



# Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)<sup>1</sup>

This standard is issued under the fixed designation C 1579; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method compares the surface cracking of fiber reinforced concrete panels with the surface cracking of control concrete panels subjected to prescribed conditions of restraint and moisture loss that are severe enough to produce cracking before final setting of the concrete.

1.2 This test method can be used to compare the plastic shrinkage cracking behavior of different concrete mixtures containing fiber reinforcement.

1.3 The values stated in SI units are to be regarded as 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 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.)<sup>2</sup>*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

**C 125** Terminology Relating to Concrete and Concrete Aggregates

**C 143/C 143M** Test Method for Slump of Hydraulic-Cement Concrete

**C 192/C 192M** Practice for Making and Curing Concrete Test Specimens in the Laboratory

**C 403/C 403M** Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance

**C 670** Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

**C 995** Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.42 on Fiber-Reinforced Concrete.

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<sup>2</sup> Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol. 04.02.

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

## 3. Summary of Test Method

3.1 Panels of control concrete and fiber reinforced concrete are prepared in a prescribed manner and are exposed to controlled drying conditions after finishing. The drying conditions (See **Note 1**) are intended to be severe enough to induce plastic shrinkage cracking in test panels made of control concrete. The evaporation rate from a free water surface is monitored by pans placed next to the panels in the environmental chamber.

**NOTE 1**—An important parameter in this method is the rate of evaporative water loss, which is controlled by the atmospheric conditions surrounding the test specimens. Since the concrete specimens will not always have the same rate of water evaporation as the pan of water (due to evaporative and bleeding effects), the rate of evaporation of 1.0 kg/m<sup>2</sup>·h from the pan of water represents the minimum evaporation rate that must be attained for this test (**1**).<sup>4</sup> The moisture loss from the concrete test panels can also be monitored and reported, however, the rate of evaporation from the free surface of the water in the pan is the parameter that should be used to quantify the drying environment.

3.2 The test is terminated at the time of final setting of the concrete determined in accordance with Test Method **C 403/C 403M**. At 24 h from initial mixing, the average crack width is determined.

3.3 A cracking reduction ratio (CRR) is computed from the average crack width for the fiber-reinforced concrete panels and the average crack width for the control concrete panels.

## 4. Significance and Use

4.1 The test method is intended to evaluate the effects of evaporation, settlement, and early autogenous shrinkage on the plastic shrinkage cracking performance of fiber reinforced concrete up to and for some hours beyond the time of final setting (See Terminology **C 125**).

4.2 The measured values obtained from this test may be used to compare the performance of concretes with different mixture proportions, concretes with and without fibers, concretes containing various amounts of different types of fibers, and concretes containing various amounts and types of admixtures. For meaningful comparisons, the evaporative conditions during test shall be sufficient to produce an average crack width

<sup>4</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

of at least 0.5 mm in the control specimens (2, 5) (See Note 2). In addition, the evaporation rate from a free surface of water shall be within  $\pm 5\%$  for each test.

NOTE 2—To achieve evaporation rates that result in a crack of at least 0.5 mm in the control specimens, it may be necessary to use an evaporation rate higher than that discussed in Note 1.

4.3 This method attempts to control atmospheric variables to quantify the relative performance of a given fresh concrete mixture. Since many other variables such as cement fineness, aggregate gradation, aggregate volume, mixing procedures, slump, air content, concrete temperature and surface finish can also influence potential cracking, attention shall be paid to keep these as consistent as possible from mixture to mixture.

5. Apparatus

5.1 Molds:

5.1.1 For maximum coarse aggregate size equal to or less than 19 mm, use a mold with a depth of  $100 \pm 5$  mm and

rectangular dimensions of  $355 \pm 10$  mm by  $560 \pm 15$  mm (See Fig. 1). The mold can be fabricated from metal, plastic, or plywood.

NOTE 3—If plywood is used for molds, the plywood should have low moisture absorption. The mold should be constructed to be lightweight and stiff. The molds, when properly constructed, should last for approximately 50 uses.

5.1.2 This test method is designed for aggregate less than or equal to 19 mm. For coarse aggregate greater than 19 mm, the depth of the mold shall be at least 65 mm plus at least 2 times the maximum coarse aggregate size.

5.2 Stress Riser and Internal Restraints—The internal restraints and stress riser shall be bent from one piece of sheet metal, as illustrated in Fig. 1, or made from a solid piece of steel. The sheet metal shall have a thickness of  $1.2 \pm 0.05$  mm (18 gauge) (See Fig. 1 and Ref 2). Two  $32 \pm 1$  mm high restraints are placed  $90 \pm 2$  mm inward from each end of the mold. The central stress riser is  $64 \pm 2$  mm high and serves as

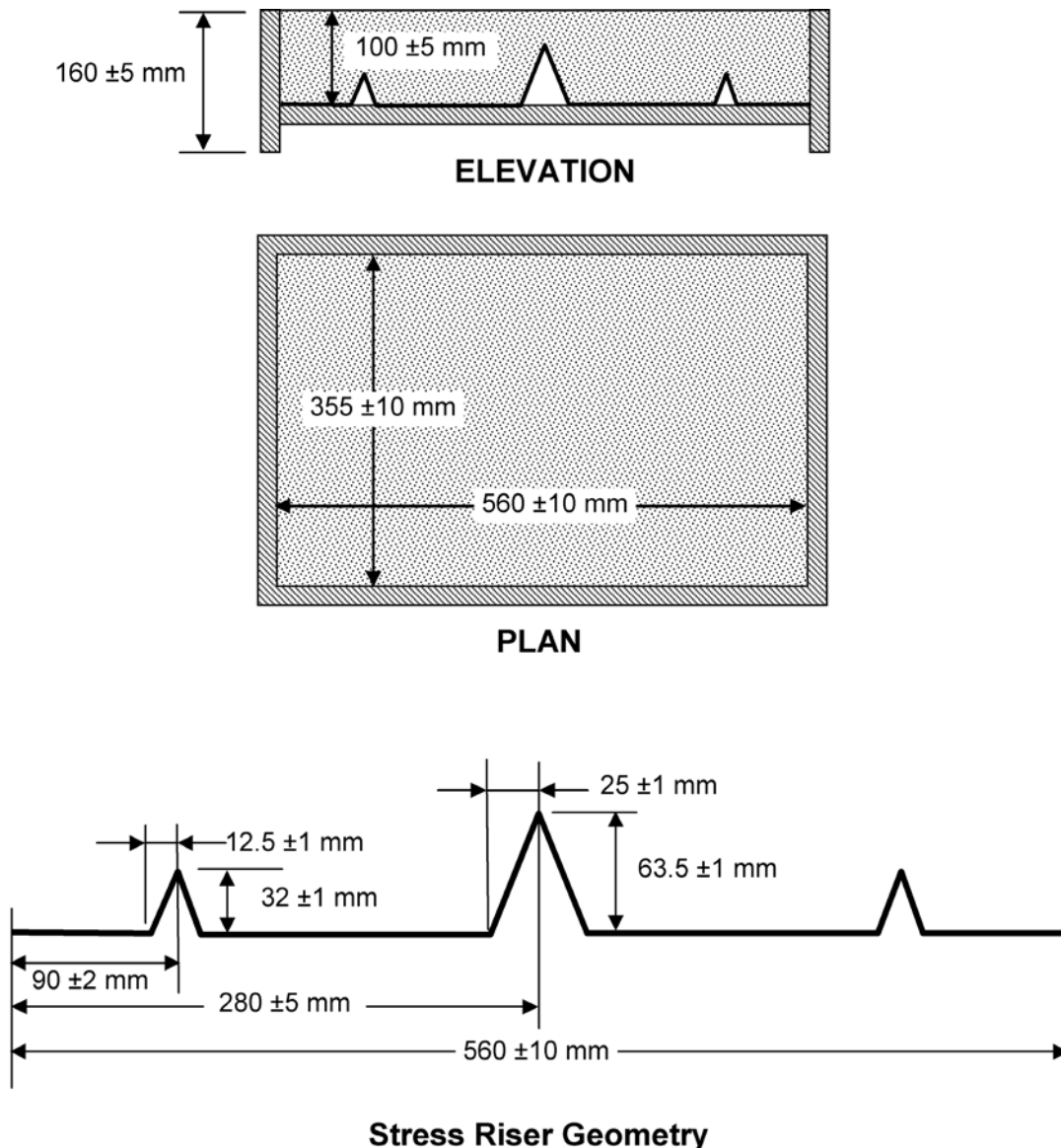


FIG. 1 Specimen and Stress Riser Geometry (4, 5)

an initiation point for cracking. This sheet metal stress riser with internal restraints shall fit at the bottom of the mold.

5.2.1 Use form release oil to coat the metal insert and mold sides to reduce bond with concrete. The insert and mold are considered to be properly oiled when the entire surface is coated and excess oil has been removed with a clean, dry rag.

5.3 *Variable Speed Fan(s)*—The fan(s) used shall be capable of achieving a wind speed of more than 4.7 m/s over the entire test panel surface area.

5.4 *Environmental Chamber*—The use of a fan box in an environmental chamber is a method for producing a uniform airflow over the panel surface (See Fig. 2). A clear cover over the panels will aid in obtaining uniform airflow and allow for observation of cracking. Another method of producing uniform airflow is to use a specifically designed environmental chamber as shown in Fig. 3. A commercially available heater, humidifier, and dehumidifier can be used to maintain the specified environmental condition. This test is conducted using either apparatus shown in Fig. 2 or Fig. 3 by exposing the panels to an evaporation rate of at least 1.0 kg/m<sup>2</sup>·h (See Note 1). For the standard test, the temperature must be maintained at 36 ± 3 °C, the relative humidity must be 30 ± 10 %, and the wind velocity must be sufficient to maintain the minimum evaporation rate during the test.

NOTE 4—Before casting the concrete panels, atmospheric variables in the environmental facility should be checked to determine that the necessary evaporative conditions can be achieved. A wind velocity of 4.7 m/s should be sufficient to achieve the minimum specified evaporation rate, but a higher wind velocity may be needed to obtain sufficient average crack width in some control panels.

5.5 *Sensors*—Use temperature, humidity, and wind velocity sensors to measure ambient air and concrete surface temperature to the nearest 0.5 °C, relative humidity to the nearest 1 %, and air speed to the nearest 0.1 m/s.

5.6 *Vibrating Platform*—Any device that can fully consolidate the test panel that meets minimum frequency requirements as stated in Practice C 192/C 192M for an external vibrator is suitable.

5.7 *Surface Finishing Equipment*—An angle iron screed shall be used for the concrete after vibration. A magnesium, steel, or wood trowel shall be used for finishing the surface of the specimen after screeding.

5.8 *Monitoring Pan*—A pan suitable for exposing water to the air stream for each concrete test panel is required. The sides of the pan shall be vertical. The pan shall be of sufficient size to expose at least 0.1 ± 0.01 m<sup>2</sup> of water to the air stream. The exposed lip of the pan shall not extend more than 5 mm above the water level at the start of the test.

NOTE 5—The test panels and monitoring pans can be placed in an environmental chamber designed for this test method (See Fig. 3) or the pans can be placed downstream from panels in a fan box (See Fig. 2).

5.9 *Scale*—If the rate of moisture loss from test panels is required by the specifier of tests, weigh test panels with a scale having a capacity of at least 100 kg and accurate to within 0.1 % of the test load. Weigh the evaporation rate monitoring pans with a balance or scale having a capacity of at least 3 kg and accurate to within 5 g.

5.10 *Crack Measurement Tool*—Optical hand-held microscope, crack comparator, or image analysis system can be used. The measurement tool should be capable of measuring crack width to at least the nearest 0.05 mm. If an automated image analysis system is used, it should be demonstrated to provide an accurate measurement. To demonstrate the accuracy of the measurement, the system shall be used to measure a 0.5 mm notch that is machined into a piece of steel and the reported notch width shall be within ± 0.05 mm of the machined width.

## 6. Sampling, Test Specimens, and Test Units

6.1 *Test Panels*—Cast test panels in accordance with the applicable provisions of Practice C 192/C 192M, using the same source of materials, preparation, mixing and finishing procedures.

6.2 *Test Unit*—A test unit is comprised of at least two control specimens and at least two fiber reinforced concrete specimens with the same mixture proportions. A group of two control specimens has to be tested each time in order to determine the plastic shrinkage crack reduction of fiber reinforced concrete.

## 7. Procedure

7.1 Determine the slump of each mixture in accordance with Test Method C 143/C 143M. If the slump is too low for a concrete mixture containing fibers, use the time of flow through an inverted slump cone to measure workability in accordance with Test Method C 995.

7.2 Fabricate specimens for setting time determination in accordance with Test Method C 403/C 403M. If fiber reinforced concrete cannot be wet sieved readily, use the control concrete specimen to measure time of final setting of both the control and the fiber-reinforced mixtures. Place the time of setting specimens in the air stream so that they are exposed to the same environmental conditions as the plastic shrinkage panels.

7.3 Fill the panel molds using one layer. Consolidate the concrete with external vibration until the concrete is approximately level with the top of the mold. Screenshot each specimen perpendicular to the stress riser three times.

7.4 After screeding, trowel specimens using a predetermined number of passes. If moisture loss from the panel is to be determined, remove any waste concrete adhering to the outside of the mold and weigh each panel while in the mold.

7.5 Place a fiber reinforced concrete mixture panel and control mixture panel in the environmental chamber downstream from the fan(s) (See arrangements in Figs. 2 and 3).

7.6 Turn on the fan(s), which have been preset to achieve the air speed to obtain the required evaporative conditions (See Note 4). The evaluation of cracking commences at this time.

7.7 At the start of the test and at 30-min intervals, record air temperature, relative humidity, and air flow speed at a location 100 ± 5 mm above each panel surface. If required by the specifier of tests, record the time at which cracking is first observed for each panel surface. Perform penetration tests at regular time intervals according to Test Method C 403/C 403M. Continue recording the environmental variables until the time of final setting.

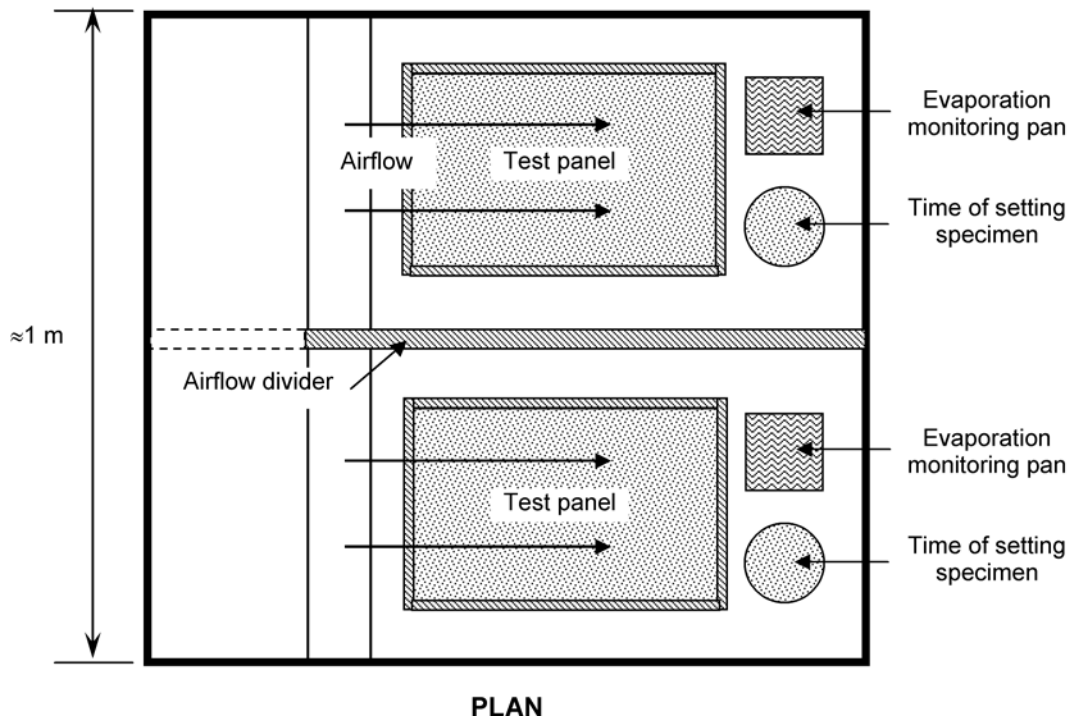
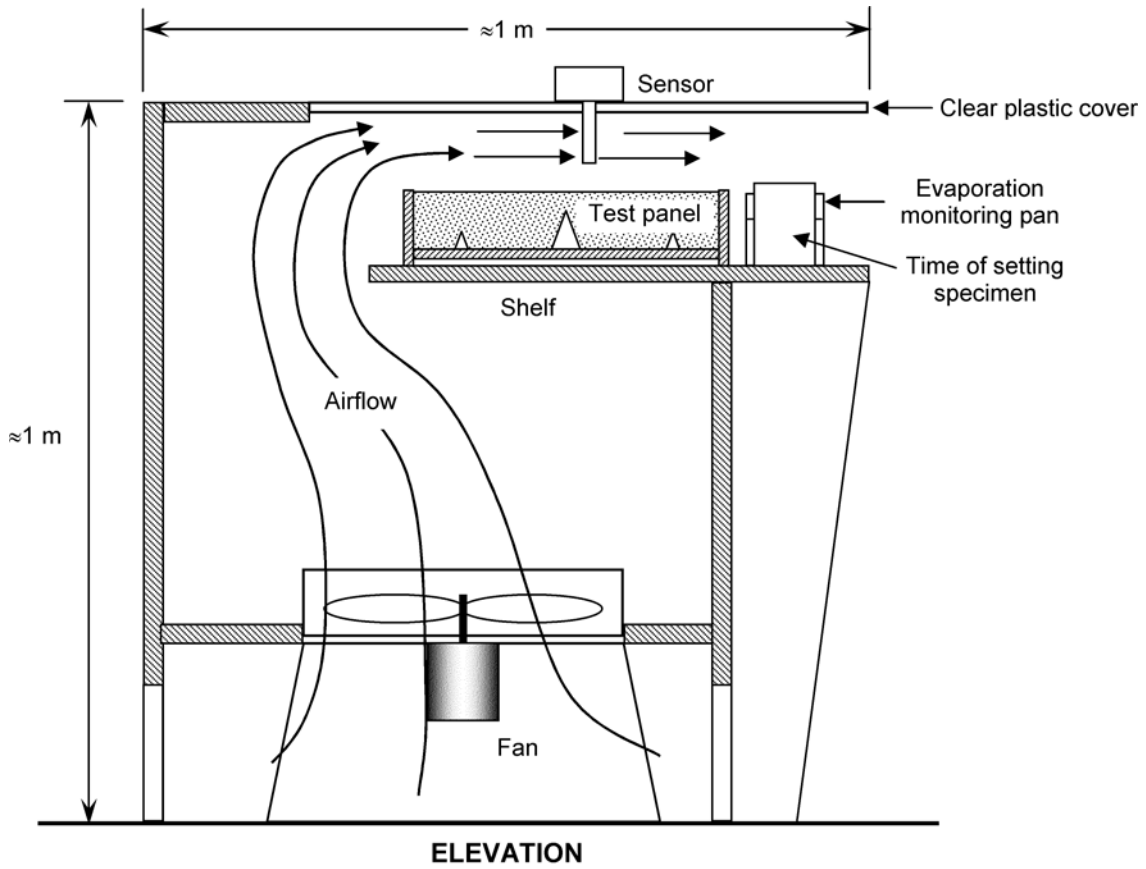
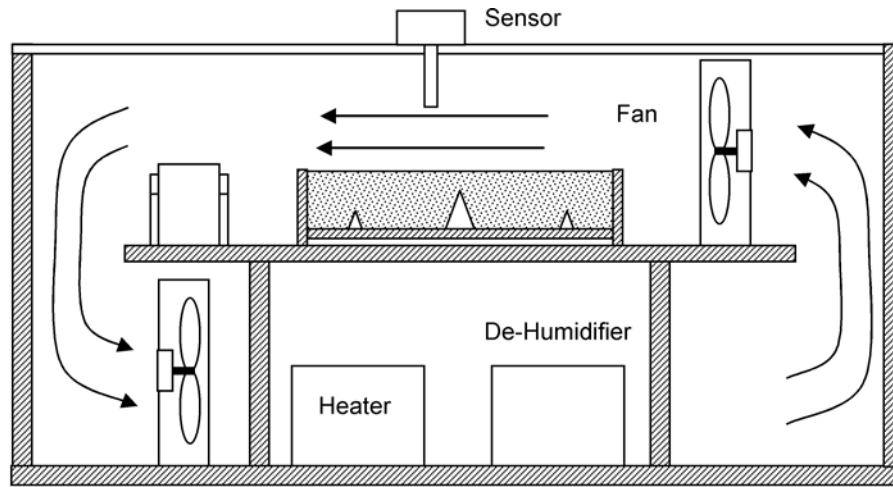
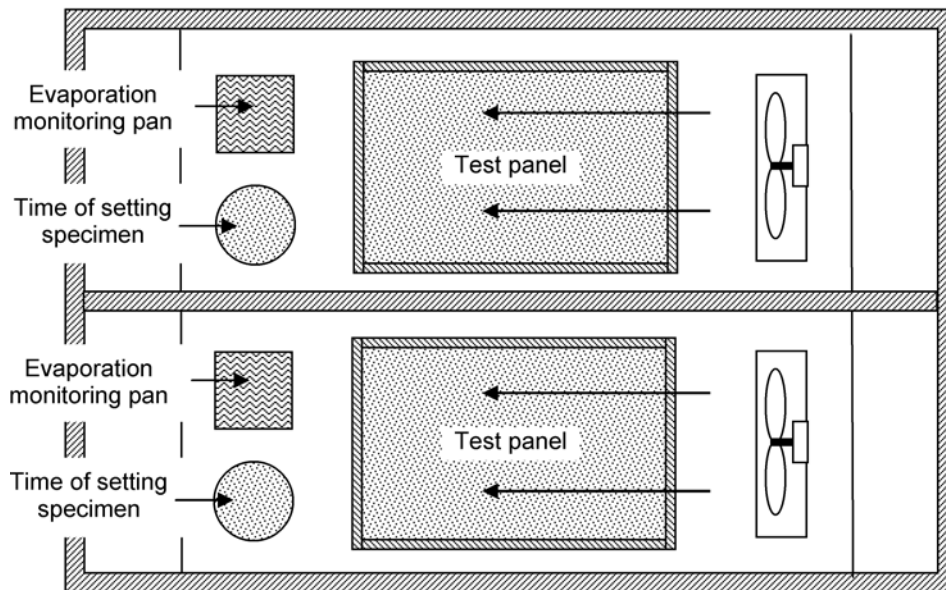


FIG. 2 Example of Fan Box to Maintain Environmental Conditions (2) (Not to Scale)



ELEVATION



PLAN

FIG. 3 Example of Chamber to Maintain Environmental Conditions (4)

7.8 The evaporation rate is determined by initially weighing the full monitoring pans at the start of the test and at 30-min intervals thereafter (3). Record the mass loss to the nearest 5 g at each weighing. To determine the evaporation rate during each time interval, divide the mass loss between successive weighings by the surface area of the water in the weighing pan and the time interval between successive weighings (See Note 6). The test is not valid if the average evaporation rate is less than 1.0 kg/m<sup>2</sup>-h.

NOTE 6—Adjustments to wind velocity should be made if necessary to maintain the evaporation rate at the required level. It is suggested that the

monitoring pans be placed on scales in the air stream for continuous monitoring without periodic removal during testing. If this is not possible, the monitoring pan should be removed from the air stream, weighed, and returned to the air stream within 15 seconds.

7.9 After final setting occurs (use the later of the measured time of setting in the two specimens), record the atmospheric variables, stop the fans, record the time, and determine the total water loss from the monitoring pans. If panel moisture loss is to be determined, weigh the test panels in their molds. Store the

panels in the laboratory at  $23 \pm 2$  °C and under plastic sheets to minimize evaporation until time of crack width measurement.

## 8. Quantification of Cracking

8.1 Quantify the amount of cracking by measuring crack widths at the surface of the panels  $24 \pm 2$  h after mixing.

NOTE 7—Studies have shown that, when panels are covered with plastic, there is no appreciable change in average crack width from a time of six hours to 24 h after mixing (5).

8.2 To avoid possible effects of panel boundaries on crack width, do not measure crack widths within 25 mm of test panel boundaries.

8.3 Measure the width of each crack along the cracking path over the stress riser in a progressive order from one side of the panel to the other. If a manual crack width measuring procedure is used, use a crack comparator or crack microscope to measure crack widths. Measure crack width to the nearest 0.1 mm at  $10 \pm 1$  mm intervals along the length of the crack. Repeat the above procedure until all cracks have been measured. If an imaging analysis procedure is used for crack width measurement, record crack widths over the same measuring distance (See Note 8). Overlap between adjacent images shall be cut off to avoid duplicated measurements (4). Record all crack widths to calculate average crack width.

NOTE 8—A grid mask can be used to sample crack widths at predetermined locations (4).

8.4 Calculate the average crack width to the nearest 0.05 mm. If an average crack width of at least 0.5 mm is not observed on the control panels (average of at least two panels), with no single control panel under 0.4 mm average crack width, the test is not valid. Increase the evaporation rate to achieve this minimal average crack width, and repeat the test (See Note 10).

NOTE 9—Requiring a minimum crack width of the control panel will help to prevent marginal modifications to the concrete mixture from

**TABLE 1 Single-Operator Average Crack Width Repeatability (22 Crack Width Measurements per Panel Using Manual Measurement Procedure)**

NOTE—The results in this table correspond with the behavior of a mixture using a single type of fiber as described in Ref 5.

Mixture Identification	Fiber Volume	Number of Panels	Average Crack Width (mm)	Standard Deviation of Average Crack Width (mm)
A	0 % Fiber	6	0.67	0.04
B	0.05 % Fiber	4	0.44	0.05
C	0.10 % Fiber	4	0.33	0.05
D	0.15 % Fiber	4	0.08	0.04
E	0.20 % Fiber	2	0.03	0.02

showing a statistically significant performance improvement, which may not be sufficient to control cracking under field conditions.

NOTE 10—Refer to ACI 305R (1) for guidance on how wind speed affects evaporation rate.

8.5 Calculate the crack reduction ratio (CRR) using the following equation:

$$CRR = \left[ 1 - \frac{\text{Average Crack Width of Fiber Reinforced Concrete Mixture}}{\text{Average Crack Width of Control Concrete Mixture}} \right] \times 100 \% \quad (1)$$

## 9. Report

9.1 Report the following for each mixture tested:

9.1.1 The mixture proportions in kg/m<sup>3</sup> of water, cement (or cementitious materials): aggregates; admixtures in L/m<sup>3</sup>; water-cement ratio (w/c) to the nearest 0.01; and slump in mm (or time of flow in seconds when used for fiber-reinforced concrete mixtures).

9.1.2 The fiber characteristics (if available) including fiber material, length, cross-sectional area, fiber shape, and addition rate in kg/m<sup>3</sup>.

9.1.3 Length, depth, and width of panels in mm.

9.1.4 Cracking value of each panel as the average crack width to the nearest 0.05 mm.

9.1.5 The temperature, relative humidity, wind velocity, and measured evaporation rate during the test.

9.1.6 If required, the moisture loss of each panel in kilograms of water per square meter of surface (kg/m<sup>2</sup>). Report the time interval between panel weighings.

9.1.7 The cracking reduction ratio (CRR) to the nearest percent (%).

## 10. Precision and Bias

10.1 *Precision*—A multi-laboratory study of precision has not been completed. Information on repeatability of this test method was derived from within-laboratory testing using a single operator and replicate panels (5) (See Practices C 670). Table 1 shows the number of replicate panels, average of the average crack width, and standard deviation of the average crack width for control panels and panels made with concretes having different amounts of fiber. The standard deviation appears to be constant and is used as the measure of repeatability. When three panels were used to determine the Crack Reduction Ratio (CRR), the value of the single operator standard deviation was 4.6 %.

10.2 *Bias*—The procedure for measuring the cracking value has no bias because the cracking value is defined only in terms of this test method.

## 11. Keywords

11.1 crack width; evaporation; fiber-reinforced concrete; plastic shrinkage cracking; restrained shrinkage cracking

## REFERENCES

- (1) “Hot Weather Concreting,” *ACI 305.R-99, ACI Manual of Concrete Practice*, American Concrete Institute, Farmington Hills, MI, 2004.
- (2) Berke, N. S., and Dalliare, M. P., “The Effect of Low Addition Rate of Polypropylene Fibers on Plastic Shrinkage Cracking and Mechanical Properties of Concrete,” *Fiber Reinforced Concrete: Development and Innovations, ACI SP-142*, American Concrete Institute, Farmington Hills, MI, 1994, pp.19-41.
- (3) Nanni, A., Ludwig, D. A., and Mcgillis, M. T., “Plastic Shrinkage Cracking of Restrained Fiber-Reinforced Concrete,” *Transportation Research Record*, 1382, 1993, pp. 69-72.
- (4) Qi, C., Weiss, J., and Olek, J., “Characterization of Plastic Shrinkage Cracking in Fiber-Reinforced Concrete Using Semi-Automated Image Analysis,” *RILEM Materials and Structures*, Vol 36, No. 260, July 2003, pp. 386-395.
- (5) Qi, C., Weiss, J., and Olek, J., “Statistical Significance of the Restrained Slab with a Stress Riser for Quantifying Plastic Cracking in Fiber Reinforced Concrete,” *ASTM Journal of Testing and Evaluation*, July 2005.

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