Designation: C 1698 – 09

Standard Test Method for Autogenous Strain of Cement Paste and Mortar[1]

This standard is issued under the fixed designation C 1698; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method measures the bulk strain of a sealed cement paste or mortar specimen, including those containing admixtures, various supplementary cementitious materials (SCM), and other fine materials, at constant temperature and not subjected to external forces, from the time of final setting until a specified age. This strain is known as *autogenous strain*. Autogenous strain is most significant in concrete with low water-cementitious materials ratio (*w/cm*).

NOTE 1—A low water-cementitious materials ratio (*w/cm*) can be considered to be a water to cement ratio of 0.40 or lower for this test.

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

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.[2])

2. Referenced Documents

2.1 *ASTM Standards:*[3]

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

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

C219 Terminology Relating to Hydraulic Cement

C305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

C403/C403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance

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

C1005 Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements

2.2 *API Specification*[4]

RP 10B-2/ ISO 10426-2 Recommended Practice for Testing Well Cements

3. Terminology

3.1 *Definitions*:

3.1.1 For definitions of terms used in this test method, refer to Terminologies C125 and C219.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *autogenous strain*, *n*—the bulk strain of a sealed specimen of a cementitious mixture, not subjected to external forces and under constant temperature, measured from the time of final setting until a specified age; negative strain corresponds to shrinkage and positive strain corresponds to expansion.

4. Summary of Test Method

4.1 A specimen of freshly mixed paste or mortar is prepared using a corrugated mold that offers little resistance to length change of the specimen. The mold is sealed to prevent moisture loss and the specimen is stored at constant temperature. Starting at the time of final setting, the length of the specimen is measured using a dilatometer. The change in length is recorded at regular time intervals until the designated age. The change in length and original length of the specimen are used to compute the autogenous strain.

5. Significance and Use

5.1 Autogenous strain is the self-created bulk strain of cement paste, mortar, or concrete during hardening at constant

[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 Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

temperature. In conventional concrete, autogenous shrinkage strain is generally negligible, but in concrete with low water-cementitious materials ratio (*w/cm*) or with silica fume it may be considerable (**1**).[5] Restraint of the autogenous strain by aggregates or adjoining structural members may result in formation of micro and macro cracks that impair strength, durability and aesthetics. Cracks may also be a problem with regard to hygienic cleaning of surfaces.

5.2 An accurate measurement of the autogenous strain of cementitious mixtures with low *w/cm* is important for evaluating the risk of early-age cracking of concrete structures. Measurements of autogenous strain have been carried out using either volumetric or linear methods. Both methods may show evidence of significant artifacts (**1**); therefore, results of the two methods may disagree considerably if not carried out properly.

5.3 A sealed, flexible corrugated mold system (**2**) combines the advantages of linear and volumetric measurement of autogenous strain, while avoiding most of their disadvantages. The mold effectively prevents moisture loss and minimizes restraint to volume change during hardening. Moreover, results obtained with the corrugated mold system agree with those from the volumetric method, once some artifacts, in particular water absorption through the membrane used to contain the test specimen, have been eliminated in the latter (**3**,**4**). The corrugated mold system is easier to use and shows better repeatability than the volumetric technique (**3**,**4**). Measurements with the corrugated mold system are in good agreement with unrestrained length change measurements obtained using Test Method C157/C157M with sealed specimens (**5**); however, Test Method C157/C157M does not allow measurement of the shrinkage occurring before 24 h (**5**).

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

5.4 This test method can be used to evaluate the effects of cementitious materials, admixtures, and mixture proportions on autogenous shrinkage strain of paste or mortar specimens.

5.5 The autogenous shrinkage strain of mortar specimens will be less than that of paste specimens for the same *w/cm*. The autogenous shrinkage strain of concrete will be less than that of mortar for the same *w/cm*. The nominal maximum aggregate size for mortar used in this test method is 4.75 mm.

6. Apparatus

6.1 The apparatus to measure autogenous strain is composed of a corrugated mold with two end plugs, a dilatometer bench, a length measuring gauge, and a reference bar (see Fig. 1).

6.2 *Molds*—The molds consist of corrugated plastic tubes, having a length of 420 ± 5 mm and an outer diameter of 29 ± 0.5 mm (see Note 2). The plastic tubes are made of 0.5 ± 0.2-mm thick low-density polyethylene (PE) and have triangular-shaped corrugations in order to minimize restraint in the longitudinal direction (see Fig. 2). The distance between corrugations is 5.8 ± 0.2 mm. The mold is tightly closed with two tapered end plugs having a length of 19 ± 0.5 mm. The diameter of the plastic end plugs tapers from 21 ± 0.1 mm to 22.4 ± 0.1 mm (see Fig. 3).

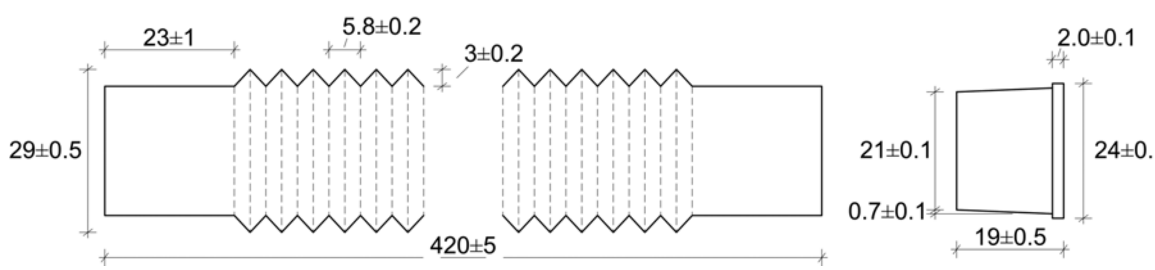
NOTE 2—The small diameter of the molds limits the temperature differences that may arise during hydration of the cementitious materials. Typical maximum temperature increase in the center of the test specimen, due to heat of hydration of cement paste or mortar has been determined to be 2 °C. The maximum longitudinal restraint stress exerted by the molds has been determined to be 0.001 MPa (**6**).

6.3 *Dilatometer Bench*—The dilatometer bench consists of three stainless steel rods with a diameter of 20 ± 1.0 mm and two stainless steel end plates. Technical drawings of a suitable dilatometer bench are shown in Fig. 4. During measurement,

NOTE—In the foreground a corrugated PE-mold with two specially shaped end plugs and a 425 mm reference bar. In the background the dilatometer bench with a test specimen placed for length measurement. To the right a digital length gauge with remote control.

FIG. 1 A Suitable Dilatometer Bench with Accessories

FIG. 2 Corrugated Polyethylene Mold



NOTE—Plastic Tube Wall Thickness 0.5 ± 0.2 mm.

FIG. 3 Outer Dimensions (mm) of Corrugated Low-Density Polyethylene Mold and End Plug

the test specimen is positioned horizontally and is supported longitudinally by the two upper rods.

6.4 *Length Measuring Gauge*—A gauge measures length changes at one end of the specimen. The measuring range of the gauge shall be at least 10 mm and the resolution shall be at least 0.0025 mm, corresponding to a resolution of about 6 µm/m for the calculated strain.

6.5 *Reference Bar*—Measurements in the dilatometer are performed relative to the length of the reference bar. The bar is made of Invar with a length of 425 ± 0.5 mm and a diameter of 20 ± 1.0, tapering to 10 ± 1.0 mm at both ends as shown in Fig. 5. The actual length of the reference bar shall be marked permanently on the bar to the nearest 0.01 mm. Two plastic rings with an external diameter 30 ± 0.5 mm are mounted on the reference bar, as shown in Fig. 1.

6.6 *Reference Masses and Devices for Determining Mass and Volume* shall conform to the requirements of Specification C1005.

6.7 *Support Tube* used to support the corrugated mold during specimen fabrication. The support tube has a length of 400 ± 5 mm and an inside diameter of 32 ± 1 mm (see Fig. 6). The tube is attached to a base that can be fixed to a vibrating table.

6.8 *Vibrating Table* as described in Practice C192/C192M.

6.9 *Tamping Rod* for consolidation of the paste or mortar. It shall be made of a rigid, non-absorptive material that does not react with the cementitious mixture. The length of the rod shall be at least 500 mm and the diameter shall be 6 ± 1 mm. The ends may be flat or hemispherical.

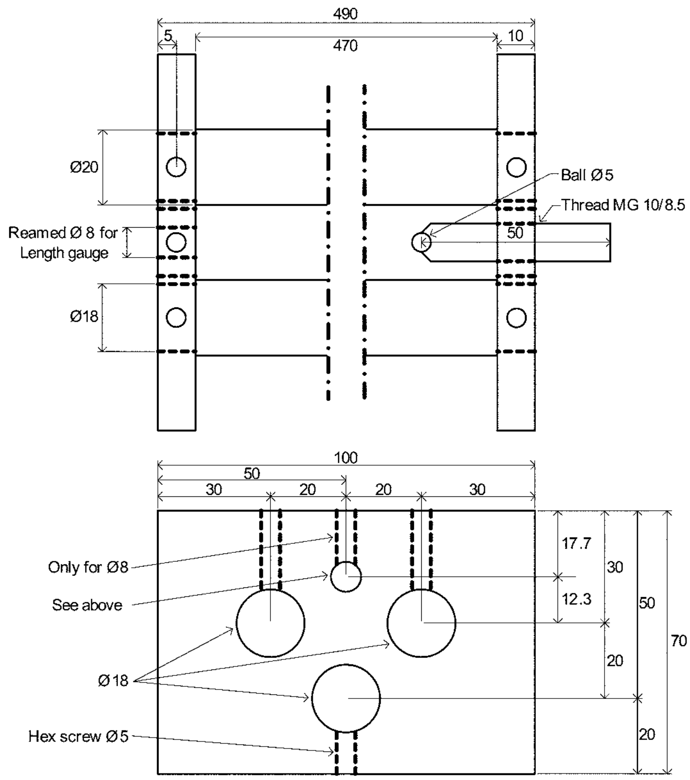
7. Procedure

7.1 *Number of Specimens*—Three replicate specimens shall be tested for each cement paste or mortar (see Note 3).

7.1.1 *Mixing*—Mix cement pastes and mortars according to Practice C305. Record the time when the cementitious materials are added to the water.

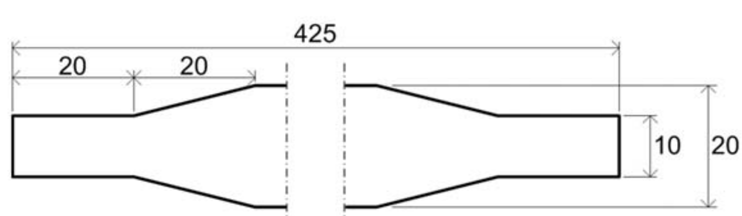
7.1.2 *Mixing Apparatus*

7.1.2.1 *Mortar Preparation*—The mixer shall comply with the sequence in Practice C305.



NOTE—All dimensions are in mm (tolerance ± 0.5 %).

FIG. 4 Technical Drawing of the Dilatometer Bench Shown in Fig. 1
Top: Plan View. Bottom: Elevation View of End Plate



NOTE—All dimensions are in mm and tolerances given in the text.

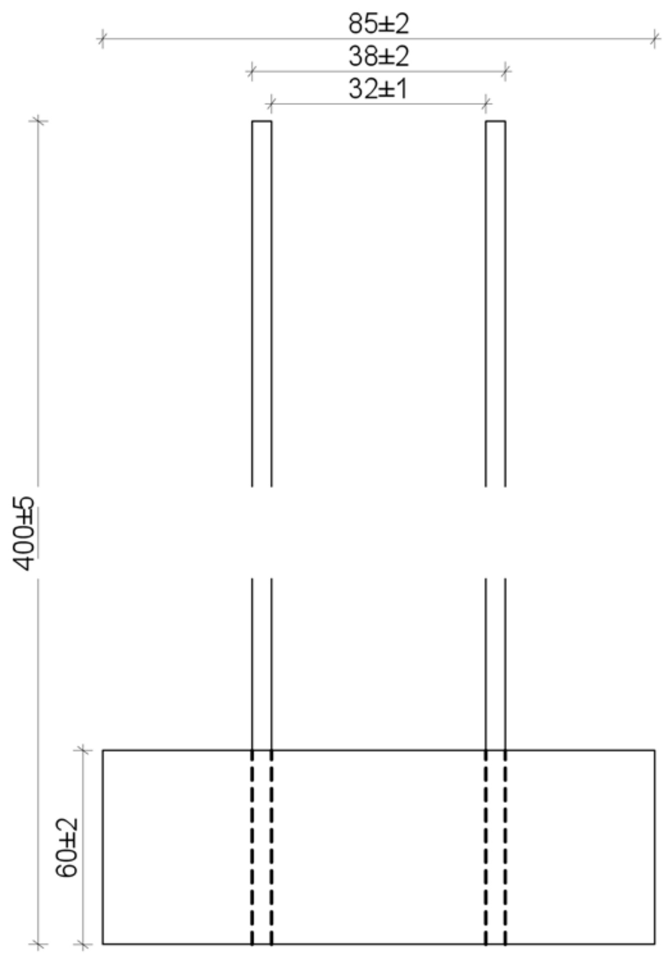
FIG. 5 Technical Drawing of the Reference Bar Shown in Fig. 1

7.1.2.2 *Paste Preparation*—A high shear blender,[6] or similar variable speed blender capable of maintaining a no-load speed of at least 15 000 r/min, with optional cooling device. A hand-held household mixer capable of mixing paste at not less than 400 r/min or other mixers for paste or mortar preparation are also permitted.

NOTE 3—About 185 mL of cement paste or mortar are needed to fill each corrugated mold. For a paste with a water-cement ratio of 0.4, this corresponds to approximately 360 g of paste.

7.2 *Filling and Closing of Molds*—Clamp the mounting base of the support tube to a vibrating table. Measure the lengths of the plugs to be used for each specimen. Place a plug into one end of the mold, and position the mold, with the closed end down, inside the support tube. If the cementitious mixture is pourable, slowly pour the mixture into the corrugated mold with the vibrating table turned on (see Fig. 7). For a semi-fluid mixture, fill the mold in four equal layers and compact each layer 5 times with the tamping rod before each subsequent layer is cast. The rod shall just penetrate the underlying layer. For a stiff mixture, hand prepare rolled sections of the cementitious mixture, drop them into the mold, and consolidate with the tamping rod. To ensure that the cast specimens have approximately the same length, do not stretch or compress the corrugated mold during filling. For fluid mixtures, the corrugated mold shall be held only by the support tube during casting. For semi-fluid and stiff mixtures, manually maintain

[6] Mixing devices described in API Specification RP 10B-2/ ISO 10426-2. Mixing devices such as Waring type blenders have been found suitable for this purpose.



NOTE—All dimensions are in mm. The base of the support tube allows clamping to a vibration table.

FIG. 6 Suitable Dimensions of the Support Tube That is Used During Filling of the Corrugated Molds

the initial length of the mold during compaction. Fill the mold to approximately 15 mm below the top end of the mold to allow room for the top end plug. Before mounting the top end plug, gently compress the corrugated mold to bring the cement paste or mortar in contact with the end plug. Mount the end plug during relief of the compression of the corrugated mold. Use a screwing motion of the end plug to ease the mounting operation. Immediately after casting, carefully wipe the surface of the corrugated mold with a dry cloth to remove any cement paste, mortar, or water.

7.3 *Measuring Room*—To minimize the influence of temperature variations, both the specimens and the dilatometer shall be kept in a thermostatically controlled room or cabinet at all times during the test. Maintain the surrounding air temperature at 23.0 ± 1.0 °C, unless otherwise specified (see Note 4). Do not store specimens in a water bath due to possible water transport through the corrugated molds.

NOTE 4—The measurement can be performed at any temperature specified by the user, provided that the temperature in the measuring room or cabinet is maintained constant during the test with a tolerance of ± 1.0 °C.

7.4 *Specimen Storage*—After filling and sealing the molds, store the specimens horizontally on a smooth surface, to avoid any restraint to length change. Support specimens along their entire length to avoid damage and to ensure they remain straight (see Note 5). Maintain a separation of at least 30 mm between specimens during the first day of measurement to allow dispersion of their heats of hydration.

NOTE 5—Corrugated plastic sheets as shown in Fig. 8 or other suitable materials can be used to support the molded specimens.

7.5 *Time of First Measurement*—Start length measurements at the time of final setting. Determine times of setting using Test Method C191 for paste or Test Method C403/C403M for mortar on specimens made with the same mixture used to mold the autogenous shrinkage specimens and cured at the same temperature as for the autogenous strain measurement. Protect the specimens used for determination of setting times from moisture loss during the measurement.

7.6 *Length Measurement*—Insert the reference bar in the dilatometer bench and bring the measuring gauge in contact with the end of the bar. Reset the measuring gauge so that it reads zero with the reference bar in position (see Note 6).

NOTE—An empty corrugated mold, closed at one end with an end plug, is inserted into the support tube and positioned vertically on a vibrating table. The fresh mixture is slowly poured into the corrugated mold during vibration, until the mold is filled.

FIG. 7 How to Fill the Corrugated Molds

Remove the reference bar and insert a specimen in the dilatometer bench. Measure the length of the specimen with the gauge (see Note 6). Remove the specimen and measure the length of the next specimen.

NOTE 6—A number of digital length measurement devices have the option of changing the sign of the length measurements. Ensure that the sign for the gauge reading is positive for elongation of the specimen (see Eq 1).

During handling of the specimens, support them at all times with both hands and use care to avoid damage. In particular at early age the specimens must be supported along their entire length while they are moved to and from the dilatometer bench (Note 7).

NOTE 7—This can be done by moving the specimen together with a corrugated support rack and rolling the specimen into the frame gently onto the dilatometer bench.

To ensure optimal measuring accuracy, place the reference bar and the specimens in the same orientation during each measurement. Draw a line mark with permanent ink on one end of the corrugated mold after the first measurement to indicate both the upside and the measuring gauge position (see Figs. 8 and 9).

7.7 *Frequency and Duration of Measurements*—Frequency and duration of measurements depends on the cementitious mixture and on the scope of the measurements. The specifier of tests shall indicate the frequency of measurements and the duration of testing (see Note 8). In the absence of other specified ages, measure specimen length at the time of final setting and ages of 1, 3, 7, 14, and 28 d from the time of initial mixing of cementitious materials and water. For longer test durations, protect the molds from moisture loss.

NOTE 8—More frequent measurements may be performed at intervals of one to three hours during the first day, twice a day during the first week, once a day after the first week. Typical duration of the measurements varies from one week to several months. For long term measurements, the corrugated molds may be further protected from moisture loss by storing them in sealed tubes between the measurements.

7.8 *Monitoring Mass Change*—Measure specimen mass using a balance with a resolution of at least 0.01 g. Measure the mass of each specimen after the first autogenous strain measurement has been taken at the time of final setting. Measure the mass of each specimen again after each autogenous strain measurement has been performed. Support the specimens along their length while they are moved to the balance and during mass measurement (Note 9).

NOTE 9—This can be done by measuring the mass of the specimen together with a corrugated support rack (see Fig. 8). Ensure that each specimen is weighed with the same support rack during each mass measurement. The measurement of mass loss indicates if drying shrinkage may be occurring, in addition to autogenous shrinkage.

8. Interferences

8.1 *Bleeding*—Bleeding is expected to influence the measured autogenous strain because reabsorption of bleed water after setting may cause expansion. Bleeding has, however, been shown to have minimal influence on the results of the test (see Note 10). For mixtures prone to bleeding, use an apparatus to slowly rotate the filled molds in a horizontal position at a speed of 1 to 3 r/min until final setting has occurred.

NOTE 10—Bleeding should not be a problem in cement pastes or mortars made with values of *w/cm* lower than about 0.4.

8.2 *Entrapped Air*—Before setting, entrapped air inside the corrugated molds as a consequence of less than perfect filling will influence the deformation of the specimens. However, the effect of entrapped air is negligible after setting, when a solid skeleton has developed in the cement paste or mortar.

9. Calculations

9.1 *Time*—The time t is defined as the time elapsed from the first addition of the cementitious materials to the water during mixing.

9.2 *Length*—The length of the paste or mortar specimen at time t is calculated with the following formula:

$$L(t) = L_{ref} + R(t) - 2 \cdot L_{plug} \quad (1)$$

where:

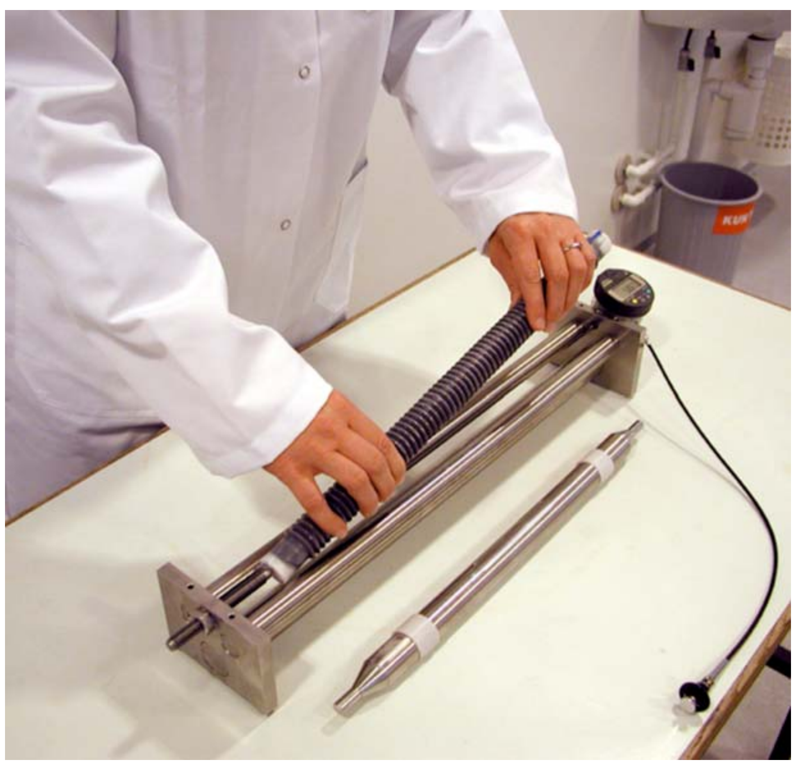
L_{ref} = length of reference bar, mm
$R(t)$ = reading of length gauge with specimen in the dilatometer, mm, and
L_{plug} = average length of end plugs, mm.

9.3 *Autogenous Strain*—The autogenous strain of the specimen at time t, expressed as µm/m, is calculated with the following formula:

$$\varepsilon_{autogenous} = \frac{L(t) - L(t_{fs})}{L(t_{fs})} \cdot 10^6 = \frac{R(t) - R(t_{fs})}{L(t_{fs})} \cdot 10^6 \ \mu m/m \quad (2)$$

NOTE—Note pen marks on the ends of the tubes to ensure proper positioning of specimens in the dilatometer bench during length measurements.

FIG. 8 Corrugated Plastic Sheets for Supporting the Specimens During the Test



NOTE—Notice the mark with permanent ink at one end of the specimen showing the upside and measuring gauge position during measurements.

FIG. 9 Placement of Specimen in the Dilatometer Bench for Length Measurement

where:

t_{fs} = time of final setting, when the first length measurement is performed, min.

9.4 *Mass Change*—The mass change of the specimen is calculated as the difference between the mass of the specimen M_s measured at the conclusion of the test and the mass at the time of final setting:

$$\Delta M = M_s(t_e) - M_s(t_{fs}) \quad (3)$$

where:

t_e = time of last mass measurement, min,

$M_s(t_e)$ = mass when last mass measurement is made (at the conclusion of the test), g, and

$M_s(t_{fs})$ = mass at time of final setting when first mass measurement is made, g.

It is assumed that all the mass change of the specimen is due to exchange of moisture between the cementitious system and the external environment. The exchange of moisture results in an error in the autogenous strain measurement for cement pastes of about 200 µm/m per gram of mass change and for mortars of about 80 µm/m per gram of mass change (7). If the calculated error in the autogenous measurement on this basis exceeds 5 % of the total autogenous strain, the test is considered invalid.

10. Report

10.1 Report the following for each mixture tested:

10.1.1 The mixture proportions in kg/m^3 of water, cement (and other cementitious materials), and aggregates; admixtures in L/m^3; and water-cementitious materials ratio (*w/cm*) to the nearest 0.01.

10.1.2 Measuring room temperature.

10.1.3 Time of first addition of the cementitious materials to water and duration of mixing if different from the mixing time in Practice C305.

10.1.4 Indicate if specimens were rotated before final setting and report the speed of rotation. Also indicate the test method used to determine the time of final setting.

10.1.5 For each length measurement: the time of measurement, gauge reading of each measured specimen at each measuring age, time elapsed from first addition of the cementitious materials to water during mixing, and the autogenous strain value calculated with Eq 1 and 2.

10.1.6 Mass of each specimen at final setting and at end of test. Change of mass (in g) calculated with Eq 3.

11. Precision and Bias

11.1 *Precision*—Preliminary information on repeatability of this test method was derived from single-operator testing in two different laboratories. The standard deviation appears to be constant and is used as the measure of repeatability. For replicate specimens of paste with values of *w/cm* between 0.35 and 0.37, the pooled value of the single operator standard deviation was found to be 110 µm/m. For mortar specimens with values of *w/cm* between 0.3 and 0.43, the pooled value of the single operator standard deviation was found to be 28 µm/m (see Note 11).

NOTE 11—A full analysis of precision, as derived from an interlaboratory program, is expected to be completed by 2013.

11.2 *Bias*—Since there is no accepted reference material suitable for determining the bias of this procedure, no statement on bias is made.

12. Keywords

12.1 autogenous strain; cement paste; length change; mortar

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