Standard Test Method for Measuring Early-Age Compressive Strength and Projecting Later-Age Strength[1]

This standard is issued under the fixed designation C 918; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Editorial corrections were made throughout the standard in August 1999.

1. Scope

1.1 This test method covers a procedure for making and curing concrete specimens and for testing them at an early age. The specimens are stored under standard-curing conditions and the measured temperature history is used to compute a maturity index that is related to strength gain.

1.2 This test method also covers a procedure for using the results of early-age compressive-strength tests to project the potential strength of concrete at later ages.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[3]

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory[4]

C 470 Specification for Molds for Forming Concrete Test Cylinders Vertically[4]

C 617 Practice for Capping Cylindrical Concrete Specimens[4]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[4]

C 1074 Practice for Estimating Concrete Strength by the Maturity Method[4]

C 1231 Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders[4]

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Practice C 1074 for the definitions of the following terms: *datum temperature*, *equivalent age*, *maturity*, *maturity function*, *maturity index*, and *temperature–time factor*.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *potential strength, n*—the strength of a test specimen that would be obtained at a specified age under standard curing conditions.

3.2.2 *prediction equation, n*—the equation representing the straight-line relationship between compressive strength and the logarithm of the maturity index.

3.2.2.1 *Discussion*—The prediction equation is used to project the strength of a test specimen based upon its measured early-age strength. The general form of the prediction equation used in this test method is:

$$S_M = S_m + b(\log M - \log m) \tag{1}$$

where:

S_M = projected strength at maturity index M,
S_m = measured compressive strength at maturity index m,
b = slope of the line,
M = maturity index under standard curing conditions, and
m = maturity index of the specimen tested at early age.

The prediction equation is developed by performing compressive strength tests at various ages, computing the corresponding maturity indices at the test ages, and plotting the compressive strength as a function of the logarithm of the maturity index. A best-fit line is drawn through the data and the slope of this line is used in the prediction equation.

3.2.3 *projected strength, n*—the potential strength estimated

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[2] *Annual Book of ASTM Standards*, Vol 04.10.

[3] *Annual Book of ASTM Standards*, Vol 04.07.

[4] *Annual Book of ASTM Standards*, Vol 04.02.

by using the measured early-age strength and the previously established prediction equation.

4. Summary of Test Method

4.1 Cylindrical test specimens are prepared and cured in accordance with the appropriate sections of Practice C 31 or in accordance with Practice C 192. The temperature of a representative specimen is monitored during the curing period. Specimens are tested for compressive strength at an early age beyond 24 h, and the concrete temperature history is used to compute the maturity index at the time of test.

4.2 A procedure is presented for acquiring a series of compressive strength values and the corresponding maturity indices at different ages. These data are used to develop a prediction equation, which can be used subsequently to project the strengths at later ages based upon measured early-age strengths.

5. Significance and Use

5.1 This test method provides a procedure to estimate the potential strength of a particular test specimen based upon its measured strength at an age as early as 24 h.[5] The early-age test results provide information on the variability of the concrete production process for use in process control.

5.2 The relationship between early-age strength of test specimens and strength achieved at some later age under standard curing depends upon the materials comprising the concrete. In this test method, it is assumed that there is a linear relationship between strength and the logarithm of the maturity index. Experience has shown that this is an acceptable approximation for test ages between 24 h and 28 days under standard curing conditions. The user of this test method should verify that the test data used to develop the prediction equation can be represented by the linear relationship. If the underlying relationship between strength and the logarithm of the maturity index cannot be approximated by a straight line, the principle of this test method may still be used provided an appropriate equation is used to represent the non-linear relationship.

5.3 Strength projections are limited to concretes using the same materials and proportions as the concrete used to establish the prediction equation.

NOTE 1—Confidence intervals developed in accordance with 10.2 are helpful in evaluating projected strengths.

5.4 This test method is not intended for estimating the in-place strength of concrete. Practice C 1074 provides procedures for using the measured in-place maturity index to estimate in-place strength.

6. Apparatus

6.1 *Equipment and Small Tools*, for fabricating specimens and measuring the characteristics of fresh concrete, shall conform to the applicable requirements of Practices C 31/C 31M or C 192.

6.2 *Molds* shall conform to the requirements for cylinder molds in Specification C 470.

6.3 *Temperature Recorder*:

6.3.1 A device is required to monitor and record the temperature of a test specimen as a function of time. Acceptable devices include thermocouples or thermistors connected to continuous chart recorders or digital data-loggers. For digital instruments, the recording time interval shall be ½ h or less for the first 48 h and 1 h or less thereafter. The temperature recording device shall be accurate to within 1°C (±2°F)

6.3.2 Alternative devices include commercial maturity instruments that automatically compute and display the temperature-time factor or the equivalent age as described in Practice C 1074.

NOTE 2—Commercial maturity instruments use specific values of the datum temperature to evaluate the temperature-time factor or of the Q-value to evaluate equivalent age. Refer to the Appendix of Practice C 1074 for additional explanation and recommendations.

7. Sampling

7.1 Sample and measure the properties of the fresh concrete in accordance with Practices C 31/C 31M or C 192.

8. Procedure for Early-Age and Projected Strengths

8.1 Mold and cure the specimens in accordance with the standard curing procedure in Practice C 31/C 31M or in accordance with Practice C 192 whichever is applicable. Record the time when molding of the specimens is completed.

8.2 Embed a temperature sensor into the center of one of the specimens of the sampled concrete. Activate the temperature recording device. Continue curing for at least 24 h. Maintain a record of the concrete temperature during the entire curing period.

8.3 *Capping and Testing*—Remove the specimens from the molds as soon as practical after 24 h. Cap the specimens in accordance with Practice C 617 or Practice C 1231.

8.3.1 The capping materials, if used, shall develop, at the age of 30 min, a strength equal to or greater than the strength of the cylinders to be tested.

8.3.2 Do not test specimens sooner than 30 min after capping.

8.4 Determine the cylinder compressive strength in accordance with Test Method C 39 at an age of 24 h or later. Record the strength and the age at the time of the test. The age of the cylinder is measured to the nearest 15 min from the time of molding. Strength at each test age shall be the average strength of at least two cylinders.

8.5 Determine the maturity index at the time of test by using the manual procedure described in the section titled Maturity Functions in Practice C 1074 or by using a maturity instrument. Record the maturity index, m, of the early-age test specimens.

8.6 When the data representing the compressive strength and the maturity index, m, are to be used to project the strength of the concrete at some later age, determine the projected strength by using the prediction equation determined in Section 9.

9. Procedure for Developing Prediction Equation

9.1 Develop a prediction equation for each concrete to be

[5] For additional information, see *Significance of Tests and Properties of Concrete and Concrete-Making Materials, ASTM STP 169C*, Chapter 15, "Prediction of Potential Concrete Strength at Later Ages," 1994.

used on the job. Prepare specimens in accordance with Practice C 192. Use the procedure in Section 8 to obtain compressive strength values and the corresponding maturity indices at the times of testing. These data shall include tests at ages of 24 h, 3, 7, 14, and 28 days. If the age for which the projected strength is to be determined exceeds 28 days, the data shall include tests at the desired later age (see 5.2). Strength at each age shall be the average strength of at least two cylinders.

9.1.1 Field data may also be used, provided they furnish all of the information in 9.1, and provided the specimens are cured in accordance with the sections of Practice C 31/C 31M dealing with standard curing.

9.2 The constant b for use in the prediction equation (Eq 1) is established using one of two alternative methods: (*1*) by regression analysis, or (2) by manual plotting.

9.2.1 *Regression Analysis*—Convert the values of the maturity indices by taking their logarithms. Plot the average cylinder strength versus the logarithm of the maturity index. Compute the best-fit straight line to the points using an appropriate calculator or computer program. The straight line has the following equation:

$$S_m = a + b \log m \tag{2}$$

where:
S_m = compressive strength at m,
a = intercept of line,
b = slope of line, and
m = maturity index.

Plot the best-fit straight line on the same graph as the data to verify that the correct equation has been determined.

9.2.2 *Manual Plotting*—Prepare a sheet of semi-log graph paper with the y-axis representing compressive strength and the logarithmic scale (x-axis) representing the maturity index (Note 3). Plot the strength values from 9.1 versus the corresponding maturity index. Determine the best-fitting straight line by drawing a line that visually minimizes the distances between the points and the line. The slope of the line is the vertical distance, in units of stress, between the intersection of the line with the beginning and the end of one cycle on the x-axis (see Fig. X1.1). This slope is the value of b for use in the prediction equation (Eq 1).

NOTE 3—The scale for the y-axis and the number of cycles in the semi-log graph paper should be chosen so that the data fill up as much of the paper as possible. When the maturity index is expressed as the temperature-time factor in 'degree'-hours, three cycles should be appropriate. If the maturity index is expressed as the equivalent age in hours, two cycles should be appropriate.

9.3 Use the constant, b, and Eq 1 to determine the projected strength based on early-age test results.

NOTE 4—If it is desired to check the accuracy of the first estimate of the value of b, fabricate companion specimens to those for testing at an early age, cure them in accordance with the standard curing procedure in Practice C 31/C 31M, record their temperature histories and test them at 28 days. The value of b may be re-estimated by use of the equation:

$$b = \frac{\Sigma(S - S_m)}{\Sigma(\log M - \log m)} \tag{3}$$

where:
S = measured compressive strength at M,
M = maturity index corresponding to test at 28 days,
S_m = measured compressive strength at m, and
m = maturity index corresponding to early-age test.

10. Interpretation of Results

10.1 As stated in Section 12, the variability of early-age compressive strength obtained by this test method is the same or less than that obtained from traditional test methods. Thus results can be used for rapid assessment of variability for process control and signaling the need for adjustments. Use of the results from this test method to predict specification compliance of strengths at later ages must be applied with caution because strength requirements in existing specifications and codes are not based upon early-age testing.

10.2 It may be desirable to develop a one-sided confidence interval for the projected strength for use in the acceptance decision. The confidence interval is based on the measured differences between projected and measured strengths at a designated age. Usually such an interval is developed at a 95 % confidence level, and the decision would be to accept the concrete as conforming to specification requirements if the following condition is satisfied:

$$S_M > (S_L + K) \tag{4}$$

where:
S_M = projected strength at designated age,
S_L = specified lower limit, specifically, the specified strength at the designated age,

$$K = \bar{d} + t_{0.95, n-1} \frac{s_d}{\sqrt{n}} \tag{5}$$

$\bar{d}$ = average difference between the measured and projected strength.

$$\bar{d} = \frac{\sum_{i=1}^{n} (S_M - S)_i}{n} = \frac{\sum_{i=1}^{n} d_i}{n} \tag{6}$$

S = measured strength after standard curing up to designated age,
d_i = the difference between the ith pair of strength values,
n = number of paired (S_M and S) values used in the analysis,
$t_{0.95,n-1}$ = value from the t-distribution at the 95 % level for $n - 1$ degrees of freedom, and
s_d = standard deviation for the difference between the measured and projected strengths.

$$s_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \bar{d})^2}{(n - 1)}} \tag{7}$$

11. Report

11.1 The report of the early-age test results shall include the following:

11.1.1 Identification number of test cylinder,

11.1.2 Diameter of test cylinder, mm (in.),

11.1.3 Cross-sectional area of test cylinder, mm^2 ($in.^2$),

11.1.4 Maximum test load on cylinder, N (lb),

11.1.5 Compressive strength of cylinder calculated to the nearest 0.1 MPa (10 psi),

11.1.6 Type of fracture of cylinder, if other than the usual cone,

11.1.7 Age of cylinder at the time of test,

11.1.8 Initial mix temperature to the nearest 1°C (2°F),

11.1.9 Temperature records, and

11.1.10 Method of transportation used for shipping the specimens to the laboratory.

11.2 If the early-age strength data are used to project later-age strength, the report shall include the following:

11.2.1 The maturity index, *m*, of the early-age specimens at the time of test,

11.2.2 The age of the projected strength, and

11.2.3 The projected strength calculated to the nearest 0.1 MPa (10 psi).

12. Precision and Bias

12.1 *Precision*:

12.1.1 The data used to prepare the following precision statements were obtained using measurements in the inch-pound system.

12.1.2 The single laboratory coefficient of variation has been determined as 3.6 % for a pair of cylinders (152 by 305 mm (6 by 12 in.)) cast from the same batch. Therefore, results of two properly conducted strength tests by the same laboratory on two individual cylinders made with the same materials should not differ more than 10 % of their average (Note 5).

12.1.3 The single-laboratory, multi-day coefficient of variation has been determined as 8.7 % for the average of pairs of cylinders (152 by 305 mm (6 by 12 in.)) cast from single batches mixed on two days. Therefore, results of two properly conducted strength tests each consisting of the average of two cylinders from the same batch made in the same laboratory on different days with the same materials and proportions should not differ by more than 25 % of their average (Note 5).

NOTE 5—These numbers represent, respectively, the (1s %) and d2s %) limits as described in Practice C 670.

12.2 *Bias*—This test method has no determinable bias as the values obtained can only be defined in terms of this test method.

13. Keywords

13.1 compressive strength; early-age strength; maturity; potential strength; projected strength

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE OF USE

X1.1 *Development of Prediction Equation:*

X1.1.1 To establish a reliable relationship between strength and the maturity index, concrete must be made from the actual materials, including admixtures, to be used in the work. While field data may be used, the initial data will normally originate in the laboratory before field production begins. Compressive strength specimens will, therefore, normally be made and cured in the laboratory and tested at ages of 24 h, 3, 7, 14, and 28 days. It is suggested that a minimum of 14 cylinders be made and cured in accordance with Practice C 192.

X1.1.1.1 *Example Data*—An example of age-strength data obtained from test cylinders (two at each age) is as follows:

Age	Average Strength, psi
24 h	1370
3 days	2480
7 days	3160
14 days	3710
28 days	4250

X1.1.1.2 In this example, the temperature-time factor, with a datum temperature of 0°C (32°F), is used as the maturity index. Refer to Practice C 1074 for additional information. The temperature-time factor may be calculated from the measured temperature history of the concrete by dividing the age into suitable time intervals and summing the products of the time intervals and the corresponding average temperatures for each interval. For this example, it is assumed that the concrete temperature is 21°C (70°F) prior to stripping the molds and is 23°C (73°F) thereafter. The cumulative temperature-time factor at the various test ages is calculated as shown in Table X1.1.

X1.1.2 The strength data shown in X1.1.1.1 and the temperature-time factor values in Table X1.1 can be plotted using semi-log axes as shown in Fig. X1.1, which is a computer generated plot.

X1.1.3 Determine the best-fit straight line through the plotted points. In this example, the straight line was obtained by regression analysis using a computer program. This line represents the prediction equation which is the assumed relationship between strength and the temperature-time factor for this particular concrete. The equation for this straight line can be expressed in the following form:

$$S_M = S_m + b\,(\log M - \log m) \tag{X1.1}$$

where S_M and S_m are the strengths at values of the temperature-time factor equal to *M* and *m*, respectively.

TABLE X1.1 Temperature-Time Factor at Test Ages

Age, days	Age Increment, (Δ*t*), h	Temperature, T, °C	Temperature-Time Factor Increment, (T-0) × Δ*t*,° C·h	Cumulative Temperature-Time Factor, °C·h (°F·h)
1	24	21	504	504 (907)
3	48	23	1104	1808 (2894)
7	96	23	2208	3816 (6869)
14	168	23	2864	7680 (13 824)
28	336	23	7728	15 408 (27 734

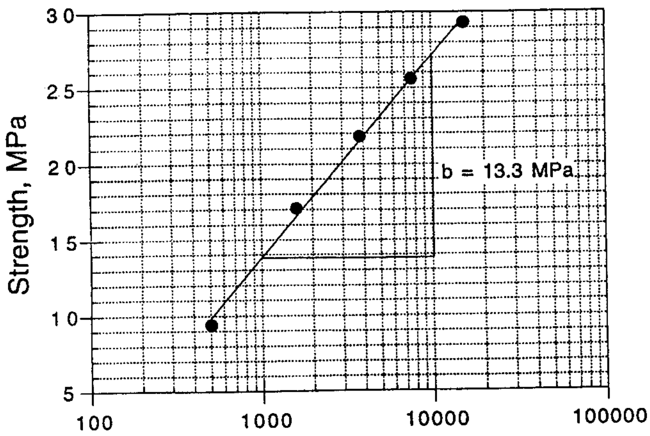

FIG. X1.1 Example Data of Strength as a Function of the Logarithm of the Temperature-Time Factor and the Best-Fit Straight Line that Represents the Prediction Equation

X1.1.4 The value b is the slope of the prediction equation and is the vertical distance, in units of stress, between the intersections of the line with the beginning and the end of one cycle on the x-axis (see Fig. X1.1). For this particular example, b = 13.3 MPa (1930 psi), which represents the strength increase for a tenfold increase in the temperature-time factor.

X1.1.5 Any concrete produced from the same materials and proportions that were used to develop the prediction equation would have the same strength versus temperature-time factor relationship.

X1.2 *Projected Strength:*

X1.2.1 To use the prediction equation to project the strength of field concrete based upon early-age strengths, sample and test the fresh concrete in accordance with Practice C 31. Mold and cure at least three specimens in accordance with the standard curing procedure in Practice C 31. Install a temperature recording device into a cylinder to monitor the concrete temperature. Continue curing for at least 24 h.

X1.2.2 As soon as practical after the minimum 24-h curing period, remove the specimens from the molds and prepare for testing in accordance with Test Method C 39. Record the age at the time of test. Use this age, together with the recorded temperature history, to determine the maturity index, m, at time of test. Report the early-age compressive strength, S_m, as the average of the cylinders tested. The prediction equation can be used to project the strength of the concrete represented by the test specimens.

X1.2.3 As an example:

X1.2.3.1 Compressive strength specimens fabricated in the field were cured for 24 h under standard conditions at the job site. At an age of 24 h, the specimens were removed from their molds, capped, and the caps were allowed to harden. The cylinders were tested at an age of 26 h. The average strength at this age was 9.8 MPa (1420 psi).

X1.2.3.2 Columns 1 and 2 in Table X1.2 show the recorded temperature history obtained from the instrumented specimen. The sixth column shows the increment of temperature-time factor during each age interval. The last column shows the cumulative temperature-time factor. At an age of 26 h, the cumulative temperature-time factor m is 616°C·h (1109°F·h).

X1.2.3.3 The temperature-time factor after 28 days of curing at the standard temperature of 23°C (73°F) is:

$$M = (23 - 0)°C \times 28 \text{ days} \times 24 \text{ h} = 15\,456°C \cdot h \; (27\,829°F \cdot h) \tag{X1.2}$$

X1.2.3.4 The projected 28-day strength is calculated as:

$$S_M = S_m + b(\log M - \log m)$$
$$S_M = 9.8 + 13.3\ (\log 15\,546 - \log 616)$$
$$S_M = 9.8 + (4.189 - 2.790)$$
$$S_M = 9.8 + 18.6$$
$$S_M = 28.4 \text{ MPa } (4120 \text{ psi})$$

Therefore, had the specimens been cured at 23°C (73°F) for the full 28 days, their expected average compressive strength would be 28.4 MPa (4120 psi) if tested at 28 days.

TABLE X1.2 Example Temperature Record and Calculations to Determine the Temperature-Time Factor at Test Age

(1) Age, h	(2) Temperature,° C	(3) Age Interval, Δt, h	(4) Average Temperature During Age Interval, °C	(5) Temperature – 0°C,° C	(6) Temperature-Time Factor Increment, °C·h	(7) Cumulative Temperature-Time Factor, °C·h (°F·h)
0	21					
1	21	1	21.0	21.0	21.0	21 (38)
2	20	1	20.5	20.5	20.5	42 (75)
3	20	1	20.0	20.0	20.0	62 (111)
4	21	1	20.5	20.5	20.5	82 (148)
10	24	6	22.5	22.5	135.0	217 (391)
11	24	1	24.0	24.0	24.0	241 (434)
12	25	1	24.5	24.5	24.5	266 (478)
14	25	2	25.0	25.0	50.0	316 (568)
15	26	1	25.5	25.5	25.5	341 (614)
20	26	5	26.0	26.0	130.0	471 (848)
21	25	1	25.5	25.5	25.5	497 (894)
22	25	1	25.0	25.0	25.0	522 (939)
23	24	1	24.5	24.5	24.5	546 (983)
24	24	1	24.0	24.0	24.0	570 (1026)
25	23	1	23.5	23.5	23.5	594 (1068)
26 (test age)	22	1	22.5	22.5	22.5	616 (1109)