ACCELERATED TESTING FOR PREDICTION OF 28-DAY STRENGTH OF CONCRETE

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There is a need for timely information on strength of concrete in construction works to help achieve better quality control. In India, not much work on accelerated strength testing of concrete has been reported, and there is a need for a systematic study of such testing by using locally available cements. This paper gives an account of an experimental study of accelerated testing of concrete for prediction of strength by using two methods based on suitable modifications of the British accelerated testing committee method and the Canadian modified boiling method. Concrete mixes with strengths ranging from 150 to 600 kgf/cm^2 (15 to 60 MPa) were tested. Test results, which were correlated by regression analyses, show that accelerated testing (hot-water curing for 3½ hours at 85 C) can be used to accurately predict 28-day concrete strengths.

•CONVENTIONAL practice for specification of concrete consists of denoting the 28-day compressive strength of 15 by 30-cm cylinders or 15-cm cubes cast, moist cured, and tested under controlled conditions. However this duration is too long in the context of current trends in new design concepts, increased pace of construction, and timely control of concrete quality. The need for an early determination of the concrete strength with satisfactory reliability has long been felt by many as evidenced by the research work published by many institutions all over the world during the past few decades. Different accelerated tests are being used in different countries for the prediction of the 28-day compressive strength, and these are available either as departmental or committee recommendations or incorporated as specification in the codes (1, 2, 3, 4, 5, 6, 7, 8). In general, these methods use the application of external heat or conservation of the heat of hydration for the accelerated strength development, and the methods differ mainly in procedural details.

In India, accelerated strength testing of concrete has not been widely attempted, and there is a need for a systematic study of such testing using locally available cements. Rehsi, Garg, and Kalra (9) have studied the suitability of the test method, recommended by the British accelerated testing committee (BATC), for application of 28-day compressive strengths of 100 kgf/cm^2 (10 MPa) to 250 kgf/cm^2 (25 MPa) to concretes of grades M 100 to M 250 (11 cement samples from the various factories of the Associated Cement Companies Ltd., Bombay). Two mixes with water-cement ratios of 0.4 and 0.6 and aggregate-cement ratios of 3.03 and 6.09 were used for the tests. It was concluded that the BATC method could be adopted for predicting the 28-day strength of the concrete mixes tried.

In this paper, a detailed laboratory study is reported on accelerated strength testing of concrete with strengths ranging from 150 to 600 kgf/cm^2 (15 to 60 MPa) by two different methods. The results of the tests have been assessed with the aid of suitable regression analyses.

EXPERIMENTAL PROGRAM

Materials and Equipment

Ordinary portland cements from three manufacturers (A, B, and C) in South India were used. The physical properties of these cements, obtained from standard tests [Indian Standard 4031 (1968)], are given in Table 1.

Crushed granite aggregate [maximum size, 8 in. (20 mm)] and river sand were used. Their gradations are given in Table 2.

Normal potable water was used for mixing and curing.

Various mixes were adopted with water-cement ratios ranging from 0.30 to 0.68; the values of aggregate cement ratios were 3.0, 4.5, 6.0, and 9.0. For the most part, the combined aggregate consisted of two parts of coarse aggregate and one part of fine aggregate by weight, and this resulted in a good continuous grading for the mix. The 28-day strengths of the mixes ranged from about 150 kgf/cm^2 to 600 kgf/cm^2 (15 to 60 MPa).

A thermostatically controlled, 87 by 60 by 38-cm-high water bath was used for accelerated curing. The bath was equipped with a main heater of adequate capacity and a secondary heater of 200 W to be operated by thermostatic control. The water level in the bath was maintained to provide for a volume of 0.05 m^3 of water for each specimen (15-cm cube). To maintain a uniform temperature, the water was continuously stirred.

Methods of Testing

Two methods of accelerated testing based on the BATC method (1) and the Canadian modified boiling method (6) were selected for the tests, and slight modifications in procedural details were made to suit the available facilities.

The modified methods adopted are named method 1 and method 2 respectively. The details of the basic methods and the modifications adopted for the tests are given in Table 3.

Test Procedure

Standard 15-cm cube specimens were cast in steel molds on a vibrating table. Twelve specimens were prepared from each concrete mix, of which four specimens were subjected to accelerated testing in the water bath and four each were normally cured in water for the 7-day and 28-day strength tests. For accelerated testing by method 1, the steel molds containing the concrete specimens were covered by 7-mm-thick steel plates, and these were cured in the water bath at the specified temperature. For method 2, the molds were covered with damp sacks for 24 hours after which the specimens were demolded and cured in the water bath at 85 C. Method 1 was attempted with 1 cement (cement A), and 25 sets of 15-cm cubes were cast, 12 cubes per set of concrete mix. Method 2 used two cements (cements B and C), and 16 sets of mixes were cast with each cement. The details of the mixes and the strengths obtained (average of four cubes each) are given in Tables 4, 5, and 6.

In Tables 4, 5, and 6, R_1 is the value of the 1-day accelerated strength test by the particular test method; R_7 and R_{28} are the 7 and 28-day strengths of normally cured specimens respectively.

Table 1. Physical properties of cements.

Cement	Setting Time (min) Initial	Setting Time (min) Final	Fineness[a] (cm^2/g)	Compressive Strength (kgf/cm^2) 3 Days	Compressive Strength (kgf/cm^2) 7 Days
A	40	115	2740	207	255
B	86	123	3240	212	300
C	70	135	3010	164	227

Note: 1 kgf/cm^2 = 0.098 MPa.

[a]Blaine's.

Table 2. Sieve analysis of aggregates.

Sieve Size	Percent Passing: Coarse Aggregate	Percent Passing: Sand	Sieve Size	Percent Passing: Coarse Aggregate	Percent Passing: Sand
20 mm	100	–	120 μm		63.1
10 mm	31.5	–	60 μm		43.8
480 μm	0	100	30 μm		11.1
240 μm		81.5	15 μm		0

Table 3. Details of accelerated test methods.

Item	BATC Method (hours)	Method 1 (hours, min)	Canadian Boiling Method (hours)	Method 2 (hours, min)
Commencement of curing[a]	½	30, ±5	24	24, ±15
Duration of curing	24[b]	23, ±15[c]	3½[d]	3½[e]
Commencement of testing[f]	½	½, ±10	1	1, ±10
Total duration for test	25	24	28½	28½

[a]Time after curing.
[b]At 55 C.
[c]At 60 ± 1C.
[d]At 100 C.
[e]At 85 ± 2 C.
[f]Time after completion of curing.

Table 4. Compressive strength results based on method 1 and cement A.

Set No.	Mix Proportions[a] (by weight)	Water-Cement Ratio (by weight)	Compressive Strength (kgf/cm^2) R_1	R_7	R_{28}
1	1:3:6	0.55	115.0	159.0	248.0
2	1:3:6	0.60	108.5	141.0	208.0
3	1:3:6	0.65	98.5	117.0	179.0
4	1:3:6	0.68	79.0	109.0	160.0
5	1:2:4	0.45	212.0	312.0	439.0
6	1:2:4	0.50	194.0	255.0	398.0
7	1:2:4	0.55	162.0	218.0	351.0
8	1:2:4	0.60	131.0	186.5	306.5
9	1:2:4	0.64	123.0	192.0	296.5
10	1:1.5:3	0.36	290.0	378.0	588.0
11	1:1.5:3	0.40	261.0	370.0	525.0
12	1:1.5:3	0.45	185.5	277.0	417.0
13	1:1.5:3	0.50	180.0	270.0	411.0
14	1:1.5:3	0.55	139.0	232.0	334.5
15	1:1.5:3	0.66	97.0	170.0	235.0
16	1:1:2	0.30	330.0	431.0	573.0
17	1:1:2	0.33	290.0	383.0	565.0
18	1:1:2	0.36	281.0	355.0	484.5
19	1:1:2	0.40	208.0	301.0	454.5
20	1:1:2	0.45	153.0	245.5	371.5
21	1:0.81:1.84	0.30	354.0	433.0	634.5
22	1:1.16:2.32	0.32	346.5	414.0	573.0
23	1:1.16:2.32	0.35	307.0	391.0	511.0
24	1:1.12:2.44	0.33	339.0	411.0	560.5
25	1:1.12:2.44	0.35	315.5	373.0	512.0

Note: 1 kgf/cm^2 = 0.098 MPa.

[a]Cement:sand:aggregate.

Table 5. Compressive strength results based on method 2 and cement B.

Set No.	Mix Proportions[a] (by weight)	Water-Cement Ratio (by weight)	Compressive Strength (kgf/cm²)		
			R_1	R_7	R_{28}
1	1:3:6	0.60	133.0	202.5	310.0
2	1:3:6	0.65	116.0	183.5	290.5
3	1:3:6	0.68	101.0	161.5	266.0
4	1:2:4	0.50	185.5	283.0	400.0
5	1:2:4	0.55	172.6	281.5	373.0
6	1:2:4	0.60	145.5	243.5	330.5
7	1:2:4	0.64	118.5	198.0	285.5
8	1:1.5:3	0.36	305.0	478.0	582.5
9	1:1.5:3	0.40	282.0	446.0	524.5
10	1:1.5:3	0.45	190.0	307.5	405.5
11	1:1.5:3	0.50	190.0	296.5	399.5
12	1:1.5:3	0.55	168.5	276.0	341.0
13	1:1:2	0.30	347.5	476.0	568.0
14	1:1:2	0.33	286.0	450.5	560.5
15	1:1:2	0.36	256.0	410.0	523.0
16	1:1:2	0.40	255.0	412.5	481.0

Note: 1 kgf/cm² = 0.098 MPa.

[a]Cement:sand:aggregate.

Table 6. Compressive strength results based on method 2 and cement C.

Set No.	Mix Proportions[a] (by weight)	Water-Cement Ratio (by weight)	Compressive Strength (kgf/cm²)		
			R_1	R_7	R_{28}
1	1:3:6	0.60	113.5	195.5	275.0
2	1:3:6	0.65	101.0	172.5	259.5
3	1:3:6	0.68	93.0	147.5	220.0
4	1:2:4	0.50	154.0	253.5	345.0
5	1:2:4	0.55	148.5	241.5	323.0
6	1:2:4	0.60	115.5	190.0	280.5
7	1:2:4	0.64	96.0	155.5	236.5
8	1:1.5:3	0.36	220.5	330.0	464.5
9	1:1.5:3	0.40	210.5	327.0	435.5
10	1:1.5:3	0.45	151.0	246.0	330.0
11	1:1.5:3	0.50	139.0	229.5	318.0
12	1:1.5:3	0.55	110.0	195.0	270.5
13	1:1:2	0.30	261.5	411.0	507.5
14	1:1:2	0.33	260.5	405.5	484.5
15	1:1:2	0.36	223.0	337.0	456.0
16	1:1:2	0.40	187.0	287.0	405.0

Note: 1 kgf/cm² = 0.098 MPa.

[a]Cement:sand:aggregate.

ANALYSIS OF RESULTS

Accelerated Test Method 1

Curves of the correlation between R_1 and R_7 and between R_1 and R_{28} are shown in Figures 1 and 2. These are parabolic in nature, and the best fit for the parabolic curve was obtained by means of statistical methods (10). The equations obtained for the best fitting curves are also shown in Figures 1 and 2. The standard errors or prediction for R_7 and R_{28} were 14.2 kgf/cm^2 (1.4 MPa) and 27.5 kgf/cm^2 (2.7 MPa) respectively.

Accelerated Test Method 2

Based on Figures 1 and 2, the correlations were almost linear, and the plots for both cements B and C nearly coincide. Hence a single linear correlation, based on the results for cements B and C (total population), was then attempted. By statistical methods (11), the regression line that gave the best linear fit was determined. The results of this analysis are shown in Figures 3 and 4. The standard error of prediction is small, 8.33 kgf/cm^2 (0.8 MPa) and 10.34 kgf/cm^2 (1.0 MPa), for prediction of R_7 and R_{28} values from R_1 values. The 95 percent confidence limits for the correlation are also shown in Figures 3 and 4.

DISCUSSION OF RESULTS

Accelerated Test Method 1

Almost all the results shown in Figures 1 and 2 are within the ±10 percent error limits. The scatter of results is relatively more with the high-strength concretes, i.e., for 28-day strengths of 500 kgf/cm^2 (50 MPa) and more. But the standard error of prediction is small. The parabolic correlation is compared with that obtained by the BATC method (Figure 5). This shows a similar trend between the two sets of results up to concrete strengths of about 500 kgf/cm^2 (50 MPa). The method appears to be quite useful for prediction of strength but involves a procedure of maintaining a constant temperature bath at 60 C for 23 hours and requires the use of the mold and a cover plate for the curing.

Accelerated Test Method 2

This method gives a linear correlation for prediction of 7-day or 28-day strengths (Figures 3 and 4), and the standard error of prediction is considerably lower than that of method 1. The 95 percent confidence limits are close together (Figures 3 and 4). The linear character of the relationship and the coefficient of correlation obtained by this method compare well with the results obtained by the Canadian modified boiling method (Figure 6) (6). The correlation obtained appears to be independent of the source of the cement, cement content, and water-cement ratio. The method has good potential for application and can give accurate results. A more representative character of the linear relationship can be obtained by undertaking a large number of laboratory and field tests, say, about 500 sets of results, with portland cements from a number of different sources in the country.

Figure 1. Accelerated strength versus 7-day strength for method 1.

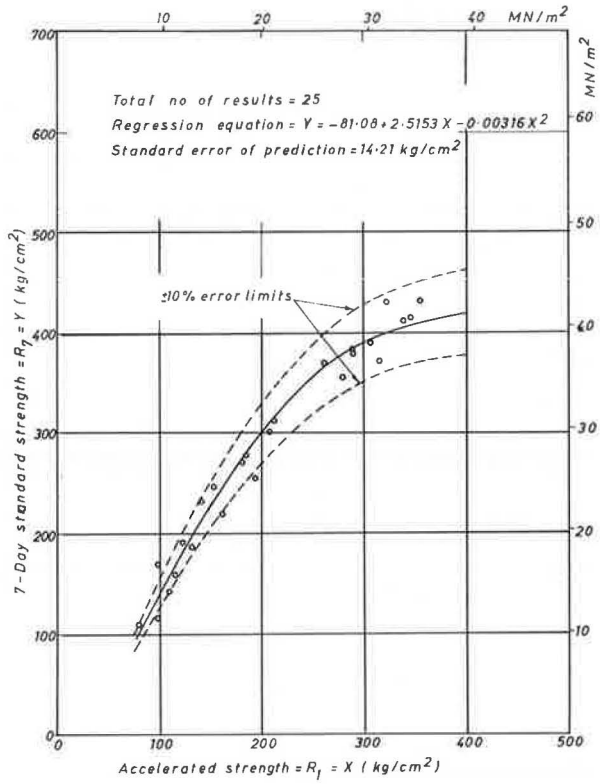

Figure 2. Accelerated strength versus 28-day strength for method 1.

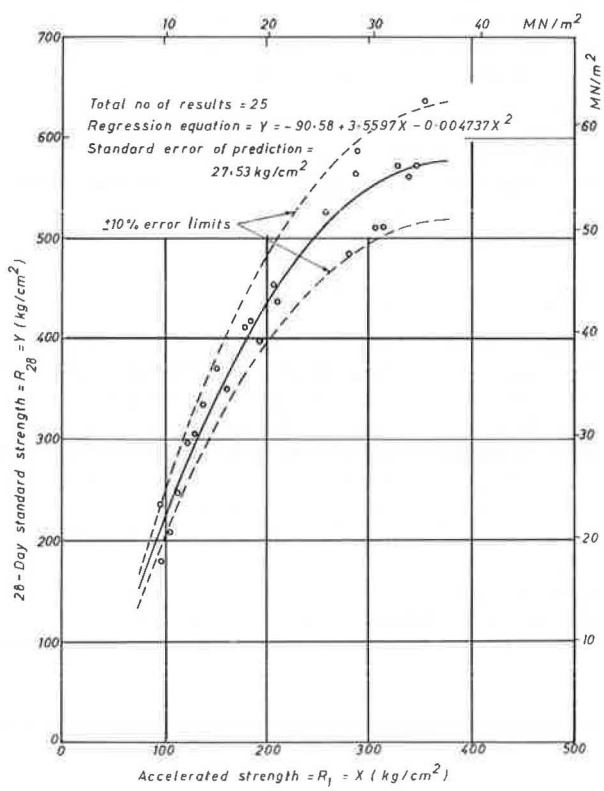

Figure 3. Accelerated strength versus 7-day strength for method 2 and cements B and C.

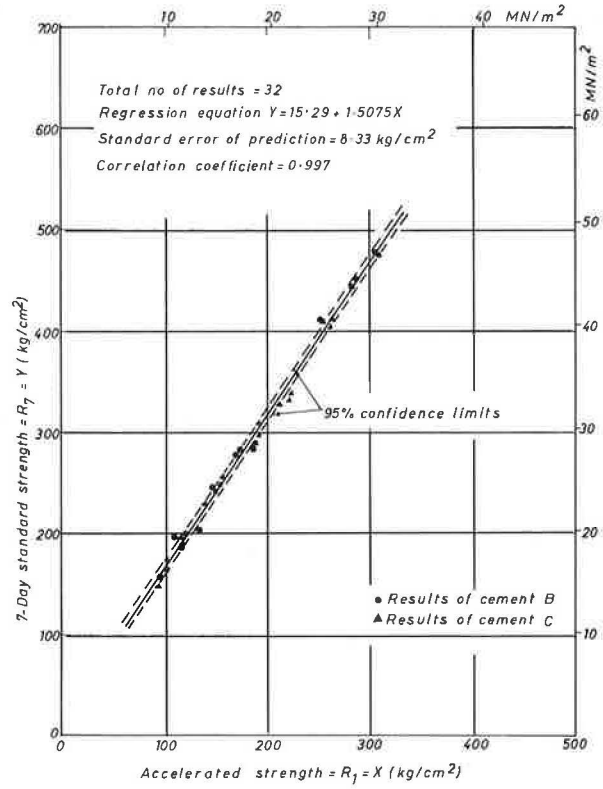

Figure 4. Accelerated strength versus 28-day strength for method 2 and cements B and C.

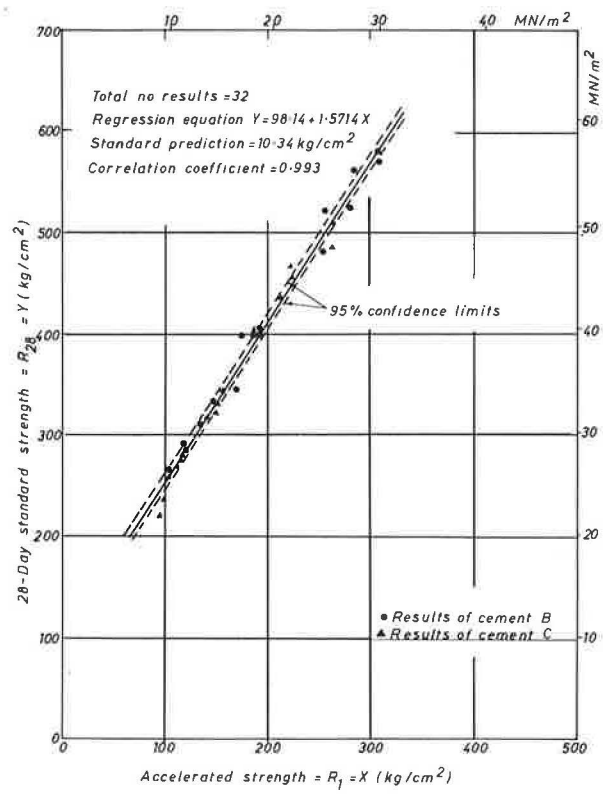

Figure 5. Method 1 versus British accelerated testing committee method.

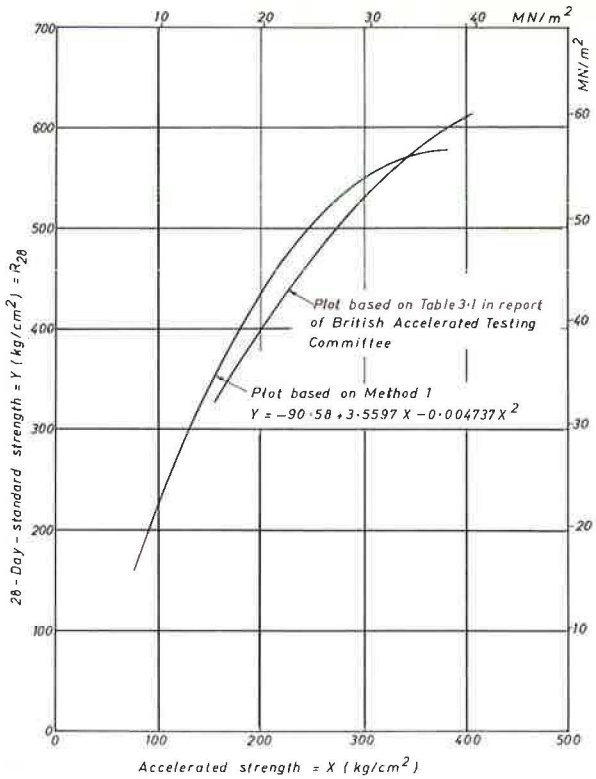

Figure 6. Accelerated strength versus 28-day strength.

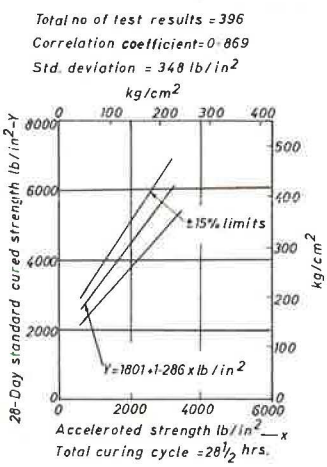

Table 7. Correlation between the 7 and 28-day strengths of normally cured specimens.

Cement	Regression Equation	Standard Error of Prediction (kgf/cm²)	Coefficient of Correlation
A	$R_{28} = 39.0 + 1.314R_7$	27.3	0.980
B	$R_{28} = 101.7 + 0.982R_7$	18.86	0.991
C	$R_{28} = 63.8 + 1.113R_7$	15.35	0.988
Total population for B and C	$R_{28} = 84.8 + 1.003R_7$	19.16	0.984

Note: 1 kgf/cm² = 0.098 MPa.

MERIT OF ACCELERATED TESTING OVER CURRENT PRACTICE

In the absence of accelerated testing, current practice for estimation of 28-day strengths is based on the 7-day strengths actually obtained. To compare the relative merits of this method against the prediction of accelerated test method, linear correlations between R_7 and R_{28} for the different cements were determined. The results of the regression analysis are given in Table 7. Comparison of these with the results of accelerated test method 2 (Figure 4) shows that the latter are at least as reliable as the 7-day (normally cured) strength tests for prediction of the 28-day strengths and can be used confidently and advantageously in time.

CONCLUSIONS

1. Both the accelerated test methods tried appear to give satisfactory results for predicting the 28-day strength of concrete.
2. Method 2, a modification of the Canadian boiling method, is recommended over method 1 because it gives better accuracy in prediction and provides a simple linear relationship and because the operating procedure and curing characteristics are simpler than those of method 1.
3. The accelerated test method (method 2) can be advantageously adopted in place of 7-day (normally cured) strengths for reliable estimation of 28-day strengths.
4. The relationship obtained for prediction of 28-day strength appears to be independent of the concrete variables like cement content, water-cement ratio, and the source of cement.
5. The accelerated test method 2 can be further developed for wide application by using a large number of tests covering the practical range of concrete mixes used in the laboratory and field. This method can be used to help in the design of trial mixes, to evaluate the uniformity of field concrete for quality control, and to evaluate the strength and quality of concrete by replacing the 28-day strength test entirely.

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