Designation: C1581/C1581M – 16

Standard Test Method for
Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage[1]

1. Scope*

1.1 This test method covers the laboratory determination of the age at cracking and induced tensile stress characteristics of mortar or concrete specimens under restrained shrinkage. The procedure can be used to determine the effects of variations in the proportions and material properties of mortar or concrete on cracking due to both drying shrinkage and deformations caused by autogenous shrinkage and heat of hydration.

1.2 This test method is not intended for expansive materials.

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 *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 to 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])

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C33/C33M Specification for Concrete Aggregates
C125 Terminology Relating to Concrete and Concrete Aggregates
C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C150/C150M Specification for Portland Cement
C171 Specification for Sheet Materials for Curing Concrete
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C387/C387M Specification for Packaged, Dry, Combined Materials for Concrete and High Strength Mortar
C595/C595M Specification for Blended Hydraulic Cements
C1157/C1157M Performance Specification for Hydraulic Cement
C1437 Test Method for Flow of Hydraulic Cement Mortar
F441/F441M Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80

2.2 *ASME Standards:*[4]

B 46.1 Surface Texture (Surface Roughness, Waviness and Lay)

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *age at cracking, n*—the age of each test specimen, measured from the time of casting, when a sudden decrease in strain occurs.

3.2.2 *net strain, n*—the value corresponding to the difference between the strain in the steel ring at each recorded time and the initial strain.

4. Summary of Test Method

4.1 A sample of freshly mixed mortar or concrete is compacted in a circular mold around an instrumented steel ring. The compressive strain developed in the steel ring caused by shrinkage of the mortar or concrete specimen is measured from

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[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.68 on Volume Change.

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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.

[4] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

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

the time of casting (**1-6**).[5] Cracking of the test specimen is indicated by a sudden decrease in the steel ring strain. The age at cracking and the rate of tensile stress development in the test specimen are indicators of the material's resistance to cracking under restrained shrinkage.

5. Significance and Use

5.1 This test method is for relative comparison of materials and is not intended to determine the age at cracking of mortar or concrete in any specific type of structure, configuration, or exposure.

5.2 This test method is applicable to mixtures with aggregates of 13-mm [0.5-in.] maximum nominal size or less.

5.3 This test method is useful for determining the relative likelihood of early-age cracking of different cementitious mixtures and for aiding in the selection of cement-based materials that are less likely to crack under retrained shrinkage. Actual cracking tendency in service depends on many variables including type of structure, degree of restraint, rate of property development, construction and curing methods, and environmental conditions.

5.4 This test method can be used to determine the relative effects of material variations on induced tensile stresses and cracking potential. These variations can include, but are not limited to, aggregate source, aggregate gradation, cement type, cement content, water content, supplementary cementing materials, or chemical admixtures.

5.5 For materials that have not cracked during the test, the rate of tensile stress development at the time the test is terminated provides a basis for comparison of the materials.

6. Apparatus

6.1 *Steel ring*—Structural steel pipe with a wall thickness of 13 ± 1 mm [0.50 ± 0.05 in.], an outside diameter of 330 ± 3 mm [13.0 ± 0.12 in.] and a height of 150 ± 6 mm [6.0 ± 0.25 in.] (see Fig. 1). Machine the inner and outer faces to produce smooth surfaces with a texture of 1.6 micrometres [63 microinches] or finer, as defined in ASME B 46.1.

6.2 *Strain gages*—As a minimum, use two electrical resistance strain gages to monitor the strain development in the steel ring. Each strain gage shall be wired in a quarter-bridge configuration (that is, one leg of a full Wheatstone bridge). See Note 1 for additional information.

6.3 *Data acquisition system*—The data acquisition system shall be compatible with the strain instrumentation and automatically record each strain gage independently. The resolution of the system shall be ±0.0000005 m/m [in./in.]. The system shall be capable of recording strain data at intervals not to exceed 30 minutes.

NOTE 1—Use of a precision resistor, to balance the leg of the bridge, a strain conditioner input module, to complete the other half of the bridge, and a 16-channel interface board has been found to adequately provide the required resolution of the system.

6.4 *Base*—Epoxy-coated plywood or other non-absorptive and non-reactive surface.

6.5 *Outer ring*—Use one of the following alternative materials as the outer ring.

6.5.1 *PVC pipe*—Schedule 80-18 PVC pipe, in accordance with Specification F441/F441M, with a 405 ± 3-mm [16.0 ± 0.12-in.] inside diameter and 150 ± 6-mm [6.0 ± 0.25-in.] height (see Fig. 1).

6.5.2 *Steel outer ring*—3-mm [0.125-in.] thick steel sheeting formed to obtain a 405 ± 3-mm [16.0 ± 0.12-in.] inside diameter and 150 ± 6-mm [6.0 ± 0.25-in.] height.

6.5.3 *Other materials*—Other suitable non-absorptive and non-reactive materials formed to obtain a 405 ± 3-mm [16.0 ± 0.12-in.] inside diameter and 150 ± 6-mm [6.0 ± 0.25-in.] height.

6.6 *Testing environment*—Store the specimens in an environmentally controlled room with constant air temperature of 23.0 ± 2.0 °C [73.5 ± 3.5 °F] and relative humidity of 50 ± 4 %.

7. Materials and Mixing

7.1 *Materials:*

7.1.1 *Cement*—Cement shall conform to Specifications C150/C150M, C595/C595M, or C1157/C1157M.

7.1.2 *Aggregates*—Aggregates shall conform to Specification C33/C33M. The maximum nominal size of the coarse aggregate shall be 13 mm [0.5 in.] or less.

7.2 *Mixing:*

7.2.1 *Concrete mixtures*—Machine mix the concrete as prescribed in Practice C192/C192M.

7.2.2 *Mortar mixtures*—Mix the mortar as prescribed in Specification C387/C387M.

8. Properties of Fresh Mixtures

8.1 *Concrete mixtures*—Samples of freshly mixed concrete shall be tested in accordance with the following methods:

8.1.1 *Density (unit weight) and air content*—Test Method C138/C138M.

8.1.2 *Slump*—Test Method C143/C143M.

8.2 *Mortar mixtures*—Samples of freshly mixed mortar shall be tested in accordance with the following methods:

8.2.1 *Density*—Specification C387/C387M.

8.2.2 *Flow*—Test Method C1437.

9. Specimen Fabrication and Test Setup

9.1 Bond two strain gages at midheight locations on the interior surface of the steel ring along a diameter; that is, mount the second gage diametrically opposite the first gage. Orient the gages to measure strain in the circumferential direction. Follow the manufacturer's procedures for mounting and waterproofing the gages on the steel ring and connecting leadwires to the strain gage tabs.

9.2 *Test specimen mold*—The test specimen mold consists of a base, an inner steel ring and an outer ring.

9.2.1 Fabricate a base for each test specimen as described in Section 6.4. The top surface of each base shall minimize frictional restraint of the specimen.

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[5] The boldface numbers in parenthesis refer to the list of references at the end of this test method.

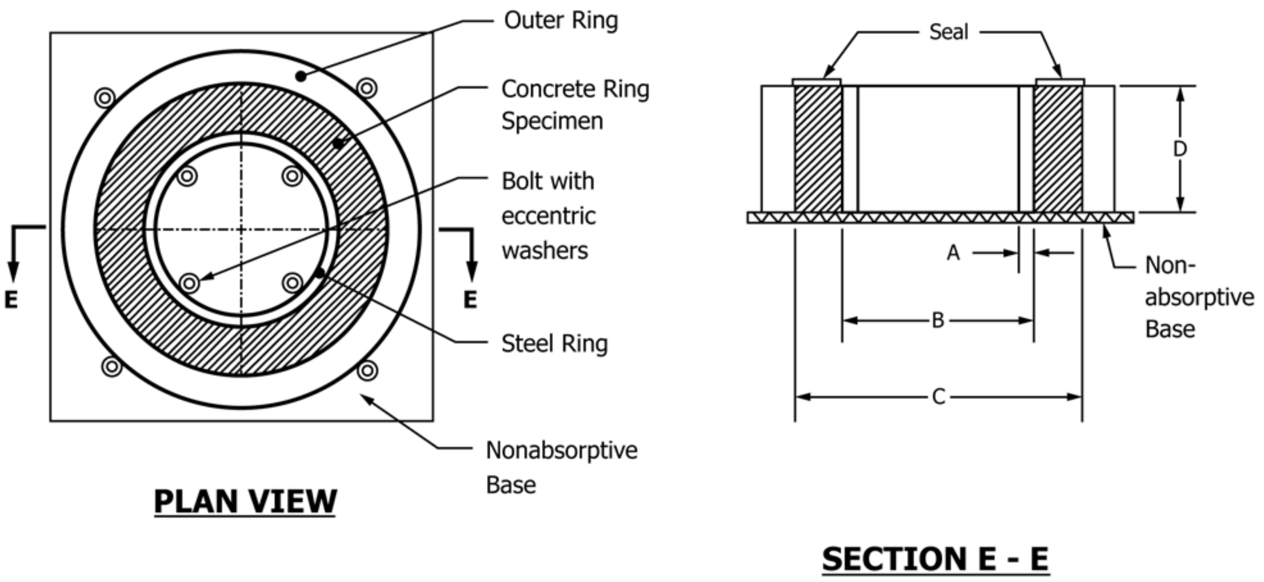

Figure Dimensions	SI Units	Inch-Pound Units
A	13 ± 1 mm	0.50 ± 0.05 in.
B	330 ± 3 mm	13.0 ± 0.12 in.
C	405 ± 3 mm	16.0 ± 0.12 in.
D	150 ± 6 mm	6.0 ± 0.25 in.

Notes:

1. Not to scale.
2. Bolts with eccentric washers for securing steel ring and outer ring to the base during casting of the test specimen (8 required).

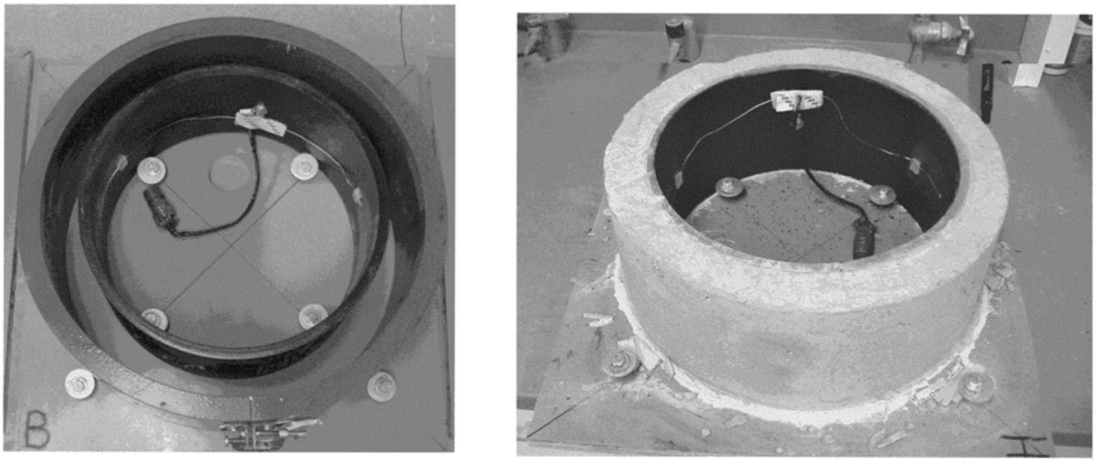

FIG. 1 Test specimen dimensions (top), specimen mold (bottom left), and specimen (bottom right).

NOTE 2—Use of an epoxy coating or a Mylar sheet covering has been found to provide a suitable surface between the test specimen and the base.

9.2.2 Secure the steel ring to the base before casting using bolts with eccentric washers (see Fig. 1).

9.2.2.1 Coat the outer surface of the steel ring with a release agent.

9.2.3 Coat the inner surface of the outer ring with a release agent.

9.2.4 Secure the outer ring to the base to complete the test specimen mold using bolts with eccentric washers. Maintain a 38 ± 1.5-mm [1.50 ± 0.06-in.] space between the inner steel ring and the outer ring (see Fig. 1).

9.3 Make and cure at least three test specimens for each material and test condition following the applicable requirements of Practice C192/C192M. In making a specimen, place the test specimen mold on a vibrating table, fill the mold in two approximately equal layers, rod each layer 75 times using a 10-mm [⅜-in.] diameter rod, and vibrate each layer to consolidate the mixture.

9.4 Strike-off the test specimen surface after consolidation. Finish with the minimum manipulation necessary to achieve a flat surface. Remove any fresh concrete or mortar that has spilled inside the steel ring or outside the outer ring so that the base is clean. Transfer the test specimens to the testing environment within 10 minutes after completion of casting.

9.5 Upon transfer of the test specimens to the testing environment, immediately loosen the bolts with eccentric washers and rotate the washers so they are not in contact with the steel ring and outer ring. Within 2 minutes after loosening the bolts with eccentric washers, connect the strain gage lead-wires to the data acquisition system, record the time, and begin monitoring the strain gages at intervals not greater than 30 minutes. Ensure that the strain gage connecting wires are clean of loose material before making the connections. The time of the first strain measurement is taken as zero age of the specimen.

NOTE 3—Monitoring the strain gages soon after casting provides information on the internal deformations caused by autogenous shrinkage and heat of hydration (**4**).

9.6 *Curing*—Unless otherwise specified, test specimens shall be moist cured in the molds for 24 h at 23.0 ± 2.0 °C [73.5 ± 3.5 °F] using wet burlap covered with polyethylene film meeting the requirements of Specification C171. Begin the curing process within 5 minutes after the first strain reading. If the curing period is longer than 24 h, remove the outer ring at 24 h and continue the curing process.

9.7 At the end of curing and between strain measurements, prepare the test specimens for drying as follows. Complete the test specimen preparation within 15 minutes.

9.7.1 Remove the outer ring, if it is still in place, and/or remove the polyethylene film and burlap.

9.7.2 Gently remove loose material, if present, from the top surface of the test specimen.

9.7.3 Seal the top surface of the test specimen using one of the following alternative procedures.

NOTE 4—With the top surface sealed, and the specimen resting on its base, the test specimen dries from the outer circumferential surface only.

9.7.3.1 *Paraffin wax*—Coat the top surface of the test specimen with molten paraffin wax. Take precautions to ensure that the outer circumference of the test specimen is not coated with the paraffin wax.

NOTE 5—Use of a 40-mm [1.5-in.] wide brush has been found to be an appropriate means of applying the paraffin wax to the top surface of the test specimens.

9.7.3.2 *Adhesive aluminum-foil tape*—Seal the top surface of the test specimen with adhesive aluminum-foil tape.

9.7.4 For the calculations outlined subsequently, the age when drying is initiated is the time when the first strain reading is made after the test specimens have been sealed.

10. Measurement Procedure

10.1 Record the time at the start of strain monitoring as stated in Section 9.5.

10.2 Record ambient temperature and relative humidity of the testing environment every day.

10.3 Monitor the strains in the steel rings at intervals not to exceed 30 minutes, recording the output of each strain gage separately with the data acquisition system. Record both the time and the strain at each measurement. A sudden decrease in compressive strain in one or both strain gages indicates cracking (see Note 6) (**1-5**). Review the strain measurements and visually inspect the specimens for cracking at time intervals not greater than 3 days.

NOTE 6—The sudden decrease in compressive strain at cracking is usually greater than 30 microstrains (see Fig. 2).

10.4 Monitor and record the strain in the steel rings for at least 28 days after initiation of drying, unless cracking occurs prior to 28 days.

10.5 Plot the steel ring strain for each strain gage against specimen age (see Fig. 2).

11. Calculation

11.1 *Age at cracking*—Determine the age at cracking as the age of each test specimen (measured from the time of casting) when a sudden decrease in strain occurs. Report the age at cracking to the nearest 0.25 day. If a test specimen does not crack within the duration of the test, report the result as "no cracking" and record the age when the test was terminated.

11.1.1 *Average age at cracking*—Calculate the average age at cracking for the test specimens to the nearest day.

11.2 *Initial strain*—From the time-strain data for each strain gage, record the initial strain as the strain corresponding to the age when drying was initiated (see Fig. 2).

11.2.1 *Average initial strain*—Calculate the average initial strain for the test specimens.

NOTE 7—The average initial strain indicates the net effect of deformations caused by early-age autogenous shrinkage and heat of hydration under the restrained conditions (**4**).

11.3 *Maximum strain*—From the time-strain data for each strain gage on each test specimen, record the maximum strain as the strain corresponding to the age at cracking or the age when the test is terminated.

11.3.1 When cracking occurs, the maximum strain is the strain value just prior to the sudden decrease in strain (see Fig. 2).

11.4 *Average maximum strain,* ε_{max}—Calculate the average maximum strain for the test specimens.

NOTE 8—The average maximum strain relates to the magnitude of stress buildup in the material under the conditions of restraint provided in this test method.

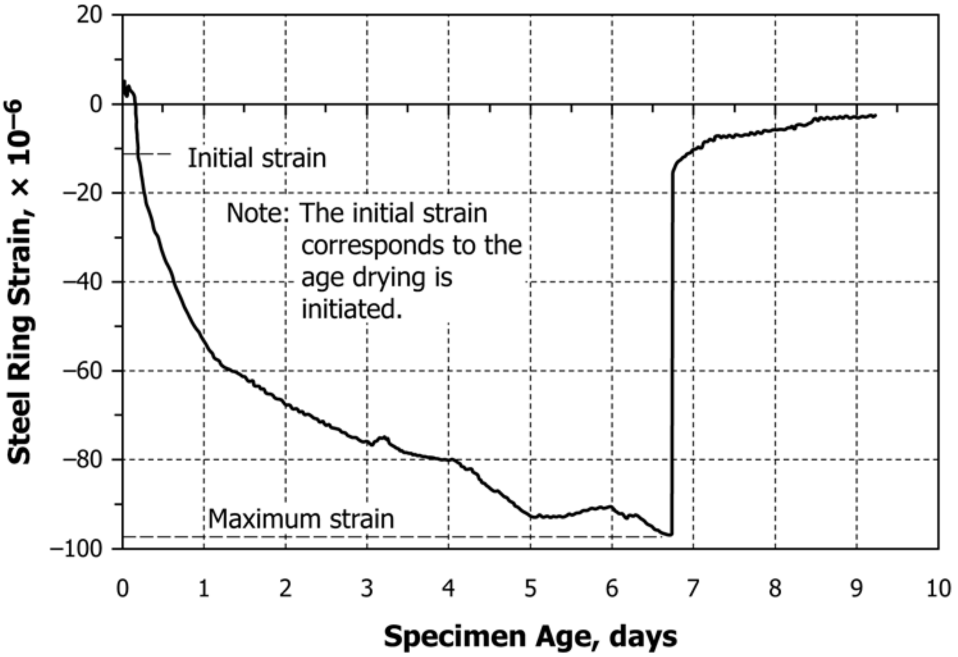

FIG. 2 Steel ring strain versus specimen age.

11.5 *Stress rate, S*—For the test material, use the following procedure to calculate the rate of tensile stress development that corresponds to the age at cracking or the age when the test is terminated (see Section 5.5).

11.5.1 *Elapsed time, t*—Calculate the elapsed time for each test specimen as the difference between each recorded time and the age drying was initiated.

11.5.2 *Net strain*—For each strain gage on the test specimen, calculate the net strain at each recorded time, starting from the age drying was initiated, as the difference between the strain in the steel ring at each recorded time and the initial strain.

11.5.3 *Strain rate factor,* α—Plot the net strain against the square root of elapsed time for each strain gage on the test specimen and use linear regression analysis to fit a straight line through the data. The strain rate factor is the slope of the line (see Eq 1):

$$\varepsilon_{net} = \alpha\sqrt{t} + k \qquad (1)$$

where:

ε_{net} = net strain, m/m [in./in.],
α = strain rate factor for each strain gage on the test specimen (m/m)/day$^{1/2}$ [(in./in.)/day$^{1/2}$],
t = elapsed time, days, and
k = regression constant

NOTE 9—The square root function has been found to consistently provide a good fit to the test data (**3**).

11.5.4 *Average strain rate factor,* α_{avg}—Calculate the average strain rate factor for each test specimen.

11.5.5 *Stress rate, q*—Calculate the stress rate in each test specimen at cracking or at the time the test is terminated (**3**):

$$q = \frac{G\,|\alpha_{avg}|}{2\sqrt{t_r}} \qquad (2)$$

where:

q = stress rate in each test specimen, MPa/day [psi/day],
G = 72.2 GPa [10.47×10^6 psi],
$|\alpha_{avg}|$ = absolute value of the average strain rate factor for each test specimen, (m/m)/day$^{1/2}$ [(in./in.)/day$^{1/2}$], and
t_r = elapsed time at cracking or elapsed time when the test is terminated for each test specimen, days

NOTE 10—G in Eq 2 is a constant based on the ring dimensions used in this test method (**1-4**).

11.5.6 *Average stress rate, S*—Calculate the average stress rate for the test specimens to the nearest 0.01 MPa/day [1 psi/day].

12. Report

Record in the report the following data as pertinent to the variables studied:

12.1 Properties of the material being tested: mixture proportions, air content, slump and density of concrete mixtures, and mixture proportions, flow, and density of mortar mixtures.

12.2 Type and duration of curing;

12.3 Daily ambient temperature and relative humidity data for the test environment;

12.4 Plots of steel ring strain vs. specimen age for each test specimen;

12.5 Average age at cracking;

12.6 Age when the test was terminated for specimens that have not cracked during the test;

12.7 Average initial strain;

12.8 Average maximum strain;

12.9 Plots of net strain vs. square root of elapsed time for each specimen; and

12.10 Average stress rate at cracking or at the time the test was terminated.

13. Precision and Bias

13.1 *Precision*—The precision of this test method has not been determined. The single laboratory repeatability standard deviation of the age at cracking is 2 days. The single laboratory repeatability standard deviation of the stress rate at cracking is 0.03 MPa/day [4 psi/day] for materials with an average stress rate equal to or less than 0.28 MPa/day [40 psi/day]. The single laboratory repeatability standard deviation of the stress rate at cracking is 0.08 MPa/day [11 psi/day] for materials with an average stress rate greater than 0.28 MPa/day [40 psi/day] (**3**).

13.2 *Bias*—No statement on bias is being made since there is no accepted reference material suitable for determining the bias of these procedures.

14. Keywords

14.1 Cracking; restrained shrinkage; ring test; shrinkage; tensile stress.

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF RESULTS

TABLE X1.1 Potential for cracking classification

Net Time-to-Cracking, t_{cr}, days	Average Stress Rate, S (MPa/day)	Average Stress Rate, S (psi/day)	Potential for Cracking
$0 < t_{cr} \le 7$	$S \ge 0.34$	$S \ge 50$	High
$7 < t_{cr} \le 14$	$0.17 \le S < 0.34$	$25 \le S < 50$	Moderate-High
$14\ t_{cr} \le 28$	$0.10 \le S < 0.17$	$15 \le S < 25$	Moderate-Low
$t_{cr} > 28$	$S < 0.10$	$S < 15$	Low

X1.1 *Net Time-to-cracking, t_{cr}*—Calculate the net time-to-cracking for the material as the difference between the age at cracking and the age drying was initiated. Note that if a test material cracks during the period of curing (that is, before drying is initiated), the net time-to-cracking is zero.

X1.2 *Potential for cracking*—A classification table for cracking potential based on the net time-to-cracking and the average stress rate at cracking or at the time the test is terminated is provided to aid in the comparison of materials (**3**).

X1.2.1 The net time-to-cracking classification in Table X1.1 can be used to assess the relative performance of materials that crack during the test.

X1.2.2 For materials with average stress rates lower than 0.10 MPa/day [15 psi/day] that have not cracked during the test, the magnitudes of average stress rate can be compared to assess the relative potential for cracking. This allows for an appropriate comparison of materials where time constraint does not permit testing to be carried out until cracking occurs.

REFERENCES

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(2) Attiogbe, E. K., See, H. T. and Miltenberger, M. A., "Tensile Creep in Restrained Shrinkage," *Creep, Shrinkage and Durability Mechanics of Concrete and other Quasi-Brittle Materials, Proceedings of the Sixth International Conference,* F.J. Ulm, Z.P. Bazant and F.H. Wittmann (eds.), Elsevier Science, Aug. 2001, pp. 651–656.

(3) See, H. T., Attiogbe, E. K. and Miltenberger, M. A., "Potential for Restrained Shrinkage Cracking of Concrete and Mortar," *Proceedings of the ASTM Symposium on Early-Age Cracking of Concrete*, Dec. 2003.

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(6) Grzybowski, M. and Shah, S. P., "Shrinkage Cracking of Fiber Reinforced Concrete," *ACI Materials Journal,* V. 87, No. 2, March-April 1990, pp. 138–148.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C1581 – 09a, that may impact the use of this test method. (Approved July 1, 2016.)

(1) Added Section 3.

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