation Coefficient
Hot-water	1	Steel	9	$f_{28} = 0.46\ f_{acc} + 3,248$	0.577
	1	All	11	$f_{28} = 0.458\ f_{acc} + 3,314$	0.592
	All	All	13	$f_{28} = 1.149\ f_{acc} + 1,840$	0.874
Warm-water	All	Steel	6	$f_{28} = -0.0075\ f_{acc} + 4,903$	-0.013
	All	All	10	$f_{28} = 0.095\ f_{acc} + 4,634$	0.059
	All	Paper	3	$f_{28} = 0.581\ f_{acc} + 3,639$	0.425
	K	All	3	$f_{28} = 1.053\ f_{acc} + 3,605$	0.838
	1	All	6	$f_{28} = 0.822\ f_{acc} + 3,008$	0.986
	1	Steel	3	$f_{28} = 0.729\ f_{acc} + 3,162$	0.992
Boiling-water	1	Steel	11	$f_{28} = 2.294\ f_{acc} + 169$	0.580
	K	All	8	$f_{28} = 1.158\ f_{acc} + 3,021$	0.703
	1	All	15	$f_{28} = 1.404\ f_{acc} + 1,644$	0.735
	K	Steel	5	$f_{28} = 0.258\ f_{acc} + 5,277$	0.832
	All	All	25	$f_{28} = 2.086\ f_{acc} + 682$	0.871
	All	Plastic	4	$f_{28} = 2.088\ f_{acc} + 1,077$	0.879
	1	Paper	3	$f_{28} = 4.053\ f_{acc} - 3,160$	0.907
	All	Steel	17	$f_{28} = 2.087\ f_{acc} + 681$	0.892
	All	Paper	4	$f_{28} = 1.571\ f_{acc} + 1,276$	0.954

various parameters involved in the casting and curing be separately analyzed; otherwise, the results of the regression equations will not be valid.

It also appears that the efficiency of a test is not an important consideration because the efficiencies found in this test were the lowest at 33 percent. Further research is needed to confirm the above-mentioned conclusions.

Boiling-Water Method

Two different boiling-water methods given in Table 1 were used. One method was recommended by ASTM. In the other, curing begins 3 hours later than in the correct ASTM procedure. Due to the close proximity of these methods, no differentiation will be made between them and both are called the boiling-water method. As shown in Figure 9 and given in Table 3, this 3-hour variation in initial curing before boiling appears to have little effect on the outcome of the results.

The correlations obtained by using the boiling-water method are similar to those of the results from the hot-water method when the same procedure was used for the analyses. However, the boiling-water method is easier to conduct because

1. There is no soaking of molds in curing water, and hence there is less cleanup;
2. It is easier to conduct the procedure in the field since no sophisticated curing tank is needed and any tank to hold boiling water is sufficient; and
3. It is possible to transport specimens for a short distance before curing beings.

The boiling-water method can be used when a variety of testing parameters and conditions are encountered on a project. If only one type of mold is used throughout a project but different cements are used, good correlation can be obtained (Table 3) by using the boiling-water method. It appears that different types of molds have a greater effect on the results than different types of cements. This is probably due to the 24-hour time interval between casting and the starting of the accelerated curing of the specimen. It allows the concrete enough time to reach the fourth stage of hydration, when the rate of release of the heat of hydration is decreasing (Figure 1). At this time, heat is supplied to the concrete by the boiling water, and the rate of strength development is accelerated.

A universal equation, such as the one shown in Figure 10, could be used for predicting the 28-day strength when initial data are sparse (new project, new area) or when cement types and molds are changing in a project. However, as Figure 9 shows, when one type of cement is used throughout the project, an equation representing the actual data will give a more accurate estimate of the 28-day strength. Figure 10 shows a single curve and equation that can be used when the boiling-water method is used. The lighter lines in Figure 10 are plots of equations from other investigators' work obtained from various parts of the world (2, 8, 11, 12, 13, 14).

On the whole, this method gives good correlations when compared to 28-day strengths and is quite easy to use. However, one disadvantage in this method is the overtime work necessary if the cylinders are cast after 1 p.m. If the cylinders were cast at 5 p.m., they would have to be placed in the boiling water at 4 p.m. the following day, removed at 7:30 p.m., and tested at 9:30 p.m. However, this overtime work is more than compensated for because of the ease in testing and the good correlations resulting even under adverse conditions. There is no overtime work involved in the use of the warm-water method if it is used during working hours.

Expansive Cement

Data obtained from testing concrete cylinders made of type K cement are given in Table 2. In the hot-water method, concrete made of type K cement developed higher efficiencies (66 percent) than concrete made of type 1 cement (51 percent). In the warm-water method concrete made of type K cement has an average efficiency of 27

Figure 8. Twenty-eight-day versus accelerated-strength results from the warm-water method.

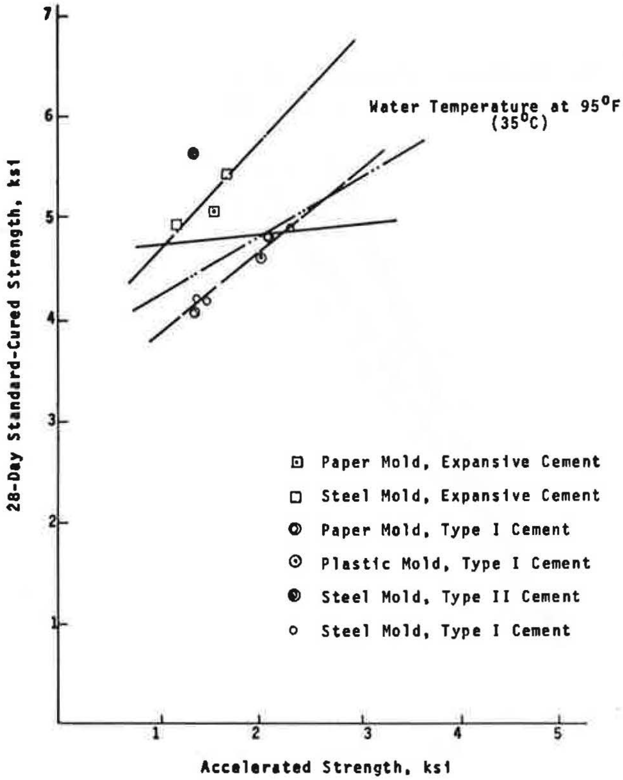


Figure 9. Twenty-eight-day versus accelerated-strength results from two procedures for boiling-water method.

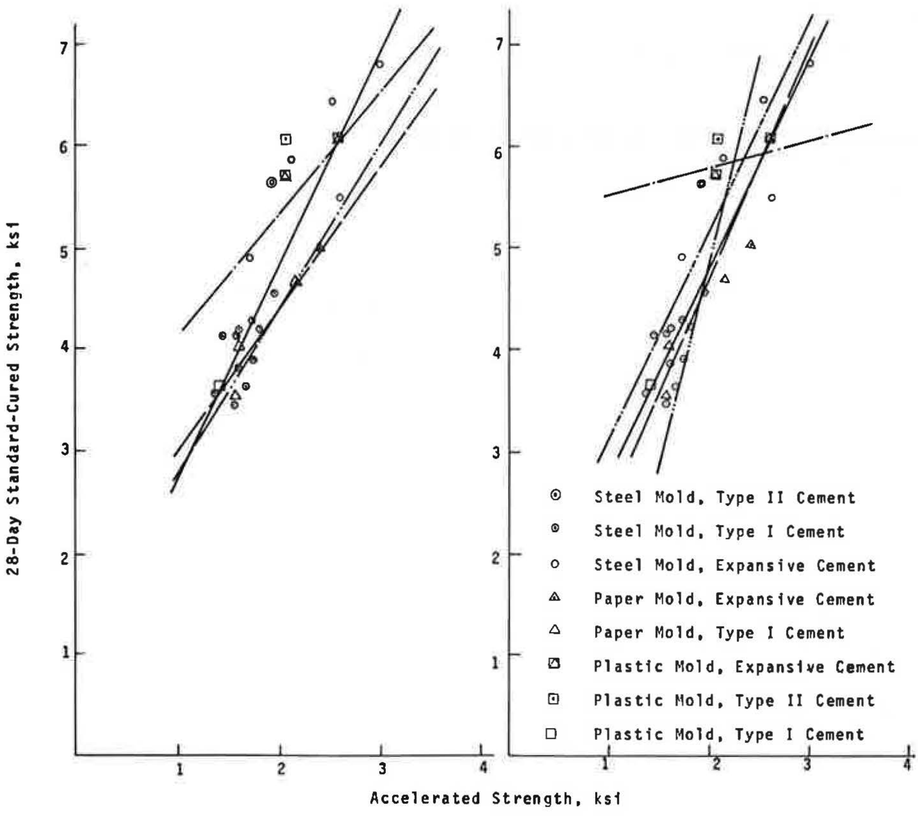


Figure 10. Twenty-eight-day versus accelerated-strength results from two equations for boiling-water method.

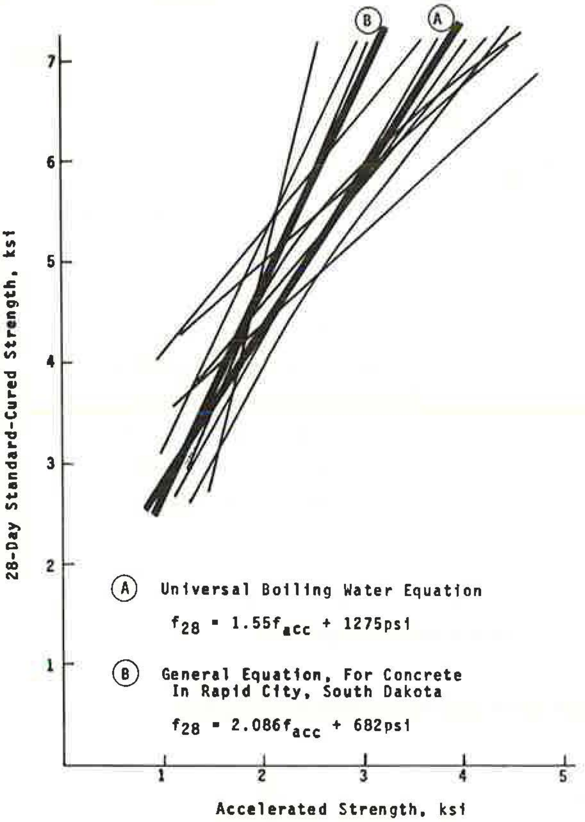
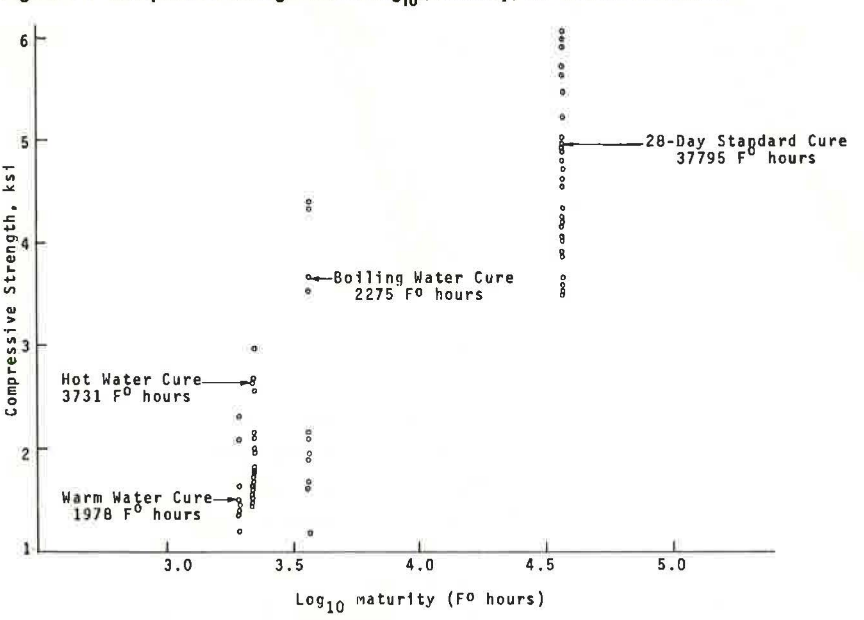


Figure 11. Compressive strength versus $\log_{10}$ (maturity) for various concretes.



percent versus 39 percent for type 1 cement concrete. In the boiling-water method, type K cement concrete had an efficiency of 41 percent, which is about the same as that of type 1 cement concrete (42 percent). In both hot-water and warm-water methods, the test points were few; it is therefore difficult to make specific comments about the results. Expansive cement concrete behaves differently in the hot-water and warm-water curing methods than type 1 cement concrete. Expansive cement concrete develops higher efficiencies in the hot-water method and lower efficiencies in the warm-water method than type 1 cement concrete. This shows that the rates of strength development are different for types 1 and K cement concretes. These two accelerated-curing methods (using hot and warm water) appear to accentuate the already inherent differences between types 1 and K cements that cause the cements to react differently.

When the boiling-water method is used, the data do not give a clear picture of any specific trends. The trend appears to be similar to type 1 cement concrete; however, more data points are needed to actually develop an equation that will estimate the 28-day strength of expansive cement concrete. At present the general equation (Figure 10) representing all cements and all molds for the area of Rapid City, South Dakota, appears to be able to estimate the 28-day strength of concrete made of types 1 and K cement with reasonable accuracy.

The 28-day strengths obtained by using type K cement range from 4,600 to 6,780 psi (31 700 to 46 780 kPa) with water-cement ratios ranging from 0.45 to 0.56. Further research is needed in regard to the accelerated curing of expansive cement concrete.

Maturity Method

The compressive strengths obtained for the various concretes are plotted against their $\log_{10}$ (maturity) values in Figure 11, which shows that there is no linear relation between compressive strength and $\log_{10}$ (maturity). Some researchers (6, 7, 8, 9) have recognized that the accuracy of the prediction of concrete strength based on the maturity concept can be improved by including water-cement ratio as one of the parameters in addition to the duration and temperature of curing. Ramakrishnan and Li (9) have proposed equations, based on maturity concept, in which water-cement ratio, duration and temperature of curing, and type of curing are the variables. The results from this investigation are compared with the proposed equations (9) in Figure 12. These equations show a reasonable agreement with the test results.

When the water-cement ratio is taken into consideration as shown in Figure 12, the test results show a better correlation with the predicted strengths. Table 4 gives equations for a certain water-cement ratio range that can be used to estimate the 28-day compressive strength. The accuracy of this method appears to be as good as that for the accelerated methods. In this method (Figure 12), differences in molds, cements, and curing have a pronounced effect on the results. As an example, cylinders cast in cardboard molds and cured for 28 days (standard cure) will have the same maturity but lower strength (approximately 10 to 15 percent lower) than cylinders cast in steel molds and cured 28 days (standard cure). Any equation derived to estimate the 28-day compressive strength or strength at any other age must take into consideration all influencing parameters that affect the strength results.

Effect of Accelerated Curing

The major effect of accelerated curing is accelerating the strength development of concrete. This can be done at various rates, depending on the type of cure used.

An adverse effect that has not been adequately recognized in earlier research is the fact that concrete cured by accelerated methods for a short period and then cured normally for the remaining period of 28 days in many cases will not develop the same compressive strength as that of a similar cylinder cured by standard methods for 28 days.

A few pilot tests were conducted to examine the effects of accelerated curing on the

Figure 12. Compressive strength versus $\log_{10}$ (maturity) for various water-cement ratios.

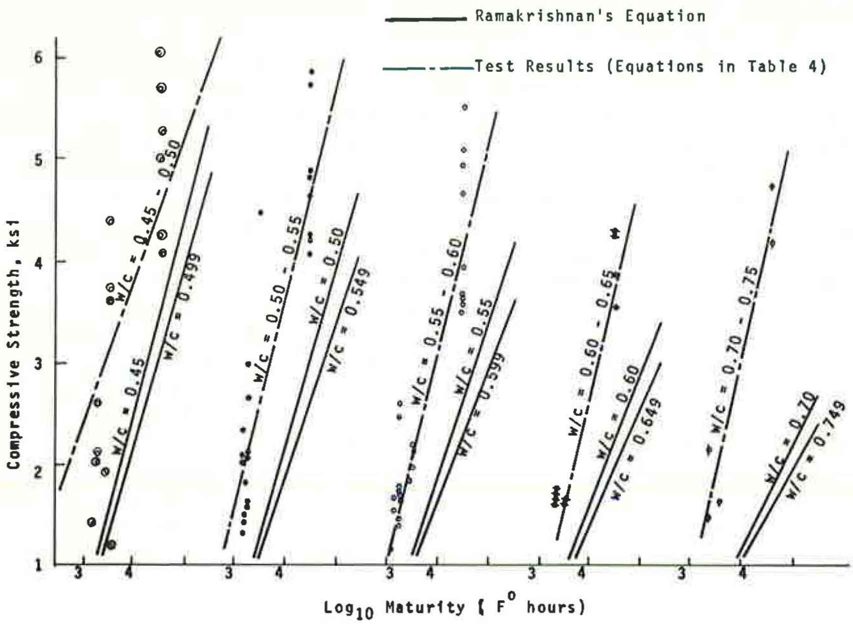


Table 4. Strength estimation equations based on maturity and various water-cement ratio ranges.

Cement	Mold	No. of Tests	Water-Cement Ratio Range	Equations	Correlation Coefficient
1, K	Steel Plastic Paper	16	0.45 to 0.50	f_c = 1,431 $\log_{10}$(maturity) - 1,949 psi	0.844
1, K	Steel Plastic	23	0.50 to 0.55	f_c = 2,033 $\log_{10}$(maturity) - 4,521 psi	0.889
1, K	Steel Plastic Paper	23	0.55 to 0.60	f_c = 2,065 $\log_{10}$(maturity) - 5,194 psi	0.819
1	Steel Paper	10	0.60 to 0.65	f_c = 1,969 $\log_{10}$(maturity) - 5,068 psi	0.880
			0.65 to 0.70	No test points in this range	
1	Steel Paper	5	0.70 to 0.75	f_c = 2,284 $\log_{10}$(maturity) - 6,035 psi	0.962

Note: 1 psi = 6.9 kPa.

Table 5. Effects of ASTM accelerated curing on 28-day compressive strength.

Test Batch	Curing Method	Water-Cement Ratio	Molds	No. of Tests	Cement Type	1-Day Strength (psi)		28-Day Strength (psi)	
						Accelerated	Normal	Accelerated	Normal
6	Hot-water at 168 F	0.48	Steel	1	1	3,682	800	4,061	5,237
18	Warm-water at 95 F	0.45	Steel	2	2	1,323	900	5,286	5,662
5	Boiling-water at 199 F	0.56	Steel	2	1	1,375	500	2,732	3,545
14	Boiling-water at 199 F	0.71	Paper	3	1	2,167	400	4,245	4,721
16	Boiling-water at 199 F	0.56	Steel	2	K	1,747	700	4,948	4,900
17	Boiling-water at 199 F	0.52	Steel	2	1	1,610	650	2,887	4,200

Note: 1 psi = 6.9 kPa. 1 F = 1.8 (C) + 32.

28-day compressive strength. These results are given in Table 5 (19). It appears that at higher curing temperatures the effects of accelerated curing are more pronounced. The best time to begin curing appears to be 4 to 6 hours after casting; the lower curing temperatures will have less long-term effect on concrete compressive strength (19, 20).

When accelerated methods are used in strength estimation, the previously mentioned adverse effect need not be considered because it does not affect the results. If, however, accelerated methods are used for other purposes, such as achieving high early strength in concrete by steam curing, high-temperature-immersion curing, or other methods, this long-term effect should be considered.

CONCLUSIONS

1. The boiling-water method can be used when a variety of testing parameters and conditions are encountered on a project. Currently, we recommend its use because of the ease in testing, its satisfactory correlations with standard-curing methods, and the shortage of information regarding the other accelerated methods.
2. There is need for more research work using the hot- and warm-water methods over a greater range of strengths before any one method can be recommended. This could be done in conjunction with work that will expand the maturity concept with actual measurements of temperatures inside the cylinders.
3. Expansive cement concrete reacts favorably to accelerated curing. Because of its inherent physical and chemical properties, expansive cement concrete has strength development rates that are different from those of type 1 cement concrete. When expansive cement concrete becomes more widely accepted and used, separate correlation curves should be developed.
4. Accelerated methods are needed and can benefit the owner, construction contractor, and concrete producer in the form of reduced costs, less chance of construction delay due to testing uncertainty, and more uniform concrete throughout the project.
5. When the advantage of using accelerated testing is understood and accepted by all engineers, contractors, and testing agencies, this could possibly be the only test used as a measure of the strength of concrete.
6. Casting in steel molds resulted in concrete cylinder strengths 10 to 15 percent higher than in paper molds and 3 to 6 percent higher than in plastic molds. These conclusions were reached by comparing concrete strengths obtained when different molds were used in the same test batch.

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