Designation: ~~C1074 – 11~~ C1074 – 17

Standard Practice for Estimating Concrete Strength by the Maturity Method[1]

This standard is issued under the fixed designation C1074; 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 practice provides a procedure for estimating concrete strength by means of the maturity method. The maturity index is expressed either in terms of the temperature-time factor or in terms of the equivalent age at a specified temperature.

1.2 This practice requires establishing the strength-maturity relationship of the concrete mixture in the laboratory and recording the temperature history of the concrete for which strength is to be estimated.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.* (**Warning—**Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
~~C78~~C78/C78M Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
C125 Terminology Relating to Concrete and Concrete Aggregates
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
~~C403/C403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance~~
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
~~C684 Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens (Withdrawn 2012)~~[4]
C803/C803M Test Method for Penetration Resistance of Hardened Concrete
C873/C873M Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
C900 Test Method for Pullout Strength of Hardened Concrete
C918/C918M Test Method for Measuring Early-Age Compressive Strength and Projecting Later-Age Strength
C1768/C1768M Practice for Accelerated Curing of Concrete Cylinders

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminology C125.

[1] This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

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[2] Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

[3] 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**

3.2 *Definitions of Terms Specific to This Standard:*

3.1.1 *datum temperature*—the temperature that is subtracted from the measured concrete temperature for calculating the temperature-time factor according to Eq 1.

3.1.2 *equivalent age*—the number of days or hours at a specified temperature required to produce a maturity equal to the maturity achieved by a curing period at temperatures different from the specified temperature.

3.1.3 *maturity*—the extent of the development of a property of a cementitious mixture.

3.1.3.1 *Discussion*—

While the term is used usually to describe the extent of relative strength development, it can also be applied to the evolution of other properties that are dependent on the chemical reactions that occur in a cementitious mixture. At any age, maturity depends on the curing history.

3.1.4 *maturity function*—a mathematical expression that uses the measured temperature history of a cementitious mixture during the curing period to calculate an index that is indicative of the maturity at the end of that period. Refer to Appendix X1 for additional discussion of this term.

3.1.5 *maturity index*—an indicator of maturity that is calculated from the temperature history of the cementitious mixture by using a maturity function.

3.1.5.1 *Discussion*—

The computed index is indicative of maturity provided there has been a sufficient supply of water for hydration or pozzolanic reaction of the cementitious materials during the time used in the calculation. Two widely used maturity indexes are the *temperature-time factor* and the *equivalent age*.

3.2.1 *maturity method*—a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of the maturity index (**1**, **2**, **3**).[4]

3.2.2 *strength-maturity relationship*—an empirical relationship between compressiveconcrete strength and maturity index that is obtained by testing specimens whose temperature history up to the time of test has been recorded.

3.1.8 *temperature-time factor*—the maturity index computed according to Eq 1.

4. Summary of Practice

4.1 A strength-maturity relationship is developed by laboratory tests on the concrete mixture to be used.

4.2 The temperature history of the field concrete, for which strength is to be estimated, is recorded from the time of concrete placement to the time when the strength estimation is desired.

4.3 The recorded temperature history is used to calculate the maturity index of the field concrete.

4.4 Using the calculated maturity index and the strength-maturity relationship, the strength of the field concrete is estimated.

5. Significance and Use

5.1 This practice can be used to estimate the in-place strength of concrete to allow the start of critical construction activities such as: (*1*) removal of formwork and reshoring; (*2*) post-tensioning of tendons; (*3*) termination of cold weather protection; and (*4*) opening of roadways to traffic.

5.2 This practice can be used to estimate strength of laboratory specimens cured under non-standard temperature conditions.

5.3 The major limitations of the maturity method are: (*1*) the concrete must be maintained in a condition that permits cement hydration; (*2*) the method does not take into account the effects of early-age concrete temperature on the long-term strength;strength (**3**, **4**); and (*3*) the method needs to be supplemented by other indications of the potential strength of the concrete mixture.field concrete.

5.4 The accuracy of the estimated strength depends, in part, on using the appropriate maturity function for the particular concrete mixture. Annex A1 provides a procedure for determining experimentally the best parameters (datum temperature or value of *Q*) for the maturity functions described in Section 6.

NOTE 1—Approximate values of the datum temperature, T_o, and the *Q*-value for use in Eq 1 or Eq 2, respectively, are given in Appendix X2. If maximum accuracy of strength estimation is desired, the appropriate values of T_o or *Q* for a specific concrete mixture may be determined using the procedures given in Appendix X1.

[4] The last approved version of this historical standard is referenced on www.astm.org.

[4] The boldface numbers in parentheses refer to the list of references at the end of this practice.standard.

6. Maturity Functions

6.1 There are two alternative functions for computing the maturity index from the measured temperature history of the concrete. Refer to Note 1.

6.2 One maturity function is used to compute the *temperature-time factor* as follows:

$$M(t) = \sum (T_a - T_o) \Delta t \quad (1)$$

where:

$M(t)$ = the temperature-time factor at age t, degree-days or degree-hours,
Δt = a time interval, days or hours,
T_a = average concrete temperature during time interval, Δt, °C, and
T_o = datum temperature, °C.

where:

$M(t)$ = the temperature-time factor at age t, degree-days or degree-hours,
Δt = a time interval, days or hours,
T_a = average concrete temperature during time interval, Δt, °C, and
T_o = datum temperature, °C.

6.3 The other maturity function is used to compute *equivalent age* at a specified temperature as follows (**45**):

$$t_e = \sum e^{-Q\left(\frac{1}{T_a} - \frac{1}{T_s}\right)} \Delta t \quad (2)$$

where:

t_e = equivalent age at a specified temperature T_s, days or h,
Q = activation energy divided by the gas constant, K,
T_a = average temperature of concrete during time interval Δt, K,
T_s = specified temperature, K, and
Δt = time interval, days or h.

NOTE 2—Temperature used in Eq 2 is expressed using the absolute temperature scale. Temperature in kelvin (K) equals approximately temperature °C + 273 °C.

6.4 Approximate values of the datum temperature, T_o, and the activation energy divided by the gas constant, Q, are given in Appendix X1. Where maximum accuracy of strength estimation is desired, the appropriate values of T_o or Q for a specific concrete mixture are determined according to the procedures given in Annex A1.

7. Apparatus

7.1 A device is required to monitor and record the concrete temperature as a function of time and compute the maturity index in accordance with Eq 1 or Eq 2.

NOTE 3—Acceptable devices include commercial maturity instruments that monitor temperature and compute and display either temperature-time factor or equivalent age. Some commercial maturity instruments use fixed values of datum temperature or activation energy in evaluating the maturity index; thus the displayed maturity index may not be indicative of the true value for the concrete mixture being used. Refer to Appendix X1X2 for information on correcting displayed time-temperature values for another value of datum temperature. Equivalent-age values displayed by a maturity instrument cannot be adjusted for another activation energy value.

7.2 Alternative devices include temperature sensors connected to data-loggers, or embedded digital devices that measure, record, and store temperature data as a function of time. The temperature data are used to calculate the maturity index according to Eq 1 or Eq 2.

7.3 The time interval between temperature measurements shall be ½ h 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.

8. Procedure to Develop Strength-Maturity Relationship

8.1 Prepare at least 15 cylindrical specimens according to Practice C192/C192M. The mixture proportions and constituents of the concrete shall be similar to those of the concrete whose strength will be estimated using this practice. If two batches are needed to prepare the required number of cylinders, cast an equal number of cylinders from each batch, and test one cylinder from each batch at the test ages given in 8.4.

8.2 Embed After the specimens are molded, embed temperature sensors to within ±15 mm of the centers of at least two specimens. Immediatelyspecimens (Note 4). After inserting the sensor, tap the side of the cylinder mold with a rubber mallet or the tamping rod so that the fresh concrete comes into contact with the sensor. After tapping is completed, connect the sensors to a maturity instrumentsinstrument or to temperature-recording devices such as data-loggers or strip-chart recorders. a temperature-recording device.

NOTE 4—A method to assist in the proper positioning of the sensor is to insert a small diameter rigid rod into the center of the freshly made cylinder. The rod will push aside any interfering aggregate particles. The rod is removed and the sensor is inserted into the cylinder. The side of the cylinder mold

~~should be tapped with a rubber mallet or the tamping rod to ensure that the concrete comes into contact with the sensor.~~

8.3 Moist cure the specimens in a water bath or in a moist room meeting the requirements of Specification C511.

NOTE 5—Curing under water will aid in reducing temperature differences among test specimens.

8.4 Unless specified otherwise, perform compression tests at ages of 1, 3, 7, 14, and 28 days in accordance with Test Method C39/C39M. Test two specimens at each age and compute the average strength. If the range of compressive strength of the two specimens exceeds 10 % of their average strength, test another cylinder and compute the average of the three tests. If a low test result is due to an obviously defective specimen, discard the low test result.

~~NOTE 4—For concrete mixtures with rapid strength development, or when strength estimates are to be made at low values of maturity index, tests should begin as soon as practicable. Subsequent tests should be scheduled to result in approximately equal increments of strength gain between test ages. At least five test ages should be used.~~

NOTE 6—For concrete mixtures with rapid strength development, or when strength estimates are to be made at low values of maturity index, tests should begin as soon as practicable. Subsequent tests should be scheduled to result in approximately equal increments of strength gain between test ages. At least five test ages should be used.

8.5 At each test age, record the average maturity index for the instrumented specimens.

8.5.1 If maturity instruments are used, record the average of the displayed values.

8.5.2 If temperature recorders are used, evaluate the maturity index according to Eq 1 or Eq 2. Unless specified otherwise, use a time interval (Δt) of ½ h or less for the first 48 h of the temperature record. Longer time intervals are permitted for the relatively constant portion of the subsequent temperature record.

NOTE 7—Judgement should be used in selecting the initial time intervals to record temperature in mixtures that result in rapid changes in early-age temperature due to rapid hydration. Appendix ~~X2~~X3 gives an example of how to evaluate the temperature-time factor or equivalent age from the recorded temperature history of the concrete.

8.6 Plot the average compressive strength as a function of the average value of the maturity index. Draw or calculate a best-fit curve ~~through~~to the ~~data.~~ data (Note 8). The resulting curve is the strength-maturity relationship to be used for estimating the strength of the concrete mixture cured under other temperature conditions. Fig. 1 is an example of a relationship between compressive strength and temperature-time factor, and Fig. 2 is an example of a relationship between compressive strength and equivalent age at 20 °C.

NOTE 8—The strength-maturity relationship can ~~also~~ be established by using regression analysis to determine a best-fit equation to the data. Possible equations that have been found to be suitable for this purpose may be found in Ref. (**3**). A popular equation is to express strength as a linear function of the logarithm of the maturity index (see Fig. 3).

8.7 ~~When~~If specified, a flexural strength versus maturity index relationship is permitted. Prepare at least 15 beam specimens in accordance with Practice C192/C192M. If two batches are needed to prepare the required number of specimens, cast an equal number of beams from each batch, and test one beam from each batch at the test ages given in 8.4. Embed temperature sensors in two specimens, one from each batch if two batches are made. Connect the sensors to maturity instruments or temperature recording devices, and moist cure the specimens in a water bath or in a moist room meeting the requirements of Specification C511~~.~~ (see Note 5). Measure flexural strength in accordance with Test Method ~~C78~~C78/C78M at time intervals of 1, 3, 7, 14 and 28 days, or as specified otherwise ~~(See~~(see Note ~~4~~6). Test two specimens at each age and compute the average strength. If the range of flexural strength of the two specimens exceeds 15 % of their average strength, test another beam and compute the average of the three tests. If a low test result is due to an obviously defective specimen, discard the low test result. Use the same procedures as in 8.5 and 8.6 to develop the flexural strength-maturity relationship.

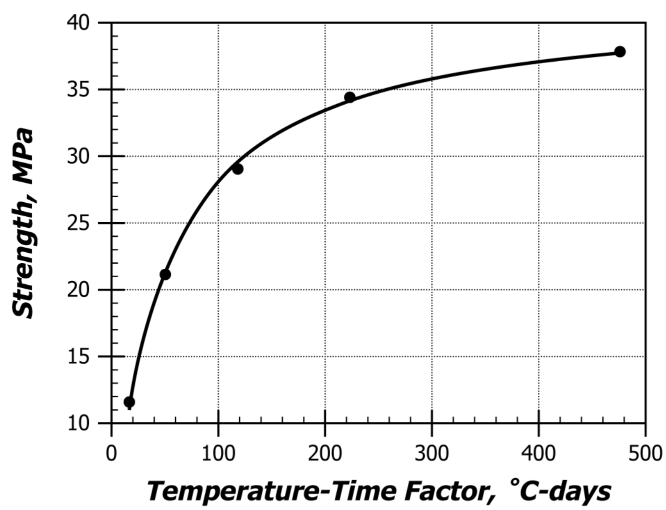

FIG. 1 Example of a Relationship Between Compressive Strength and Temperature-Time Factor

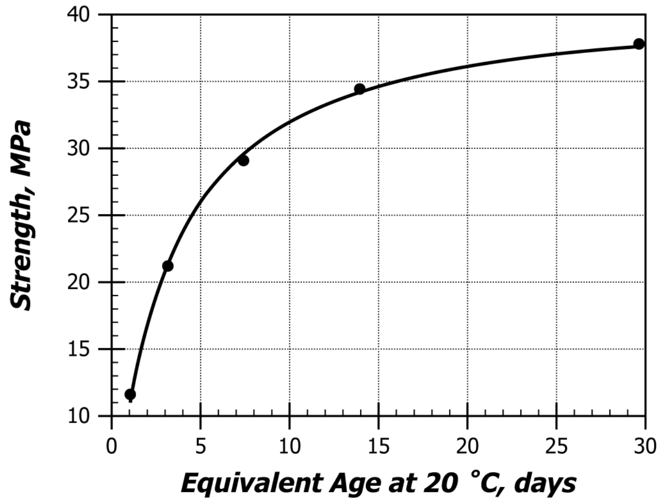

FIG. 2 Example of a Relationship Between Compressive Strength and Equivalent Age at 20 °C

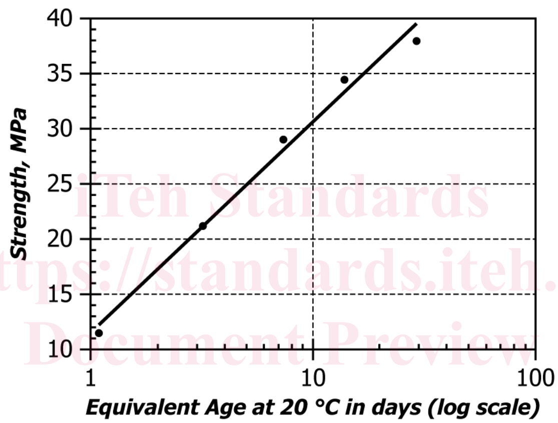

FIG. 3 Example of Compressive Strength as a Function of Logarithm of Equivalent Age

8.8 It is also permitted to develop a relationship between cube strength of concrete and the maturity index. Follow the procedure as given for cylinders except that the cubes ~~should~~ are to be prepared and tested in accordance with the applicable test method. Insert temperature sensors at the centers of at least two cubes. Test two cubes at each test age. In deciding whether to discard a low cube strength result, use the precision statement of the standard test method for cube strength as guidance.

9. Procedure to Estimate In-Place Strength

9.1 Secure temperature sensors within the section to be cast before concrete placement, or embed temperature sensors into the fresh concrete as soon as is practicable after concrete placement (see Note ~~7~~9). Place temperature sensing elements so that they will be surrounded by concrete and not be in direct contact with metallic embedments or other features that will be partially exposed to the environment (see Note ~~8~~10). If this practice is used to decide whether critical construction operations may begin, install sensors at locations in the structure that are critical in terms of exposure conditions and structural requirements (see Note ~~9~~11).

NOTE 9—The appropriate method will depend on the type of sensor that is used and the conditions at the construction site. Manufacturer's recommendations provide additional guidance.

NOTE 10—The intent is to avoid placing temperature sensing elements in contact with embedments that are partially exposed to the ambient environment and that could potentially be at a different temperature than the concrete.

NOTE 11—In building construction, exposed portions of slabs and slab-column connections are typically critical locations. The advice of the Engineer should be sought for critical locations in the particular structure under construction.

9.2 Connect the sensors to maturity instruments or temperature-recording devices and activate the recording devices as soon as is practicable. Use the same value of datum temperature or ~~*activation*~~*Q* ~~energy,~~ -value, whichever is applicable, as was used in computing the maturity index during development of the strength-maturity relationship ~~(See~~(see Section 8).

9.3 When the strength at the location of a sensor is to be estimated, read the value of the maturity index from the maturity instrument or evaluate the maturity index from the temperature record.

9.4 Using the strength-maturity relationship developed in Section 8, ~~read off~~ determine the value of compressive (or flexural) strength corresponding to the measured maturity index.

9.5 Before performing critical operations, such as formwork removal or post-tensioning, that are based on estimated strength from the concrete maturity, perform other tests to ensure that the concrete in the structure has a potential strength that is similar to that of the concrete used to develop the strength-maturity relationship. Appropriate techniques include:

9.5.1 In-place tests that give indications of strength, such as Test Method C873/C873M, Test Method C803/C803M, or Test Method C900.

NOTE 12—The latter two test methods require mixture-specific strength relationships to estimate in-place strength.

9.5.2 Early-age compressive strength tests in accordance with Test Method C918/C918M of standard-cured specimens molded from samples of the concrete as-delivered.

9.5.3 Compressive strength tests on specimens molded from samples of the concrete as-delivered and subjected to accelerated curing in accordance with ~~Test Method~~ Practice ~~C684~~C1768/C1768M.

9.5.4 Early-age tests of field-molded cylinders instrumented with maturity instruments. These cylinders shall be subjected to standard curing in accordance with Practice C31/C31M. The early-age strengths are measured after the in-place maturity of the structure indicates that the concrete has attained the target strength on the basis of the strength-maturity relationship. The measured strengths are compared with the strengths estimated from the established strength-maturity relationship and the maturity index of the test cylinders. If the difference consistently exceeds 10 %, a new strength-maturity relationship is to be developed in accordance with Section 8.

~~10. Precision and Bias~~

~~10.1 This practice is used to estimate the in-place strength of concrete based on the measured thermal history at a point in the structure and a previously established strength-maturity relationship. The accuracy of the estimated strength depends on several factors, such as the appropriateness of the maturity function for the specific mixture, the early-age temperature history, and the actual mixture proportions. For this reason, it is not possible to write statements about the precision and bias of the estimated strength.~~

10. Interpretation

10.1 This practice is used to estimate the in-place strength of concrete based on the measured thermal history at a point in the structure and a previously established strength-maturity relationship. The accuracy of the estimated strength depends on several factors, such as the appropriateness of the maturity function for the specific concrete mixture, the in-place early-age temperature history, and the actual mixture proportions of the field concrete. High early-age temperature of the field concrete may reduce the long-term potential strength (**3, 4**). Thus if attainment of specific level of in-place strength is critical, the estimated strength obtained from the strength-maturity relationship needs to be verified in accordance with 9.5.

11. Keywords

11.1 in-place strength; maturity method; nondestructive testing; temperature

~~ANNEX~~

~~(Mandatory Information)~~

~~A1. DETERMINATION OF DATUM TEMPERATURE OR ACTIVATION ENERGY~~

~~A1.1 Procedure~~

~~A1.1.1 The testing required to determine experimentally the datum temperature or the activation energy can be performed using mortar specimens, and the results are applicable to the concrete under investigation (**5, 6, 7**). The basic approach is to establish the compressive strength versus age relationships for mortar specimens cured in water baths maintained at three different temperatures. Two baths are at the maximum and minimum concrete temperatures expected for the in-place concrete during the period when strengths are to be estimated. The third bath temperature is midway between the extremes. Depending on the data analysis procedure that is used, the final setting times of the mortar at the three temperatures may also have to be measured.~~

~~A1.1.2 Proportion a mortar mixture having a fine aggregate-to-cement ratio (by mass) that is the same as the coarse aggregate-to-cement ratio of the concrete mixture under investigation (**6**). The paste shall have the same water-cementitious materials ratio and the same amounts of admixtures that will be used in the concrete.~~