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## Standard Test Methods for Self-leveling Mortars Containing Hydraulic Cements<sup>1</sup>

This standard is issued under the fixed designation C1708/C1708M; 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 reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

### 1. Scope\*

1.1 These test methods are appropriate to evaluate the performance of self-leveling mortars containing hydraulic cements that are used to improve the levelness, smoothness, and flatness of existing floors. These materials may be used as an underlayment to receive floor finishes, or as an overlayment to serve as the wear surface. The self-leveling mortars covered by these test methods consist of proprietary blends of hydraulic cements, along with fine aggregate, polymers, fillers, and other additives.

1.2 *Units*—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~~ are not ~~be~~ necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other. Combining other, and values from the two systems may result in non-conformance with the standard. Some values have only SI units because the inch-pound equivalents are not used in practice shall not be combined.

1.3 *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>

1.4 *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:<sup>3</sup>

[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](#)

[C157/C157M Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete](#)

[C191 Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle](#)

[C305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency](#)

[C348 Test Method for Flexural Strength of Hydraulic-Cement Mortars](#)

[C490/C490M Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete](#)

[C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes](#)

[C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials](#)

[C778 Specification for Standard Sand](#)

[C928/C928M Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs](#)

[C1005 Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements](#)

[C1107/C1107M Specification for Packaged Dry, Hydraulic-Cement Grout \(Nonshrink\)](#)

[C1803 Guide for Abrasion Resistance of Mortar Surfaces Using a Rotary Platform Abraser](#)

<sup>1</sup> These test methods are under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and are the direct responsibility of Subcommittee C09.43 on Packaged Dry Combined Materials.

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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, 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

D1200 Test Method for Viscosity by Ford Viscosity Cup

D5125 Test Method for Viscosity of Paints and Related Materials by ISO Flow Cups

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

### 3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, refer to Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *flow, n—of self-leveling mortars*, the ability of a freshly-mixed, self-leveling mortar to spread under its own weight or flow through an orifice.

3.2.2 *healing, n—of self-leveling mortars*, the ability of a self-leveling mortar to return to its original state of levelness and smoothness after a specified cut is introduced into the surface.

3.2.2.1 *Discussion*—

The specified cut is described in 8.4.4.3.

3.2.3 *mortar, self-leveling, n*—mortar containing hydraulic cement that, in the fresh state, exhibits flow sufficient to seek gravitational leveling.

3.2.4 *overlayment, n—in flooring*, a layer of material usually placed upon the sub-floor that provides a smooth, even surface to be left exposed as the wear surface of the floor.

3.2.5 *time, healing, n—of self-leveling mortars*, the period from the starting time until the moment when a specified cut leaves no observable indentation or ridge on the surface after setting.

3.2.5.1 *Discussion*—

The specified cut is described in 8.4.4.3.

3.2.6 *time, starting, n—of self-leveling mortars*, the time when water is brought into contact with the dry ingredients of a self-leveling mortar.

3.2.7 *underlayment, n—in flooring*, a layer of material usually placed upon the sub-floor that provides a smooth, even base for flooring.

### 4. Significance and Use

4.1 The test methods in this standard are used to evaluate freshly mixed properties such as the initial flow, flow retention, and healing time as well as hardened properties such as compressive strength, setting time, and flexural strength, of self-leveling mortars.

4.2 Tests are conducted under standardized conditions for comparative purposes and results are not intended to be representative of performance under field conditions.

### 5. Standard Laboratory Conditions

5.1 Unless otherwise specified, curing and testing of specimens shall be conducted at standard laboratory conditions which are defined as  $23.0 \pm 2.0$  °C [ $73.5 \pm 3.5$  °F] and the relative humidity of the laboratory shall be not less than 50 %. The self leveling mortar dry powder and mixing liquid must be equilibrated to  $23.0 \pm 2.0$  °C [ $73.5 \pm 3.5$  °F] prior to mixing. For optional tests at the manufacturer's stated temperature extremes, the curing and testing temperatures must be within  $\pm 2.0$  °C [ $\pm 3.5$  °F] of the stated extreme temperatures.

### 6. Sampling

6.1 Sample according to the Sampling section of Specification C1107/C1107M.

### 7. Mixing

7.1 *Apparatus*

7.1.1 Use the mixer and scraper as specified in Practice C305. The standard batch size is 3000 g (See Note 1) of dry self-leveling mortar. Use a splash guard to prevent excessive splashing.

**Warning**—The clearances between the paddle and the bowl specified in Practice C305 are suitable when using mortar made with standard sand as described in Specification C778. To permit the mixer to operate freely and to avoid serious damage to the paddle and bowl when coarser aggregates are used, it may be necessary to set the clearance adjustment bracket to provide greater clearances than those specified in 4.1 of Practice C305.

7.1.2 Weighing devices used in determining the mass of materials shall conform to Specification **C1005**.

7.1.3 A timer accurate to 1 s with a range of at least 60 min.

NOTE 1—This batch size is used for self-leveling mortars with a typical freshly mixed density of approximately 1920 kg/m<sup>3</sup> [120 lb/ft<sup>3</sup>]. Adjust the batch size as needed to accommodate densities significantly different from the typical value.

## 7.2 Procedure

7.2.1 Mix the self-leveling mortar with liquid as prescribed by the manufacturer. In the absence of manufacturer's instructions the liquid content shall be adjusted to achieve an initial flow of 125 to 150 mm [5 to 6 in.] as per **8.4**.

NOTE 2—Water is the most common mixing liquid although latex admixtures or other liquids may be recommended by some manufacturers.

7.2.2 Add the entire quantity of mixing liquid to the bowl. Start the mixer on speed 1 and start the timer. Mix times are to be observed within  $\pm 5$  s of the recommended times.

7.2.3 Add the dry self-leveling mortar to the mixer while mixing at speed 1 during the first 30 s. (0-30 s on timer)

7.2.4 Mix for an additional 30 s period, at speed 1. (30-60 s on timer)

7.2.5 Stop the mixer and quickly scrape down into the batch any mortar that may have collected on the side of the bowl or blade. This must be completed within 30 s (60-90 s on timer)

7.2.6 Mix at speed 2 for 240 s. (90-330 s on timer)

7.2.7 In any case requiring a remixing interval, any mortar adhering to the side of the bowl shall be quickly scraped down into the batch with the scraper prior to remixing.

## 8. Initial Flow, Flow Retention, Viscosity by Flow Cup, and Healing Time

8.1 *Scope*—This test method measures the flow of freshly-mixed, self-leveling mortar by releasing it from a rigid tube after a given time. The diameter of the spread mixture is measured after a specified time. Flow retention is measured by repeating the test on aged material. Viscosity by Flow Cup is measured using an ISO flow cup and a modified Test Method **D5125** procedure on self-leveling mortars that do not contain fibers greater than 1 mm in length. Healing time is determined by making specific cuts in the surface of the self-leveling mortar at regular time intervals and determining the latest time for which the mortar will still heal as evaluated after setting.

8.2 *Significance and Use*—The flow of a self-leveling mortar is a measure of its placeability. Establishing an acceptable flow range for the self-leveling mortar is critical to the proper use of the self-leveling mortar. If the flow is too low, the self-leveling mortar will not be self-leveling and if the flow is too high, the designed properties of the self-leveling mortar will be compromised. A proper flow range must be established in order to determine the proper water content to use when evaluating the physical properties of the mortar. The flow retention and healing time provide an indication of the useful working time of the mortar. The viscosity of the mortar gives additional information about the rheological characteristics, such as but not limited to, information about the ability to convey the material in a mechanical pump.

## 8.3 Apparatus

8.3.1 Flow Ring: A tube made of smooth, non-corrosive material of  $30.0 \pm 0.1$  mm [ $1\frac{1}{4} \pm \frac{1}{16}$  in.] internal diameter and  $50.0 \pm 0.1$  mm [ $2 \pm \frac{1}{16}$  in.] high.

8.3.2 A clean, dry  $400 \times 400 \times 6$  mm [16 in.  $\times$  16 in.  $\times$   $\frac{1}{4}$  in.] square glass plate.

8.3.3 A timer accurate to 1 s with a range of at least 60 min.

8.3.4 A length-measuring device such as a ruler or tape measure divided into 1 mm [ $\frac{1}{16}$  in.] divisions at least 300 mm [12 in.] long.

8.3.5 Rectangular pan with inside dimensions of at least 210 mm  $\times$  210 mm [ $8\frac{1}{2} \times 8\frac{1}{2}$  in.] with a nominal depth of at least 9 mm [ $\frac{3}{8}$  in.] made of metal or glass not attacked by the self-leveling mortar.

8.3.6 A metal bar 6 mm [ $\frac{1}{4}$  in.] thick, with square edges, and at least 150 mm [6 in.] long.

NOTE 3—The side of a mold used to prepare specimens for Test Method **C157/C157M** is acceptable for this purpose.

8.3.7 *ISO Capillary Flow Cups* as described in Test Method **D5125**.

NOTE 4—ISO cups look like Ford cups, but instead of the non-capillary hole in the bottom of the Ford cup, the ISO cup has a 20 mm long capillary and is more like a true capillary viscometer. The typical orifice openings used for self-leveling mortar are 6 mm and 8 mm. Ford cups are described in Test Method **D1200**.

## 8.4 Procedure

### 8.4.1 Initial Flow:

8.4.1.1 Place the flow ring centrally on the glass plate and place this assembly on a firm horizontal surface not to depart from horizontal by more than  $0.5^\circ$  (approximately equivalent to 1 mm in 100 mm [0.12 in. in 12 in.]).

8.4.1.2 Within 30 s from the completion of mixing, completely fill the flow ring, immediately lift the flow ring and simultaneously start the timer. Lift the flow ring from the glass plate in a vertical direction to a height of 50 to 100 mm [2 to 4 in.] within 2 s and allow the material to empty from the ring onto the glass plate.

8.4.1.3 Allow the mortar to spread for  $240 \pm 10$  s and measure the diameter of the spread in two directions at right angles using the length-measuring device. Record the average diameter as the initial flow of the self-leveling material.

8.4.1.4 Report the initial flow, mm [in.].

8.4.2 *Flow Retention:*

8.4.2.1 Repeat the flow test at 20 min and 30 min from the starting time and record the flow. Remix the material by using the Practice C305 mixer, speed 1, for 5 to 10 s before filling the flow ring.

8.4.2.2 Report the flow retention as the flow, mm [in.] at 20 min and 30 min.

NOTE 5—Self-leveling mortars with flow retention times either shorter or longer than 20-30 min reported in 8.4.2.2 may be measured at appropriate 10 min intervals until material no longer flows out of the flow ring.

NOTE 6—An alternate procedure for flow retention is to fill three flow rings after the completion of mixing. The first ring is lifted immediately and the second and third rings are lifted at 20 min and 30 min respectively from the starting time. This procedure is not recommended as the primary method of measuring flow retention but may be used to provide additional information about the behavior of the material in a completely undisturbed condition. The precision of this method is included in section 10.1.2.1 (2).

8.4.3 *Viscosity by Flow Cup Time:—*

8.4.3.1 Verify the cup is standardized using the procedure outlined in Test Method D5125. Standardization shall be performed at least every 2 years and more frequently if wear of the cup is evident or if errant results are present.

8.4.3.2 Position the flow cup in a stand and level the stand and cup. Position a receiving container under the cup.

8.4.3.3 Within 30 s from the completion of mixing, close the orifice with finger and slightly overfill the flow cup with self-leveling mortar by pouring slowly over 10-15 seconds.

8.4.3.4 Remove any meniscus formed by drawing straight edge across the top of the cup.

8.4.3.5 Remove the finger to start the flow and simultaneously start a stopwatch.

8.4.3.6 Watch for consistent flow. If sand or other contaminant interrupts flow discard test and repeat with new material.

8.4.3.7 Looking into the top of the cup, stop the stopwatch when the orifice first becomes visible.

NOTE 7— The cup need not be completely empty; some material may remain on the sides. It is not necessary to see daylight through the orifice.

8.4.3.8 Report the cup used and the time that the hole became visible as the flow time.

NOTE 8—This value can be used to determine the viscosity by looking up the correct value on the chart provided with the flow cup.

NOTE 9—The test result can be influenced by the mixing energy imparted to the mix. For laboratory testing purposes it is important to follow Practice C305 and use the recommended mixing procedure. For field testing the results may differ due to the different mixer used.

NOTE 10—The flow test can be repeated at later times as needed. If performed, remix the material by using the Practice C305 mixer at Speed 1 for 5 to 10 s before sampling.

8.4.4 *Healing Time:*

8.4.4.1 Place the pan on a level, vibration free surface.

8.4.4.2 Upon completion of mixing, pour self-leveling mortar into the pan until a thickness of  $6 \pm 1$  mm [ $\frac{1}{4} \pm \frac{1}{16}$  in.] is obtained.

8.4.4.3 Start making a full-depth cut in the test specimen at 10 min from the starting time using the 6 mm [ $\frac{1}{4}$  in.] thick metal bar (See Fig. 1). Hold the bar at approximately a 45° angle. Start at the far side of the pan about 25 mm [1 in.] from the left edge of the pan. Pull the bar smoothly through the mix stopping at the near edge of the pan. Complete the cut in approximately 5 to 10 s. Record the time of the beginning of each cut from the defined starting time.

8.4.4.4 Continue making cuts every 5 min until the material no longer heals. Each cut shall be made about 25 mm [1 in.] to the right of the previous cut.

8.4.4.5 Allow the specimen to cure overnight before rating healing time.



**FIG. 1 Full-Depth Cut in Test Specimen**

8.4.4.6 Healing time is determined by both touching and observing the cuts made the previous day. If there is an obvious ridge or indentation in the cut, the material is not healing (see definition). Make observations near the center of the cuts avoiding areas near the edge of the pan.

8.4.4.7 Report the healing time as the longest time for which no obvious indentation or ridge is observed.

## 9. Physical Properties

9.1 The following test methods are used to characterize the time of setting, ~~strength and dimensional stability~~ strength, dimensional stability, and abrasion resistance of the self-leveling mortar and will require several batches to complete the testing. In order to ensure valid comparisons, all tests shall be conducted at the same liquid content using the amount and type of liquid prescribed by the manufacturer (See **Note 2**). In the absence of manufacturer's instructions the correct liquid content shall be established by using an initial trial batch for that purpose. Liquid content shall be adjusted to achieve a flow of 125 to 150 mm [5 to 6 in.]. The trial batch shall not be used for specimen preparation. It will then be necessary to mix additional batches of material using the same amount of liquid as was established by the trial batch. Always use freshly mixed material for each test.

### 9.2 Setting Time

9.2.1 *Scope*—This method covers the determination of the time of initial setting and time of final setting of self-leveling mortars using the Vicat apparatus. Either procedure A or B as defined in Test Method **C191** is acceptable.

9.2.2 *Significance and Use*—This test method determines the setting time of self-leveling mortars mixed to the normal placement consistency as defined in **9.1**. Special precautions are taken to ensure a proper seal around the Vicat ring.

9.2.3 *Apparatus*—Vicat Apparatus, in accordance with Test Method **C191**.

9.2.4 *Test Sample*—The test sample shall consist of at least 300 mL of self-leveling mortar taken from a freshly-mixed batch prepared in accordance with **7.2**.

#### 9.2.5 Procedure:

9.2.5.1 Seal the Vicat ring to the base plate in one of the following ways:

(1) Sealing wax method: Warm the Vicat conical ring and base plate to approximately 100 °C [212 °F]. Apply a thin film of paraffin wax to the base of the conical ring and place the waxed conical ring on the base plate. Place a weight on the conical ring to ensure intimate contact with the base plate and allow the conical ring and plate to cool to room temperature.

(2) High viscosity lubricant method: Apply a layer of high-vacuum silicone grease or other suitable material to the base of the conical ring. Press the conical ring against the base plate so that the grease forms a seal between the ring and base plate to prevent leakage.

9.2.5.2 Fill the conical ring apparatus with freshly mixed self-leveling mortar flush with its top within 2 min after completion of mixing. Strike off flush with the top of the conical ring by a single oblique stroke of a margin trowel held at a slight angle to the top of the ring.

9.2.5.3 Store the specimen on the bench top at laboratory conditions as described in **5.1**.

9.2.5.4 Determine the time of initial setting and the time of final setting using the procedure described in Test Method **C191** except that the first reading shall be taken approximately 30 min before the anticipated time of initial setting and the needle wiped of adhering material between penetrations.

NOTE 11—Fast setting self-leveling mortars will normally reach initial setting time in about 1 to 3 h.

9.2.6 *Report*—The report shall include the following:

9.2.6.1 The method that was used, Method A or B.

9.2.6.2 Time of initial setting and final setting in h and min.

### 9.3 Compressive Strength

9.3.1 *Scope*—This test method covers determination of the compressive strength of self-leveling hydraulic cement mortars, using 50-mm [2-in.] cube specimens.

9.3.2 *Significance and Use*—This test method affords a means for determining the compressive strength of mortars that are used as underlayments and overlayers in flooring applications.

9.3.3 *Apparatus*—As described in Test Method **C109/C109M**.

#### 9.3.4 Procedure:

9.3.4.1 Prepare nine compressive strength specimens following the consolidation procedure for fluid grouts of the compressive strength testing portion of Specification **C1107/C1107M** using watertight molds.

9.3.4.2 Cure the compressive strength specimens one day uncovered in the molds. At  $23 \pm \frac{1}{2}$  h from the starting time, remove the cubes from the molds and determine the 1-day compressive strength of three cubes in accordance with Test Method **C109/C109M**.

9.3.4.3 Cure the remaining specimens under standard laboratory conditions as defined in **5.1** and determine the compressive strength at 7 and 28 days from the starting time in accordance with Test Method **C109/C109M**.

9.3.4.4 Report the average compressive strength in MPa [psi] at 1, 7, and 28 days to the nearest 0.1 MPa [10 psi].

NOTE 12—For rapid setting self-leveling mortars a 4-h test is optional.

#### 9.4 Flexural Strength:

9.4.1 *Scope*—This test method covers determination of the flexural strength of self-leveling mortars using 40 × 40 × 160-mm prism specimens as described in Test Method [C348](#).

9.4.2 *Significance and Use*—This test method affords a means for determining the flexural strength of mortars that are used as underlayments and overlayments in flooring applications.

9.4.3 *Apparatus*—As described in Test Method [C348](#).

##### 9.4.4 Procedure:

9.4.4.1 Prepare six flexural strength specimens following the consolidation procedure for fluid grouts of the compressive strength testing portion of Specification [C1107/C1107M](#) using watertight molds.

9.4.4.2 The specified batch size will only allow for molding six specimens. If additional test ages are desired, prepare additional batches using the same water content as the initial batch.

9.4.4.3 Cure the flexural strength specimens one day uncovered in the molds. At  $23 \pm \frac{1}{2}$  h from the starting time, remove the prisms from the molds and determine the 1-day flexural strength of three prisms in accordance with Test Method [C348](#).

9.4.4.4 Cure the remaining specimens under standard laboratory conditions as defined in [5.1](#) for 28 days and test the second set of specimens in accordance with Test Method [C348](#).

9.4.4.5 Report the average flexural strength in MPa [psi] at 1 and 28 days to the nearest 0.1 MPa [10 psi].

9.4.4.6 *Report*—The report shall include the following:

- (1) Record the total maximum load indicated by the testing machine.
- (2) The calculated flexural strength for each specimen.
- (3) The average flexural strength of each age group of specimens tested.

#### 9.5 Length Change:

9.5.1 *Scope*—This test method is carried out to assess the shrinkage and expansion properties of self-leveling mortars by measuring the length change of specimens stored in air and optionally in water for a specified period of time. The initial reading is made at 24 hours after the starting time. Self-leveling Mortars exhibiting a fast setting time are known to have significant length change before the initial reading of 24 hours. As this length change may affect the performance of the product, other test methods may be needed to evaluate this early movement.<sup>4</sup>

9.5.2 *Significance and Use*—This test method determines the length change of self-leveling mortars using an unrestrained method as described in Test Method [C157/C157M](#).

NOTE 13—Length change is a measure of dimensional stability. Dimensional stability is an important characteristic related to volume change, bond, and cracking potential.

9.5.3 *Apparatus*—As described in Practice [C490/C490M](#). The molds used must be watertight.

9.5.4 *Procedure*—Using freshly mixed mortar mixed in accordance with Section [7](#), pour four length change bars ([Note 14](#)) as described for mortars in Test Method [C157/C157M](#), except consolidate the material in the bars using the consolidation method described in Specification [C1107/C1107M](#) for fluid grout.

NOTE 14—If the optional wet storage procedure is to be used, then an additional 4 specimens will be needed for that procedure.

9.5.4.1 Store the specimens uncovered in the molds under standard laboratory conditions as defined in [5.1](#) until demolded.

9.5.4.2 Demold the specimens at  $23 \pm \frac{1}{2}$  h unless otherwise specified by the manufacturer. Take an initial reading at 24 h ± 15 min in accordance with Test Method [C157/C157M](#).

9.5.4.3 After the initial reading store the specimens in accordance with the instructions for air storage in Specification [C928/C928M](#).

NOTE 15—If specimens have been prepared for the optional water storage procedure, then store those specimens in accordance with the instructions for water storage in Specification [C928/C928M](#).

##### 9.5.5 Report:

9.5.5.1 Report the average percent length change at 3, 7, 14, and 28 days from the starting time for specimens stored in air. Report expansion as a positive number and shrinkage as a negative number.

NOTE 16—The measurements are taken at 3, 7, 14, and 28 days after the starting time, which correspond to 2, 6, 13, and 27 days after the initial reading.

NOTE 17—If the optional wet storage procedure is performed then report the average percent length change at 3, 7, 14, and 28 days for specimens stored in water in accordance with Specification [C928/C928M](#). Report expansion as a positive number and shrinkage as a negative number.

#### 9.6 Abrasion Resistance:

9.6.1 *Scope*—This method measures the abrasion mass loss of self-leveling mortars using a rotary platform abraser after curing periods of 48 h and 28 days.

9.6.2 *Significance and Use*—Abrasion resistance of a self-leveling underlayment is important as the material is often times exposed to jobsite abuse before a final floor covering is placed. The performance evaluation of an underlayment is based on mass

<sup>4</sup> Sant, G., Lura, P., and Weiss, J., “Measurement of Volume Change in Cementitious Materials at Early Ages: Review of Testing Protocols and Interpretation of Results,” *Transportation Research Record Journal*, Vol 1979 / Concrete Materials, 2006.