Standard Method of Test for

Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)

AASHTO Designation: T 106M/T 106-22

Technically Revised: 2022

Technical Subcommittee: 3a, Cement, Lime, and Concrete Materials

ASTM Designation: C109/C109M-21

AASHTO

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1. SCOPE

1.1. This test method covers determination of the compressive strength of hydraulic cement mortar using 50-mm [or 2-in.] cube specimens (see Note 1).

Note 1—ASTM C349 provides an alternative procedure for this determination (not to be used for acceptance tests).

1.2. This test method covers the application of the test using either inch-pound or SI units. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. 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 nonconformance with the standard.

1.3. Values in SI units shall be obtained by measurement in SI units or by appropriate conversion, using the Rules for Conversion and Rebounding given in Standard IEEE/ASTM SI 10, of measurements made in other units.

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.

1.5. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 152M/M 152, Flow Table for Use in Tests of Hydraulic Cement

- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 240M/M 240, Blended Hydraulic Cement
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Slag Cement for Use in Concrete and Mortars
- M 339M/M 339, Thermometers Used in the Testing of Construction Materials
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- T 105, Chemical Analysis of Hydraulic Cement
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:
- C91/C91M, Standard Specification for Masonry Cement
- C349, Standard Test Method for Compressive Strength of Hydraulic-Cement Mortars (Using Portions of Prisms Broken in Flexure)
- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C778, Standard Specification for Standard Sand
- C1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- C1157/C1157M, Standard Performance Specification for Hydraulic Cement
- C1328/C1328M, Standard Specification for Plastic (Stucco) Cement
- C1329/C1329M, Standard Specification for Mortar Cement
- E1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E230/E230M, Standard Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples
- E2877, Standard Guide for Digital Contact Thermometers

2.3. *IEEE/ASTM Standard*:
- SI10, American National Standard for Metric Practice

2.4. *International Electrotechnical Commission Standard:*
- IEC 60584-1:2013 Thermocouples - Part 1: EMF Specifications and Tolerances

3. SUMMARY OF TEST METHOD

3.1. The mortar used consists of one part cement and 2.75 parts of sand proportioned by mass. Portland, air-entraining portland, portland-limestone, or air-entrained portland-limestone cements are mixed at a specified water content. Water content for other cements is that sufficient to obtain a flow of 110 ± 5 in 25 drops of the flow table. Fifty-millimeter [or 2-in.] test cubes are compacted by tamping in two layers. The cubes are cured 24 h in the molds, and then stripped and immersed in lime water until tested.

4. SIGNIFICANCE AND USE

4.1. This test method provides a means of determining the compressive strength of hydraulic cement and other mortars, and results may be used to determine compliance with specifications. Further, this test method is referenced by numerous other specifications and test methods. Caution must be exercised in using the results of this test method to predict the strength of concretes.

5. APPARATUS

5.1. *Weights and Weighing Devices*—Shall conform to the requirements of ASTM C1005. The weighing device shall be evaluated for precision and accuracy at a total load of 2000 g.

5.2. *Glass Graduates*—Of suitable capacities (preferably large enough to measure the mixing water in a single operation) to deliver the indicated volume at 20°C. The permissible variation shall be ±2 mL. These graduates shall be subdivided to at least 5 mL, except that the graduation lines may be omitted for the lowest 10 mL for a 250-mL graduate and for the lowest 25 mL for a 500-mL graduate. The main graduation lines shall be circles and shall be numbered. The least graduations shall extend at least one-seventh of the way around, and intermediate graduations shall extend at least one-fifth of the way around.

5.3. *Specimen Molds*—For the 50-mm [or 2-in.] cube specimens shall be tight fitting. The molds shall have no more than three cube compartments and shall be separable into no more than two parts. The parts of the molds when assembled shall be positively held together. The molds shall be made of hard metal not attacked by the cement mortar. For new molds, the Rockwell hardness number of the metal shall be not less than 55 HRB. The sides of the molds shall be sufficiently rigid to prevent spreading or warping. The interior faces of the molds shall be plane surfaces and shall conform to the tolerances of Table 1.

Table 1—Permissible Variations of Specimen Molds

	50-mm Cube Molds		2-in. Cube Molds	
Parameter	New	In Use	New	In Use
Planeness of sides	<0.025 mm	<0.05 mm	<0.001 in.	<0.002 in.
Distance between opposite sides	50 mm ± 0.13 mm	50 mm ± 0.50 mm	2 in. ± 0.005	2 in. ± 0.02
Height of each compartment	50 mm + 0.25 mm to − 0.13 mm	50 mm + 0.25 mm to − 0.38 mm	2 in. + 0.01 in. to − 0.005 in.	2 in. + 0.01 in. to − 0.015 in.
Angle between adjacent faces[a]	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°

[a] Measured at points slightly removed from the intersection. Measured separately for each compartment between all the interior faces and the adjacent face and between interior faces and top and bottom planes of the mold.

5.4. *Mixer, Bowl, and Paddle*—An electrically driven mechanical mixer of the type equipped with paddle and mixing bowl, as specified in T 162.

5.5. *Flow Table and Flow Mold*—Conforming to the requirements of M 152M/M 152.

5.6. *Tamper*—A nonabsorptive, nonabrasive, nonbrittle material such as a rubber compound having a Shore A durometer hardness of 80 ± 10 or seasoned oak wood rendered nonabsorptive by immersion for 15 min in paraffin at approximately 200°C [392°F], using a thermometer that shall meet the requirements of M 339M/M 339 to measure a temperature of 200°C (392°F) with an accuracy of ±5°C [±9°F] (see Note 2), and shall have a cross section of 13 by 25 mm [$^1/_2$ by 1 in.] and a convenient length of about 120 to 150 mm [5 to 6 in.]. The tamping face shall be flat and at right angles to the length of the tamper.

Note 2—Thermometer types suitable for use include ASTM E1 mercury thermometer; bimetal stem thermometer; ASTM E2877 digital metal stem thermometer; IEC 60584 thermocouple thermometer Type T, Class 1 or 2; or ASTM E230/E230M thermocouple thermometer, Type T Standard.

5.6.1. Tampers shall be checked for conformance to the design and dimensional requirements of this test method at least once every six months.

Note 3—A visual inspection of the tamper should be performed each day before use to confirm that the end is flat and at a right angle to the long axis of the tamper. Rounded or peeling tampers should not be used.

5.7. *Trowel*—Having a steel blade 100 to 150 mm [4 to 6 in.] in length, with straight edges.

5.8. *Moist Cabinet or Room*—Conforming to the requirements of M 201.

5.9. *Testing Machine*—Either the hydraulic or the screw type, with sufficient opening between the upper bearing surface and the lower bearing surface of the machine to permit the use of verifying apparatus. The load applied to the test specimen shall be indicated with an accuracy of ±1.0 percent. If the load applied by the compression machine is registered on a dial, the dial shall be provided with a graduated scale that can be read to at least the nearest 0.1 percent of the full scale load (see Note 4). The dial shall be readable within 1 percent of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks, and the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment that is easily accessible from the outside of the dial case, and with a suitable device that at all times, until reset, will indicate to within 1 percent accuracy the maximum load applied to the specimen.

Note 4—"As close as can be read" is considered 0.5 mm [0.02 in.] along the arc described by the end of the pointer. Also, one half of the scale interval is about as close as can reasonably be read when the spacing on the load indicating mechanism is between 1 mm [0.04 in.] and 1.6 mm [0.0625 in.]. When the spacing is between 1.6 mm [0.0625 in.] and 3.2 mm [0.125 in.], one third of the scale interval can be read with reasonable certainty. When the spacing is 3.2 mm [$^1/_8$ in.] or more, one fourth of the scale interval can be read with reasonable certainty.

5.9.1. If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 percent of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 percent for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times, until reset, will indicate within 1 percent system accuracy the maximum load applied to the specimen.

5.9.2. The upper bearing assembly shall be a spherically seated, hardened metal block firmly attached at the center of the upper head of the machine. The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 percent of the radius of the sphere. Unless otherwise specified by the manufacturer, the spherical portion of the bearing block and the seat that holds this portion shall be cleaned and lubricated with a petroleum-type oil such as motor oil at least every 6 months. The block shall be closely held in its spherical seat, but shall be free to tilt in any direction. A hardened metal bearing block shall be used beneath the specimen to minimize wear of the lower platen of the machine. To facilitate accurate centering of the test specimen in the compression machine, one of the two surfaces of the bearing blocks shall have a diameter or diagonal between 70.7 mm [2.83 in.] (see Note 5) and 73.7 mm [2.9 in.]. When the upper block bearing surface meets this requirement, the lower block bearing surface shall be greater than 70.7 mm [2.83 in.]. When the lower block bearing surface meets this requirement, the diameter or diagonal of upper block bearing surface shall be between 70.7 and 79.4 mm [2.83 and $3^1/_8$ in.]. When the lower block is the only block with a diameter or diagonal between 70.7 and 73.7 mm [2.83 and 2.9 in.], the lower block shall be used to center the test specimen. In that case, the lower block shall be centered with respect to the upper bearing block and held in position by suitable means. The bearing block surfaces intended for contact with the specimen shall have a Rockwell hardness number not less than 60 HRC. These surfaces shall not depart from plane surfaces by more than 0.013 mm [0.0005 in.] when the blocks are new and shall be maintained within a permissible variation of 0.025 mm [0.001 in.].

Note 5—The diagonal of the 50-mm [2-in.] cube is 70.7 mm [2.83 in.].

6. MATERIALS

6.1. *Graded Standard Sand*:

6.1.1. The sand (see Note 6) used for making test specimens shall be natural silica sand conforming to the requirements for graded standard sand in ASTM C778.

Note 6—*Segregation of Graded Sand*—The graded standard sand should be handled in such a manner as to prevent segregation because variations in the grading of the sand cause variation in the consistency of the mortar. In emptying bins or sacks, care should be exercised to prevent the formation of mounds of sand or craters in the sand, down the slopes of which the coarser particles will roll. Bins should be of sufficient size to permit these precautions. Devices for drawing the sand from bins by gravity should not be used.

7. TEMPERATURE AND HUMIDITY

7.1. For tests under laboratory conditions, the storage, mixing, and curing environment shall be in accordance with M 201, using thermometers meeting the requirements of M 339M/M 339.

8. TEST SPECIMENS

8.1. Make two or three specimens from a batch of mortar for each period of test or test age.

9. PREPARATION OF SPECIMEN MOLDS

9.1. Apply a thin coating of release agent to the interior faces of the mold and nonabsorptive base plates. Apply oils and greases using an impregnated cloth or other suitable means. Wipe the mold faces and the base plate with a cloth as necessary to remove any excess release agent and to achieve a thin, even coating on the interior surfaces. When using an aerosol lubricant, spray the release agent directly onto the mold faces and base plate from a distance of 150 to 200 mm [6 to 8 in.] to achieve complete coverage. After spraying, wipe the surface with a cloth as necessary to remove any excess aerosol lubricant. The residue coating should be just sufficient to allow a distinct fingerprint to remain following light finger pressure (see Note 7).

Note 7—Because aerosol lubricants evaporate, molds should be checked for a sufficient coating of lubricant immediately prior to use. If an extended period of time has elapsed since treatment, retreatment may be necessary.

9.2. Seal the surfaces where the halves of the mold join by applying a coating of light cup grease such as petrolatum. The amount should be sufficient to extrude slightly when the two halves are tightened together. Remove any excess grease with a cloth.

9.3. Seal molds to their base plates with a watertight sealant. Use microcrystalline wax or a mixture of three parts paraffin to five parts rosin by mass. Paraffin wax is permitted as a sealant with molds that clamp to the base plate. Liquefy the wax by heating it to a temperature of between 110 and 120°C [230 and 248°F]. Effect a watertight seal by applying the liquefied sealant at the outside contact lines between the mold and its base plate (see Note 8). The thermometer for measuring the temperature of the wax or paraffin / rosin mixture shall meet the requirements of M 339M/M 339 with a temperature range of at least 110 to 120°C (230 to 248°F) and an accuracy of ± 1°C [±2°F] (see Note 9).

Note 8—*Watertight Molds*—The mixture of paraffin and rosin specified for sealing the joints between molds and base plates may be found difficult to remove when molds are being cleaned. Use of straight paraffin is permissible if a watertight joint is secured; however, due to the low strength of paraffin, it should be used only when the mold is not held to the base plate by paraffin alone. When securing clamped molds with paraffin, an improved seal can be obtained by slightly warming the mold and base plate prior to applying the wax. Molds so treated should be allowed to return to room temperature before use.

Note 9—Thermometer types suitable for use include ASTM E1 mercury thermometers; ASTM E2877 digital metal stem thermometer; IEC 60584 thermocouple thermometer Type T, Class 2; or ASTM E230 thermocouple thermometer, Type T Standard.

9.4. Optionally, a watertight sealant of petroleum jelly is permitted for clamped molds. Apply a small amount of petroleum jelly to the entire surface of the face of the mold that will be contacting the base plate. Clamp the mold to the base plate, and wipe any excess sealant from the interior of the mold and base plate.

10. PROCEDURE

10.1. *Composition of Mortars*:

10.1.1. Materials for the standard mortar shall be cement, graded standard sand, and water. The quantities of materials to be mixed at one time in the batch of mortar for making six, nine, and twelve test specimens shall be in accordance with Table 2. Use specified water content for all portland, portland-limestone, air-entraining portland, or air-entrained portland-limestone cements. The amount of mixing water for other cements shall be such as to produce a flow of 110 ± 5 as determined in accordance with Section 10.3.

Note 10—The water-to-portland cement and water-to-portland-limestone cement ratio used in Table 2 is 0.485 by mass. For air-entraining cements, the water-to-portland cement or water-to portland-limestone cement ratio is 0.460 by mass. The sand-to-cement ratio is 2.75.

Table 2—Standard Test Mortar Proportions

	No. of Specimens		
	6	9	12
Cement, g	500	740	1060
Sand, g	1375	2035	2915
Water, mL:			
Portland or portland-limestone cements	242	359	514
Air-entraining portland or air-entrained portland-limestone cements	230	340	488
Other cements (to flow of 110 ± 5)	—	—	—

10.2. *Preparation of Mortar*:

10.2.1. Mechanically mix in accordance with the procedure given in T 162.

10.3. *Determination of Flow*:

10.3.1. Carefully wipe the flow-table top clean and dry, and place the flow mold at the center. Place a layer of mortar about 25 mm [1 in.] in thickness in the mold and tamp 20 times with the tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Then fill the mold with mortar and tamp as specified for the first layer. Cut off the mortar to a plane surface, flush with the top of the mold, by drawing the straight edge of a trowel (held nearly perpendicular to the mold) with a sawing motion across the top of the mold. Wipe the table top clean and dry, being especially careful to remove any water from around the edge of the flow mold. Lift the mold away from the mortar 60 s after completing the mixing operation. Immediately drop the table through a height of 13 mm [$^1/_2$ in.], 25 times in 15 s.

10.3.2. Using the calipers, determine the flow by measuring the diameters of the mortar along the four lines scribed in the table top, recording each diameter as the number of caliper divisions, estimated to one-tenth of a division. If some other caliper is being used, measure the diameter of the mortar along the four lines scribed in the table top, recording each diameter to the nearest millimeter.

10.3.3. For portland, portland-limestone, air-entraining portland, or air-entrained portland-limestone cements cements, record the flow.

10.3.4. In the case of cements other than portland, portland-limestone, air-entraining portland, or air-entrained portland-limestone cements, make trial mortars with varying percentages of water until the specified flow is obtained. Make each trial with fresh mortar. Record the water content used to achieve the specified flow as weight percent of cement.

10.3.5. Immediately following completion of the flow test, return the mortar from the flow table to the mixing bowl. Quickly scrape the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl, and then remix the entire batch 15 s at medium speed. Upon completion of mixing, the mixing paddle shall be shaken to remove excess mortar into the mixing bowl.

10.3.6. When a duplicate batch is to be made immediately for additional specimens, the flow test may be omitted and the mortar allowed to stand in the mixing bowl 90 s without covering. During the last 15 s of this interval, quickly scrape the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl. Then remix for 15 s at medium speed.

10.4. *Molding Test Specimens*:

10.4.1. Complete the consolidation of the mortar in the molds by either hand tamping or a qualified alternative method. Alternative methods include, but are not limited to, the use of a vibrating table or mechanical devices.

10.4.2. *Hand Tamping*:

10.4.2.1. Start molding the specimens within a total elapsed time of not more than 2 min and 30 s after completion of the original mixing of the mortar batch. Place a layer of mortar about 25 mm [1 in.] (approximately one-half of the depth of the mold) in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 s in four rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen, as illustrated in Figure 1. The tamping pressure shall be just sufficient to ensure uniform filling of the molds. The four rounds of tamping (32 strokes) of the mortar shall be completed in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first layer.

10.4.2.2. During tamping of the second layer, bring in the mortar forced out onto the tops of the molds after each round of tamping by means of the gloved fingers and the tamper upon completion of each round and before starting the next round of tamping. On completion of the tamping, the tops of all cubes should extend slightly above the tops of the molds. Bring in the mortar that has been forced out onto the tops of the molds with a trowel and smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mold.

10.4.2.3. Then, for the purpose of leveling the mortar and making the mortar that protrudes above the top of the mold of more uniform thickness, draw the flat side of the trowel (with the leading edge slightly raised) lightly once along the length of the mold. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straight edge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the length of the mold.

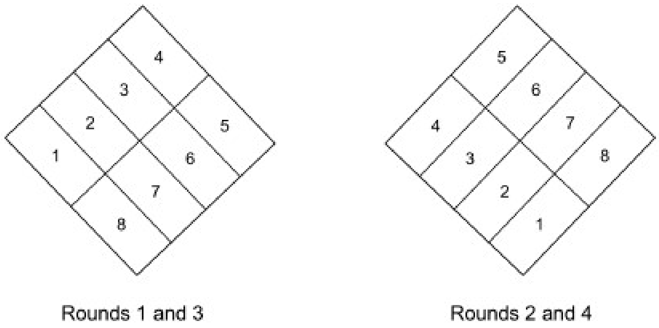

Figure 1—Order of Tamping in Molding of Test Specimens

10.4.3. *Alternative Methods*—Any consolidation method may be used that meets the qualification requirements of this section. The consolidation method consists of a specific procedure, equipment, and consolidation device, as selected and used in a consistent manner by a specific laboratory. The mortar batch size of the method may be modified to accommodate the apparatus, provided the proportions maintain the same ratios as given in Section 10.1.2.

10.4.3.1. Separate qualifications are required for the following classifications:

10.4.3.2. *Class A, Non-Air Entrained Cements*—For use in concrete. Refer to M 85, M 240M/M 240, and ASTM C1157/C1157M.

10.4.3.3. *Class B, Air-Entrained Cements*—For use in concrete. Refer to M 85, M 240M/M 240, and ASTM C1157/C1157M.

10.4.3.4. *Class C, Masonry, Mortar, and Stucco Cements*—Refer to ASTM C91/C91M, ASTM C1328/C1328M, and ASTM C1329/C1329M.

10.4.3.5. An alternative method may only be used to test the cement types as given in Section 10.4.3.1 above, for which it has been qualified.

10.4.3.6. It can also be used for Strength Activity Index determinations for fly ash and slag (refer to M 295 and M 302), provided the alternative method has qualified for both Class A and Class C cements.

10.4.4. *Qualification Procedure*—Contact Cement and Concrete Reference Laboratory (CCRL) to purchase cement samples that have been used in the Proficiency Sample Program (PSP). Four samples (5 kg each) of the class to be qualified will be required to complete a single qualification (see Note 11).

Note 11—It is recommended that a large homogenous sample of cement be prepared at the time of qualification for use as a secondary standard and for method evaluation. Frequent testing of this sample will give early warning of any changes in the performance of the apparatus.

10.4.4.1. In 1 day, prepare replicate 6-cube or 9-cube batches using one of the cements and cast a minimum of 36 cubes. Complete one round of tests on each cement on different days. Store and test all specimens as prescribed in the sections below. Test all cubes at the age of 7 days.

10.4.4.2. Tabulate the compressive strength data and complete the mathematical analyses as instructed in Annex A1.

10.4.5. *Requalification of the Alternate Compaction Method*:

10.4.5.1. Requalification of the method shall be required if any of the following occur:

- Evidence that the method may not be providing data in accordance with the requirements of Table 4.
- Results that differ from the reported final average of a CCRL-PSP sample with a rating of three or less.
- Results that differ from the accepted value of a known reference sample with established strength values by more than twice the multilaboratory 1s percent values of Table 4. Before starting the requalification procedure, evaluate all aspects of cube fabrication and the testing process to determine if the offending result is due to some systematic error or just an occasional random event.

10.4.5.2. If the compaction equipment is replaced, significantly modified, repaired, or has been recalibrated, requalify the equipment in accordance with Section 10.4.4.

10.5. *Storage of Test Specimens*—Immediately upon completion of molding, place the test specimens in the moist closet or moist room. Keep all test specimens, immediately after molding, in the molds on the base plates in the moist closet or moist room from 20 to 72 h with their upper surfaces exposed to the moist air but protected from dripping water. If the specimens are removed from the molds before 24 h, keep them on the shelves of the moist closet or moist room until they are 24 h old. Then immerse the specimens, except those for the 24-h test, in saturated lime water in storage tanks constructed of noncorroding materials. Keep the storage water clean by changing as required.

10.6. *Determination of Compressive Strength*:

10.6.1. Test the specimens immediately after their removal from the moist closet in the case of 24-h specimens, and from storage water in the case of all other specimens. All test specimens for a given test age shall be broken within the permissible tolerance prescribed as follows in Table 3:

Table 3—Testing Time Tolerances

Test Age	Permissible Tolerance
24 h	$\pm^1/_2$ h
3 days	±1 h
7 days	±3 h
28 days	±12 h
56 days	±24 ho

If more than one specimen at a time is removed from the moist closet for the 24-h tests, keep these specimens covered with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, keep these specimens in water at a temperature of

23 ± 2°C [73.5 ± 3.5°F] and of sufficient depth to completely immerse each specimen until time of testing.

10.6.2. Wipe each specimen to a surface-dry condition, and remove any loose sand grains or incrustations from the faces that will be in contact with the bearing blocks of the testing machine.

Check these faces by applying a straightedge (see Note 12). If there is appreciable curvature, grind the face or faces to plane surfaces or discard the specimen. A periodic check of the cross-sectional area of the specimen should be made.

Note 12—*Specimen Faces*—Results much lower than the true strength will be obtained by loading faces of the cube specimen that are not truly plane surfaces. Therefore, it is essential that the specimen molds be kept scrupulously clean; otherwise, large irregularities in the surface will occur. Instruments for cleaning molds should always be softer than the metal in the molds to prevent wear. In case grinding specimen faces is necessary, it can be accomplished best by rubbing the specimen on a sheet of fine emery paper or cloth glued to a plane surface, using only a moderate pressure. Such grinding is tedious for more than a few hundredths of a millimeter (thousandths of an inch); where more than this is found necessary, it is recommended that the specimen be discarded.

10.6.3. Apply the load to specimen faces that were in contact with the true plane surfaces of the mold. Carefully place the specimen in the testing machine below the center of the upper bearing block. Prior to the testing of each cube, it shall be ascertained that the spherically seated block is free to tilt. Use no cushioning or bedding materials. Bring the spherically seated block into uniform contact with the surface of the specimen. Apply the load rate at a relative rate of movement between the upper and lower platens corresponding to a loading on the specimen with the range of 900 to 1800 N/s [200 to 400 lb/s]. Obtain this designated rate of movement of the platen during the first half of the anticipated maximum load and make no adjustment in the rate of movement of the platen in the latter half of the loading, especially while the cube is yielding before failure. (See Note 13.)

Note 13—It is advisable to apply only a very light coating of a good quality, light mineral oil to the spherical seat of the upper platen.

11. CALCULATION

11.1. Record the total maximum load indicated by the testing machine, and calculate the compressive strength as follows:

$$fm = P/A \tag{1}$$

where:

fm = compressive strength in MPa [psi],

P = total maximum load in N [lbf], and

A = area of loaded surface in mm^2 [$in.^2$].

Either 50-mm or 2-in. cube specimens may be used for the determination of compressive strength, whether SI or inch-pound units are used. However, consistent units for load and area must be used to calculate strength in the units selected. If the cross-sectional area of the specimen varies more than 1.5 percent from the nominal, use the actual area for the calculation of the compressive strength. The compressive strength of all acceptable test specimens (see Section 13) made from the same sample and tested at the same period shall be averaged and reported to the nearest 0.1 MPa [10 psi].

12. REPORT

12.1. Report the flow to the nearest 1 percent and the water used to the nearest 0.1 percent. Average compressive strength of all specimens from the same sample shall be reported to the nearest 0.1 MPa [10 psi].

13. FAULTY SPECIMENS AND RETESTS

13.1. In determining the compressive strength, do not consider specimens that are manifestly faulty.

13.2. The maximum permissible range between specimens from the same mortar batch, at the same test age, is 8.7 percent of the average when three cubes represent a test age and 7.6 percent when two cubes represent a test age (see Note 14).

Note 14—The probability of exceeding these ranges is 1 in 100 when the within-batch coefficient of variation is 2.1 percent. The 2.1 percent is an average for laboratories participating in the portland cement and masonry cement reference sample programs of the Cement and Concrete Reference Laboratory (CCRL).

13.3. If the range of three specimens exceeds the maximum in Section 13.2, discard the result that differs most from the average and check the range of the remaining two specimens. Make a retest of the sample if fewer than two specimens remain after discarding faulty specimens or discarding tests that fail to comply with the maximum permissible range of two specimens. (See Notes 15 and 16.)

Note 15—Example for Permissible Range—For a data set of three cubes (31.0, 34.0, and 35.0 MPa) the average strength is 33.3 MPa with a range of 4.0 MPa. According to the 8.7% limit, the range should not be more than 2.9 MPa (33.3×0.087). Since the range here is greater than 2.9 MPa, discard the value most different from the average, in this case 31.0 MPa. Now, the new average based on only two specimens is 34.5 MPa and the range should not be more than 2.6 MPa (34.5×0.076). Since the difference between the two values is less than the range this is an acceptable data set and the reported average should be 34.5 MPa.

Note 1617—Reliable strength results depend upon careful observance of all the specified requirements and procedures. Erratic results at a given test period indicate that some of the requirements and procedures have not been carefully observed (e.g., those covering the testing of the specimens as prescribed in Sections 10.6.2 and 10.6.3). Improper centering of specimens resulting in oblique fractures or lateral movement of one of the heads of the testing machine during loading will often cause lower strength results.

14. PRECISION AND BIAS

14.1. *Precision*—The precision statements for this test method are listed in Table 4 and are based on results from the CCRL Reference Sample Program. They are developed from data where a test result is the average of compressive strength tests of three cubes molded from a single batch of mortar and tested at the same age. A significant change in precision will not be noted when a test result is the average of two cubes rather than three.

Table 4—Precision

		Test Age, Days	Coefficient of Variation 1s, Percent[a]	Acceptable Range of Test Results d2s, Percent[a]
Portland cements:				
Constant water as percent of cement:				
Single-laboratory		3	4.0	11.3
		7	3.6	10.2
	Av		3.8	10.7
Multilaboratory		3	6.8	19.2
		7	6.4	18.1
	Av		6.6	18.7
Blended cements (excluding portland-limestone cements):				
Constant flow mortar:				
Single-laboratory		3	4.0	11.3
		7	3.8	10.7
		28	3.4	9.6
	Av		3.8	10.7
Multilaboratory		3	7.8	22.1
		7	7.6	21.5
		28	7.4	20.9
	Av		7.6	21.5
Masonry cements:				
Constant flow mortar:				
Single-laboratory		7	7.9	22.3
		28	7.5	21.2
	Av		7.7	21.8
Multilaboratory		7	11.8	33.4
		28	12.0	33.9
	Av		11.9	33.7

[a] These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C670. Precision data for tests at ages of 24 hours and 56 days are not available.

14.2. These precision statements are applicable to mortars made with cements mixed and tested at the ages as noted. The appropriate limits are likely somewhat larger for tests at younger ages and slightly smaller for tests at older ages.

14.3. *Bias*—The procedure in this test method has no bias because the value of compressive strength is defined in terms of the test method.

15. KEYWORDS

15.1. Compressive strength; hydraulic cement mortar; hydraulic cement strength; mortar strength; strength.

16. REFERENCE

16.1. Goodspeed, C. H., S. Vanikar, and R. Cook. High Performance Concrete Defined for Highway Structures. *Concrete International*, Vol. 18, No. 2, February 1996, pp. 62–67.

ANNEX

(Mandatory Information)

A1. ANALYSES OF TEST RESULTS FOR QUALIFICATION OF ALTERNATE COMPACTION METHODS

A1.1. *Calculation of Average Within-Batch Standard Deviation and Elimination of Outliers*—Tabulate the results for each cement sample (or round) in separate spreadsheets. In the spreadsheet, list results of each batch in columns and complete the calculations as shown in Table A1.1.

A1.1.1. Eliminate any outliers from the test data and repeat the calculations until none of the values lie outside the normal range.

A1.1.2. Tabulate the cube strengths with all the outliers eliminated and complete the calculations as shown in Table A1.2.

A1.2. *Summary of Results*—Compile the results of the four rounds and complete the calculations as shown in Table A1.3. The number of outliers shall not exceed 5 percent of the total number of tests when rounded to the nearest whole number (e.g., 4 rounds by 4 batches by 9 cubes = 144 tests by 5% (5/100) = 7.2 or 7).

A1.3. *Precision Qualification*—Calculate the relative within-batch error (*RWBE*%) as shown in Table A1.3. This value must be less than 2.1 percent to comply with the limit established in Note 14 of this specification.

A1.4. *Bias Qualification*—The test results compiled in Table A1.3 are evaluated against three limits to demonstrate an acceptable qualification. The limits have been established statistically from analyses of historical CCRL data and are given in Table A1.4.

A1.5. *Rationale for the Limits Given in Section A1.4*:

A1.5.1. The multilaboratory precision (1s%) for the average of n batches is given by:

Table A1.1—Example Using 9-Cube Batch

Round—2				
CCRL Sample #140	Industry Average Strength, X_i = 32.923			
Cast Date—00/00/00				
		7-Day Strengths, MPa		
A	B	C	D	E
Batch Number	1	2	3	4
Cube 1	33.0	34.3	34.4	33.2
Cube 2	33.9	32.5	34.0	34.0
Cube 3	33.4	34.0	34.1	33.8
Cube 4	33.1	33.8	34.0	33.8
Cube 5	33.0	33.4	34.2	34.0
Cube 6	32.8	33.7	31.8	33.1
Cube 7	33.6	32.6	33.9	32.8
Cube 8	31.5	32.1	33.0	33.3
Cube 9	33.6	34.3	33.4	34.4
Average, X_b	33.10	33.42	33.65	33.60
SD_b	0.70	0.82	0.81	0.52
N_b	9	9	9	9
$(N_b–1)SD_b^2$	3.936	5.432	5.265	2.145
			N_r	36
			X_r	33.44
			SD_r	0.692
			MND	1.703
Normal Range				
Maximum	34.81	35.12	35.35	35.30
Minimum	31.40	31.71	32.95	31.89
Outliers	None	None	Cube 6	None

where:

X_i = industry average strength (CCRL);

X_b = average of test values in a single batch;

SD_b = standard deviation of a single batch

$$= \sqrt{\frac{\sum_{\text{cube}}\left(x - x_b\right)^2}{N_b - 1}}$$

N_b = number of tests per batch;

$(N_b - 1)SD_b^2$= an intermediate calculation;

N_r = total number of tests per round;

X_r = grand average of tests values obtained per round, MPa;

SD_r = mean standard deviation of round

$$= \sqrt{\frac{\sum_{\text{Batch}}\left(N_b - 1\right)SD_b^2}{N_r - 1}}$$; and

MND = maximum normal deviation: use Excel™ function "=nominv (1–0.25/Nr,0,SDr)" or equivalent, or use statistical tables to find the inverse integrated nominal distribution for an integral value (1–0.25/N_r) in a normal distribution with $\sigma = SD_r$.

Normal Range:		
Maximum	=	$(X_b + MND)$
Minimum	=	$(X_b - MND)$
Outlier	=	any test value falling outside the calculated normal range

$$s\%_{ML,n} = \sqrt{s\%_{ML}^2 - \left(1 - \frac{1}{n}\right) s\%_{SO}^2}$$

$s\%$	=	coefficient of variation
ML	=	multilaboratory
n	=	batches
SO	=	single operator

A1.5.2. The limit for deviation of the individual rounds (no failures being allowed when four rounds are performed) is 1.2 $s\%_{ML,n}$, as used in T 105.

A1.5.3. The multilaboratory precision (1s%) for the mean of four rounds is 0.5 $s\%_{ML,n}$.

A1.5.4. The limit for deviation of the mean of four rounds (95 percent confidence) is 1.96 times this, or 0.98 $s\%_{ML,n}$.

Table A1.2—Test Data after the Elimination of Outlines (Example Using 9-Cube Batch)

Round—2				
CCRL Sample #140	Industry Average Strength, X_i = 32.923			
Cast Date—00/00/00				
		7-Day Strengths, MPa		
A	B	C	D	E
Batch Number	1	2	3	4
Cube 1	33.0	34.3	34.4	33.2
Cube 2	33.9	32.5	34.0	34.0
Cube 3	33.4	34.0	34.1	33.8
Cube 4	33.1	33.8	34.0	33.8
Cube 5	33.0	33.4	34.2	34.0
Cube 6	32.8	33.7		33.1
Cube 7	33.6	32.6	33.9	32.8
Cube 8		32.1	33.0	33.3
Cube 9	33.6	34.3	33.4	34.4
Average, X_{bv}	33.29	33.42	33.89	33.60
SD_{bv}	0.39	0.82	0.46	0.52
N_{bv}	8	9	8	9
$(N_{bv} - 1)SD_{bv}^2$	1.092	5.348	1.462	2.159
			N_{rv}	34
			X_{rv}	33.55
			X_i	32.92
			SD_{rv}	0.55
			E_r, MPa	0.63
			RE_r,%	1.91

where:

X_{bv}	=	average of valid test values obtained per batch, MPa;
X_i	=	industry average strength (CCRL), MPa;

$$SD_{bv} = \sqrt{\frac{\sum_{\text{Valid cube}} (x - x_{bv})^2}{N_{bv} - 1}};$$

N_{bv} = number of tests per batch;

$(N_{bv} - 1)SD_{bv}^2$ = an intermediate calculation;

N_{rv} = total number of tests per round;

X_{rv} = grand average of tests values obtained per round, MPa;

SD_{rv} = mean standard deviation of round

$$= \sqrt{\frac{\sum_{\text{Batch}} (N_{bv} - 1)SD_{bv}^2}{N_{rv} - 1}};$$

E_r = error = $(X_i - X_{rv})$, MPa; and

R_{er} = relative error for the round, % = $100(E_r/X_{rv})$.

A1.5.5. The values for $s\%_{ML}$ and $s\%_{SO}$ for Cement Classes A and C (non–air-entrained cements for mortar, respectively) are the 7-day values in the current precision statement of T 106M/T 106. There appear to be no data for Cement Class B (air-entrained cements for concrete). Working on the assumption that the value of this quantity is related to the air content, the values adopted for Class B are the mean of the A- and C-values.

A1.5.6. For the applicable conditions, the equations above give the following:

Deviations of Limits for Table A1.4

Cement class	A	B	C	A	B	C
Batches per round (*n*)	6	6	6	4	4	4
Single operator *s*% (single batch)	3.6	5.75	7.9	3.6	5.75	7.9
Multilaboratory *s*% (single batch)	6.4	9.1	11.8	6.4	9.1	11.8
Multilaboratory *s*% (*n* batches)	5.5	7.4	9.3	5.6	7.6	9.6
Limit for deviation of a single round %	6.6	8.9	11.2	6.7	9.1	11.5
Limit of deviation of mean of four rounds %	5.4	7.3	9.2	5.5	7.5	9.4

Table A1.3—Summary of Results

A	B CCRL #	C Day	D X_i MPa	E X_{rv}, MPa	F RE_r, %	G N_{rv}	H SD_{rv}	I $(N_r - 1)SD_r^2$
Round 1	139	1	28.47	30.42	6.85	36	0.97	32.93
Round 2	140	2	32.92	33.55	1.91	34	0.55	9.98
Round 3	141	3	32.64	33.14	1.53	34	0.47	7.29
Round 4	142	4	32.24	33.01	2.39	36	0.51	9.10
						Max, RE_r,%		6.85
						Mean, RE_r,%		3.17
						GMWBE, MPa		0.65
						RWBE, %		2.01
						Max, *RWBE*, %[a]		2.1
						Precision Test		Pass

[a] = See Note 14.

where:

X_r = industry average strength, MPa;
X_{rv} = grand mean value of the valid tests of a round;
RE_{rv}, % = relative error = $100(X_i - X_{rv})$;
N_{rv} = total number of valid tests of the round;
SD_{rv} = mean standard deviation of a round =

$$\sqrt{\frac{\sum_{\text{Batch}} (N_{bv} - 1) SD_{rv}^2}{N_{rv} - 1}};$$

$(N_r - 1)SD_r^2$ = intermediate calculation;
X_g = grand mean value of the valid tests (4 rounds);
N_g = total number of valid tests in 4 rounds;
$GMWBE$ = grand mean within-batch error, MPa =

$$\sqrt{\frac{\sum_{\text{Round}} (N_{rv} - 1) SD_{rv}^2}{N_g - 1}};$$

$RWBE$ = relative within-batch error, % = $100\left(\frac{GMWBE}{X_g}\right)$; and

Max, $RWBE$= maximum allowed $RWBE$ = 2.10% (see Note 14).

Table A1.4—Bias Qualification Requirements

	6-Cube Batches (Minimum 6 Batches per Round)			9-Cube Batches (Minimum 4 Batches per Round)		
Cement classification (see Section 10.4.3.1)	A	B	C	A	B	C
Maximum allowable relative error any 4 or 6 batches, *MARE*$_r$%	6.6	8.9	11.2	6.7	9.1	11.5
Maximum allowable relative error mean of 4 rounds of 4 batches or 6 batches <5% failures, *GRE*%	5.4	7.3	9.2	5.5	7.5	9.4
Minimum allowable confidence limit, *MACL* %	95	95	95	95	95	95

Table A1.5—Bias Tests (Example Using 9-Cube Batches, Class A Cement)

MRE_r %, the maximum relative error value of the 4 rounds	6.85
$MARE_r$ %, max allowable MRE_r from Table A1.4	6.7—Fails
GRE, the average RE_r % of the 4 rounds	3.13
Maximum limit of $MGRE_g$ % from Table A1.4	5.5—Pass
Bias confidence limit, *CL* %	96.99
Minimum allowable confidence limit, *MACL* % (from Table A1.4)	95—Pass

The above results indicate the data fails to show compliance.

where:

MRE_r, % = the maximum relative error, % obtained for any round (from values in column F, Table A1.3),
$MARE_r$, % = the maximum allowable relative error, % of any Round (Table A1.4),
GRE, % = the grand average of the RE_r, % values of the 4 rounds,
$MARE_g$, % = maximum allowed GRE, % value (average of Column F, Table A1.3), and
CL, % = bias confidence limit, %, the confidence with which it can be stated that the error of the mean of 4 rounds is nonzero. Calculate this by use of Excel T function "=ttest(<range of industry means>,<range of values obtained>,1,1)" or equivalent,

or use statistical tables to find the confidence in a one-tailed, paired-value t-test on the set of round errors.

Note A1—The qualification method fails for bias if (1) the MRE_r exceeds the $MARE_r$ percentage limit, or if (2) the GRE percentage exceeds the $MGRE_g$ limit and the CL percentage exceeds 95 percent.