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Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)[1]

This standard is issued under the fixed designation C 109/C 109M; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers determination of the compressive strength of hydraulic cement mortars, using 2-in. or [50-mm] cube specimens.

NOTE 1—Test Method C 349 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 system shall be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.3 Values in SI units shall be obtained by measurement in SI units or by appropriate conversion, using the Rules for Conversion and Rounding 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.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 230 Specification for Flow Table for Use in Tests of Hydraulic Cement[2]

C 305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency[2]

C 349 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using Portions of Prisms Broken in Flexure)[2]

C 511 Specification for Moist Cabinets, Moist Rooms and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[3]

C 778 Specification for Standard Sand[2]

C 1005 Specification for Weights and Weighing Devices for Use in Physical Testing of Hydraulic Cements[2]

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System[4]

3. Summary of Test Method

3.1 The mortar used consists of 1 part cement and 2.75 parts of sand proportioned by mass. Portland or air-entraining portland cements are mixed at specified water/cement ratios. Water content for other cements is that sufficient to obtain a flow of 110 ± 5 in 25 drops of the flow table. Two-inch or [50-mm] test cubes are compacted by tamping in two layers. The cubes are cured one day in the molds and 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 Specification C 1005. The weighing device shall be evaluated for precision and bias 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 of 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

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[2] *Annual Book of ASTM Standards*, Vol 04.01.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

graduations shall extend at least one fifth of the way around.

5.3 *Specimen Molds*, for the 2-in. or [50-mm] cube specimens shall be tight fitting. The molds shall have not more than three cube compartments and shall be separable into not 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.

5.4 *Mixer, Bowl and Paddle*, an electrically driven mechanical mixer of the type equipped with paddle and mixing bowl, as specified in Practice C 305.

5.5 *Flow Table and Flow Mold*, conforming to the requirements of Specification C 230.

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 392°F or [200°C], shall have a cross section of about ½by 1 in. or [13 by 25 mm] and a convenient length of about 5 to 6 in. or [120 to 150 mm]. The tamping face shall be flat and at right angles to the length of the tamper.

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

5.8 *Moist Cabinet or Room*, conforming to the requirements of Specification C 511.

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 %. 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 % of the full scale load (Note 2). The dial shall be readable within 1 % 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; 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 % accuracy the maximum load applied to the specimen.

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 % 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 % 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 % system accuracy the maximum load applied to the specimen.

NOTE 2—As close as can be read is considered 1/50 in. or [0.5 mm] 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 1/25 in. or [1 mm] and 1/16 in. or [1.6 mm]. When the spacing is between 1/16 in. or [1.6 mm] and 1/8 in. or [3.2 mm], one third of the scale interval can be read with reasonable certainty. When the spacing is 1/8 in. or [3.2 mm] or more, one fourth of the scale interval can be read with reasonable certainty.

5.9.2 The upper bearing 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 lie at the center of the surface of the block in contact with the specimen. The block shall be closely held in its spherical seat, but shall be free to tilt in any direction. The diagonal or diameter (Note 3) of the bearing surface shall be only slightly greater than the diagonal of the face of the 2-in. or [50-mm] cube in order to facilitate accurate centering of the specimen. A hardened metal bearing block shall be used beneath the specimen to minimize wear of the lower platen of the machine. 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 0.0005 in. or [0.013 mm] when the blocks are new and shall be maintained within a permissible variation of 0.001 in. or [0.025 mm].

NOTE 3—A diameter of 3⅛ in. or [79.4 mm], is satisfactory, provided that the lower bearing block has a diameter slightly greater than the diagonal of the face of the 2-in. or [50-mm] cube but not more than 2.9 in. or [74 mm], and is centered with respect to the upper bearing block and held in position by suitable means.

6. Materials

6.1 *Graded Standard Sand*:

6.1.1 The sand (Note 4) used for making test specimens

TABLE 1 Permissible Variations of Specimen Molds

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

shall be natural silica sand conforming to the requirements for graded standard sand in Specification C 778.

NOTE 4—*Segregation of Graded Sand*—The graded standard sand should be handled in such a manner as to prevent segregation, since variations in the grading of the sand cause variations 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 *Temperature*—The temperature of the air in the vicinity of the mixing slab, the dry materials, molds, base plates, and mixing bowl, shall be maintained between 68 and 81.5°F or [20 and 27.5°C]. The temperature of the mixing water, moist closet or moist room, and water in the storage tank shall be set at 73.5 ± 3.5°F or [23 ± 2°C] and shall not vary from this temperature by more than± 3°F or [±1.7°C].

7.2 *Humidity*—The relative humidity of the laboratory shall be not less than 50 %. The moist closet or moist room shall conform to the requirements of Specification C 511.

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 non-absorptive 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 6 to 8 in. or [150 to 200 mm] 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 finger print to remain following light finger pressure (Note 5).

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 After placing the mold on its base plate (and attaching, if clamp-type) carefully remove with a dry cloth any excess oil or grease from the surface of the mold and the base plate to which watertight sealant is to be applied. As a sealant, use paraffin, microcrystalline wax, or a mixture of three parts paraffin to five parts rosin by mass. Liquify the sealant by heating between 230 and 248°F or [110 and 120°C]. Effect a watertight seal by applying the liquefied sealant at the outside contact lines between the mold and its base plate.

NOTE 5—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.

NOTE 6—*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, but due to the low strength of paraffin it should be used only when the mold is not held to the base plate by the paraffin alone. A watertight joint may be secured with paraffin alone by slightly warming the mold and base plate before brushing the joint. Molds so treated should be allowed to return to the specified temperature before use.

10. Procedure

10.1 *Composition of Mortars*:

10.1.1 The proportions of materials for the standard mortar shall be one part of cement to 2.75 parts of graded standard sand by weight. Use a water-cement ratio of 0.485 for all portland cements and 0.460 for all air-entraining portland cements. The amount of mixing water for other than portland and air-entraining portland cements shall be such as to produce a flow of 110 ± 5 as determined in accordance with 10.3 and shall be expressed as weight percent of cement.

10.1.2 The quantities of materials to be mixed at one time in the batch of mortar for making six and nine test specimens shall be as follows:

	Number of Specimens	
	6	9
Cement, g	500	740
Sand, g	1375	2035
Water, mL		
Portland (0.485)	242	359
Air-entraining portland (0.460)	230	340
Other (to flow of 110 ± 5)	...	...

10.2 *Preparation of Mortar*:

10.2.1 Mechanically mix in accordance with the procedure given in Practice C 305.

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 1 in. or [25 mm] 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 1 min after completing the mixing operation. Immediately, drop the table through a height of ½ in. or [13 mm] 25 times in 15 s. Using the calipers, determine the flow by measuring the diameters of the mortar along the lines scribed in the table top, adding the four readings. The total of the four readings from the calipers equals the percent increase of the original diameter of the mortar.

10.3.2 For portland and air-entraining portland cements, merely record the flow.

10.3.3 In the case of cements other than portland or air-entraining portland cements, make trial mortars with varying percentages of water until the specified flow is obtained. Make each trial with fresh mortar.

10.4 *Molding Test Specimens*:

10.4.1 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.

10.4.2 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.

10.4.3 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 1 in. or [25 mm] (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 4 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 Fig. 1. The tamping pressure shall be just sufficient to ensure uniform filling of the molds. The 4 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. 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. 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.

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, and 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.

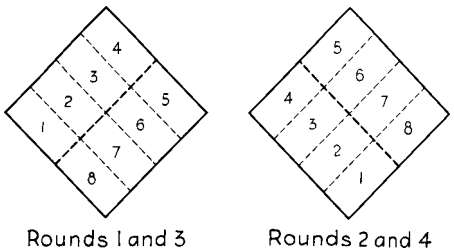

FIG. 1 Order of Tamping in Molding of Test Specimens

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:

Test Age	Permissible Tolerance
24 h	±½ h
3 days	±1 h
7 days	±3 h
28 days	±12 h

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 73.5± 3.5°F or [23 ± 2°C] 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 (Note 7). 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 specimens should be made.

NOTE 7—*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 specimen molds be kept scrupulously clean, as otherwise, large irregularities in the surfaces 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 thousandths of an inch (hundredths of a millimetre); 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 200 to 400 lbs/s [900 to 1800 N/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.

NOTE 8—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:

$$fm = P/A \quad (1)$$

where:
fm = compressive strength in psi or [MPa],
P = total maximum load in lbf or [N], and
A = area of loaded surface in^2 or $[mm^2]$.

Either 2-in. or [50-mm] cube specimens may be used for the determination of compressive strength, whether inch-pound or SI 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 a specimen varies more than 1.5 % from the nominal, use the actual area for the calculation of the compressive strength. The compressive strength of all acceptable test specimens (see Section 12) made from the same sample and tested at the same period shall be averaged and reported to the nearest 10 psi [0.1 MPa].

12. Report

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

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 % of the average when three cubes represent a test age and 7.6 % when two cubes represent a test age (Note 9).

NOTE 9—The probability of exceeding these ranges is 1 in 100 when the within-batch coefficient of variation is 2.1 %. The 2.1 %is an average for laboratories participating in the portland cement and masonry cement reference sample programs of the Cement and Concrete Reference Laboratory.

13.3 If the range of three specimens exceeds the maximum in 13.2, discard the result which differs most from the average and check the range of the remaining two specimens. Make a retest of the sample if less than two specimens remain after disgarding faulty specimens or disgarding tests that fail to comply with the maximum permissible range of two specimens.

NOTE 10—Reliable strength results depend upon careful observance of all of 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; for example, those covering the testing of the specimens as prescribed in 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 cause lower strength results.

14. Precision and Bias

14.1 *Precision*—The precision statements for this test method are listed in Table 2 and are based on results from the Cement and Concrete Reference Laboratory 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.

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

TABLE 2 Precision

		Test Age, Days	Coefficient of Variation 1s %[A]	Acceptable Range of Test Results d2s %[A]
Portland Cements				
Constant water-cement ratio:				
Single-lab		3	4.0	11.3
		7	3.6	10.2
	Av		3.8	10.7
Multi-lab		3	6.8	19.2
		7	6.4	18.1
	Av		6.6	18.7
Blended Cements				
Constant flow mortar:				
Single-lab		3	4.0	11.3
		7	3.8	10.7
		28	3.4	9.6
	Av		3.8	10.7
Multi-lab		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-lab		7	7.9	22.3
		28	7.5	21.2
	Av		7.7	21.8
Multi-lab		7	11.8	33.4
		28	12.0	33.9
	Av		11.9	33.7

[A] These numbers represent, respectively, the (1s %) and (d2s %) limits as described in Practice C 670.