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

This standard is issued under the fixed designation C918/C918M; 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.

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 either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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:*[2]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C470/C470M Specification for Molds for Forming Concrete Test Cylinders Vertically

C617 Practice for Capping Cylindrical Concrete Specimens

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C1074 Practice for Estimating Concrete Strength by the Maturity Method

C1231/C1231M Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Practice C1074 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:

$$S_M = S_m + b(\log M - \log m) \quad (1)$$

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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

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 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 C31/C31M or in accordance with Practice C192/C192M. 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, that is, 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.[3] 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 shall verify that the test data used to develop the prediction equation are represented correctly 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 is applicable 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 C1074 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 C31/C31M or C192/C192M.

6.2 *Molds* shall conform to the requirements for cylinder molds in Specification C470/C470M.

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 C1074.

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 C1074 for additional explanation and recommendations.

7. Sampling

7.1 Sample and measure the properties of the fresh concrete in accordance with Practices C31/C31M or C192/C192M.

8. Procedure for Early-Age and Projected Strengths

8.1 Mold and cure the specimens in accordance with the standard curing procedure in Practice C31/C31M or in accordance with Practice C192/C192M 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 C617 or Practice C1231/C1231M.

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 C39/C39M 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 C1074 or by using a maturity instrument. Record the maturity index, *m*, of the early-age test specimens.

[3] 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.

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 used on the job. Prepare specimens in accordance with Practice C192/C192M. 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 are acceptable, provided they furnish all of the information in 9.1, and provided the specimens are cured in accordance with the section on standard curing of Practice C31/C31M.

9.2 The constant b for use in the prediction equation (see 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 (see 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 (see 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 are generally appropriate. If the maturity index is expressed as the equivalent age in hours, two cycles are 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 C31/C31M, record their temperature histories and test them at 28 days. The value of b is re-estimated by use of the following equation:

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

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 are applicable 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 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 is 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.