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Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete[1]

This standard is issued under the fixed designation C1604/C1604M; 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 covers obtaining, preparing, and testing cores drilled from shotcrete for length, compressive strength, or splitting tensile strength determinations.

1.2 The values stated in either inch-pound units or SI units shall be regarded separately as standard. SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.4 *This standard does not purport to address 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:*[2]

C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C125 Terminology Relating to Concrete and Concrete Aggregates

C174/C174M Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores

C496/C496M Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

C617 Practice for Capping Cylindrical Concrete Specimens

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

C823 Practice for Examination and Sampling of Hardened Concrete in Constructions

C1140 Practice for Preparing and Testing Specimens from Shotcrete Test Panels

C1231/C1231M Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

2.2 *ACI Standards:*[3]

318 Building Code Requirements for Structural Concrete

506.2 Specification for Shotcreting

506.4R Guide for the Evaluation of Shotcrete

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology C125.

4. Significance and Use

4.1 This test method provides standardized procedures for obtaining cored specimens to determine the compressive strength and splitting tensile strength of shotcrete during pre-construction, during construction, and from older shotcrete structures.

4.2 Generally, test specimens are obtained *in situ* when doubt exists about the in-place shotcrete quality due either to low strength test results during construction or signs of distress in the structure. Other uses of this method are to provide specimens for acceptance testing, construction control and to assess the condition, quality and uniformity of the shotcrete in accordance with Practice C823 (see Note 1).

4.3 Specimens obtained by this method are used to verify the thickness of shotcrete and aid in the visual assessment of the shotcrete quality, workmanship, defects, shotcrete-to-substrate bond and the condition of any reinforcement used in the shotcrete.[4]

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.46 on Shotcrete.

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[2] 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.

[3] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, http://www.concrete.org.

[4] Bartlett, F. M., and MacGregor, J. G., "Effect of Core Diameter on Concrete Core Strengths," *ACI Materials Journal*, Vol 91, No. 5, September–October 1994, pp. 460–470.

4.4 Shotcrete strength is affected by the location of the shotcrete in a structure. Vertical, sub-horizontal and overhead elements of the shotcrete structure may show variability. Core strength is affected by core orientation relative to direction of shotcrete application. These factors shall be considered in planning the locations for obtaining shotcrete samples and in interpreting strength test results.

4.5 Shotcrete is applied in single or multiple layers, as plain shotcrete, reinforced shotcrete, or fiber-reinforced shotcrete. Core samples containing wire-mesh and reinforcing bars shall not be used for compressive strength testing.

4.6 The strength of shotcrete is affected by moisture content, the specified moisture conditioning procedure for cores is intended to provide test specimens with reproducible moisture contents that minimize within-laboratory and between-laboratory variations.

4.7 Sample acquisition may require a combination of core-drilling, sawing, and grinding that may have the potential to adversely affect the sample condition if care is not taken during sampling and testing.

4.8 A sampling plan shall be established that indicates the number of samples and their locations (see Note 1). The acceptance criteria for shotcrete core strengths shall be established by the specifier of tests (see Note 2).

NOTE 1—Practice C823 provides guidance on the development of a sampling plan for concrete in constructions. A number of methods that supplement the examination of hardened shotcrete by means of representative core samples and testing are discussed in ACI 506.4R.

NOTE 2—The core strength acceptance criteria cited in ACI 318 are based on a comparison of molded cylinder specimens and cores. Shotcrete strengths are always based on core specimens, therefore the 85 % factor used in core to cylinder comparisons is not relevant to the evaluation of shotcrete core strengths. A typical shotcrete specification reflecting standard industry practice is contained in ACI 506.2.

5. Apparatus

5.1 *Core Drill,* for obtaining cylindrical core specimens with diamond impregnated bits attached to a core barrel. The core drill shall have a rigid mounting base and be capable of being operated in any orientation normal to the shotcrete structure that is being sampled. The core drill shall be free from excessive vibration when in operation and shall have sufficient torque and consistent rotational speed to sustain uniform rates of penetration of the core drill. The core barrel shall be cooled and core cuttings flushed with water during operation.

5.2 *Saw,* for cutting core specimens to size for compressive strength. The saw shall have a diamond or silicon carbide cutting edge and shall be capable of cutting plain and reinforced specimens in a single pass that conform with the prescribed dimensions, without excessive heating or shock.

5.3 *Grinding wheel,* to trim and clean plain and fiber-reinforced shotcrete specimens that conform to prescribed tolerances without significantly disturbing the aggregates, matrix or fiber-reinforcement.

6. Sampling

6.1 *General:*

6.1.1 Sampling shall be planned in accordance with the applicable provisions of Practice C823. The number of samples, sample locations and sampling procedures shall be established in the plan.

6.1.2 Shotcrete samples obtained from test panels shall be in accordance with the applicable provisions of Practice C1140.

6.1.3 Samples of hardened shotcrete for use in the preparation of strength test specimens shall not be taken until the shotcrete is strong enough to permit sample removal without disturbing the bond between the mortar, coarse aggregate (see Note 3) and fiber-reinforcement. When preparing strength test specimens from samples of hardened shotcrete, samples that have been damaged in the process of removal shall not be used. Specimens of defective shotcrete that cannot be tested shall be reported as such if the defects are representative of the in-place condition of the shotcrete (see ACI 506.4R).

NOTE 3—It is not possible to specify a minimum age when shotcrete is strong enough to withstand damage during removal, because the strength at any age depends on the strength grade and curing of the shotcrete. If accelerating admixtures are used during shotcrete application, core specimens may be obtained for testing at approximately 6 h. If this is not practical, removal of shotcrete can proceed if cored or cut surfaces do not display erosion of the mortar and the exposed coarse aggregate particles are embedded firmly in the mortar. Nondestructive test methods may be used to estimate level of in-place strength development prior to attempting removal of shotcrete core samples (see ACI 506.4R).

6.1.4 Specimens containing embedded reinforcement shall not be used for determining compressive or splitting tensile strength.

6.2 *Core Drilling*—Drill core specimens perpendicular to the surface and avoid drilling near formed joints or edge placement. Record the approximate angle between the drilled core axis and the plane of the shotcrete as placed.

7. Measuring the Length of Drilled Cores

7.1 Cores for determining the thickness of shotcrete layers or other structural elements shall have a diameter of at least 3.0 in. [75 mm] when the lengths of such cores are to be measured in accordance with Test Method C174/C174M.

7.2 For cores that are not intended for determining structural dimensions, measure the longest and shortest lengths on the cut surface along lines parallel to the core axis. Record the average length to the nearest ¼ in. [5 mm].

8. Cores for Compressive Strength

8.1 *Diameter*—The diameter of core specimens for the determination of compressive strength in load bearing structural members shall be at least 3.0 in. [75 mm] (see Note 4). Core diameters less than 3.0 in. [75 mm] shall be permitted as directed by the specifier of the tests.

NOTE 4—The compressive strengths of 2-in [50-mm] diameter cores are known to be somewhat lower and more variable than those of 3-in. [75-mm] diameter cores. In addition, smaller diameter cores appear to be more sensitive to the effect of the length-diameter ratio[4].

8.2 *Length*—The preferred length of the capped or ground specimen is nominally two times the diameter.

8.2.1 If the ratio of the length to the diameter (L/D) of the core exceeds 2.1, reduce the length of the core so that the ratio of the capped or ground specimen is between 1.9 and 2.1. Core

specimens with length-diameter ratios equal to or less than 1.75 require corrections to the measured compressive strength (see. 8.8.1). A strength correction factor is not required for L/D greater than 1.75. A core having a length of less than 95 % of its diameter before capping or a length less than its diameter after capping or end grinding shall not be tested unless so directed by the specifyer of the tests.

8.2.2 For non-load bearing structural members or when it is impossible to obtain shotcrete cores with length-diameter ratio (L/D) greater than or equal to 1.0, core specimens shall be subject to the approval of the specifier of the tests.

8.3 *Moisture Conditioning*—The following procedure is intended to preserve the moisture of the drilled core and to provide a reproducible moisture condition that minimizes the effects of moisture gradients introduced by wetting during drilling and specimen preparation.

8.3.1 The following procedure is used to obtain cores having a moisture condition that is representative of the in-place shotcrete. After cores have been drilled, wipe off surface water on the drilled core with a dry cloth and allow remaining surface moisture to evaporate. When surfaces appear dry, but not later than 1 h after drilling, place cores in separate plastic bags or nonabsorbent containers and seal to prevent moisture loss. Maintain cores at ambient temperature, and protect cores from exposure to direct sunlight. Transport the cores to the testing laboratory as soon as practicable. Keep cores in the sealed plastic bags or nonabsorbent containers at all times except during end preparation and for a maximum time of 2 h to permit capping before testing.

8.3.2 If water is used during sawing or grinding of core ends, complete these operations as soon as practicable, but no later than 2 days after drilling of cores. After completing end preparation, use a dry cloth to remove surface moisture, allow the surfaces to dry, and place the cores in sealed plastic bags or nonabsorbent containers. Minimize the duration of exposure to water during end preparation.

8.3.3 Allow cores aged 28 days or more to remain in the sealed plastic bags or nonabsorbent containers for at least 5 days after last being wetted and before testing (see Note 5). For early strength testing of specimens aged 28 days or less, test specimens as directed by the specifier of the tests.

NOTE 5—The waiting period of at least 5 days is intended to reduce moisture gradients introduced when the core is drilled or wetted during sawing or grinding.

8.3.4 When the specifier of the tests so directs, test cores in a moisture condition other than achieved by conditioning according to 8.3.3. Report the alternative moisture conditioning procedure.

8.4 *Sawing of Ends*—The ends of core specimens to be tested in compression shall be flat, and perpendicular to the longitudinal axis. If necessary, saw the ends of cores that will be capped so that the following requirements are met:

8.4.1 Projections, if any, shall not extend more than 0.2 in. [5 mm] above the end surfaces.

8.4.2 The end surfaces shall not depart from perpendicularity to the longitudinal axis by a slope of more than 1:8*d* [or 1:0.3*d*], where *d* is the average core diameter in inches [or mm].

NOTE 6—This limitation is intended to avoid cap thicknesses that exceed the requirements of Practice C617.

8.5 *Capping*—If the ends of the cores do not conform to the perpendicularity and planeness requirements of Test Method C39/C39M, they shall be sawn or ground to meet those requirements or capped in accordance with Practice C617. If cores are capped in accordance with Practice C617, the capping device shall accommodate actual core diameters and produce caps that are concentric with the core ends. Measure core lengths to the nearest 0.1 in. [2 mm] before capping. Unbonded caps in accordance with Practice C1231/C1231M are not permitted.

NOTE 7—Before capping, the density of a core may be estimated by weighing it and dividing the mass by the volume calculated from the average diameter and length.

8.6 *Measurement*—Before testing, measure the length of the capped or ground specimen to the nearest 0.1 in. [2 mm] and use this length to compute the length-diameter (L/D) ratio. Determine the average diameter by averaging two measurements taken at right angles to each other at the mid-height of the specimen. Measure core diameters to the nearest 0.01 in. [0.2 mm] when the difference in core diameters does not exceed 2 % of their average; otherwise, measure to the nearest 0.1 in. [2 mm]. Do not test cores if the difference between the largest and smallest diameter exceeds 5 % of their average.

8.7 *Testing*—Test the specimens in accordance with Test Method C39/C39M. Test the specimens within 7 days after coring, unless so directed by the specifier of the tests.

8.8 *Calculation*—Calculate the compressive strength of each specimen using the computed cross-sectional area based on the average diameter of the specimen.

8.8.1 If the ratio of the core length to diameter (L/D) of the specimen is 1.75 or less, correct the results obtained in 8.8 by multiplying by the appropriate correction factor shown in the following table (see Note 8).

Ratio of Length to Diameter (L/D)	Strength Correction Factor
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87

Use interpolation to determine correction factors for L/D values not given in the table.

NOTE 8—Correction factors depend on various conditions such as moisture condition, strength level, and elastic modulus. Average values are given in the table. These correction factors apply to normal density shotcrete. They are applicable to both dry and wet shotcrete for nominal concrete strengths between 2000 psi and 6000 psi [14 MPa and 42 MPa]. For strengths above 10 000 psi [70 MPa], test data on concrete cores show that the correction factors may be larger than the values listed above[5].

8.9 *Report*—Report the results as required by Test Method C39/C39M with the addition of the following information:

8.9.1 Length of core as drilled to the nearest ¼ in. [5 mm],

[5] Bartlett, F. M., and MacGregor, J. G, "Effect of Core Length-to-Diameter Ratio on Concrete Core Strengths," *ACI Materials Journal*, Vol 91, No. 4, July–August 1994, pp. 339–348.

8.9.2 Length of test specimen before and after capping or end grinding to the nearest 0.1 in. [2 mm], and average diameter of core to the nearest 0.01 in. [0.2 mm] or 0.1 in. [2 mm],

8.9.3 Compressive strength to the nearest 10 psi [0.1 MPa] when the diameter is measured to the nearest 0.01 in. [0.2 mm] and to the nearest 50 psi [0.5 MPa] when the diameter is measured to the nearest 0.1 in. [2 mm], after correction for length-diameter ratio when required,

8.9.4 Direction of application of the load on the specimen with respect to the horizontal plane of the shotcrete as placed,

8.9.5 The moisture conditioning history:

8.9.5.1 The date and time core was obtained and first placed in sealed bag or nonabsorbent container;

8.9.5.2 If water was used during end preparation, the date and time end preparation was completed and core placed in sealed bag or nonabsorbent container,

8.9.6 The date and time when tested,

8.9.7 Nominal maximum size of shotcrete aggregate,

8.9.8 If determined, the estimated density,

8.9.9 If applicable, description of defects in cores that could not be tested, and

8.9.10 If any deviation from this test method was required, describe the deviation and explain why it was necessary.

8.10 *Precision*

8.10.1 The precision of compressive strength of shotcrete cores measured by this test method has not been established, but is believed to be similar to that of concrete cores.[6] Therefore, the following provisional statements taken from the Test Method C42/C42M are provided until an inter-laboratory study of shotcrete cores are completed.

8.10.2 The single-operator coefficient of variation on concrete cores has been found to be 3.2 %[7] for a range of compressive strength between 4500 psi [32.0 MPa] and 7000 psi [48.3 MPa]. Therefore, results of two properly conducted tests of single cores by the same operator on the same sample of material should not differ from each other by more than 9 %[7] of their average.

8.10.3 The multi-laboratory coefficient of variation on cores has been found to be 4.7 %[7] for a range of compressive strength between 4500 psi [32.0 MPa] and 7000 psi [48.3 MPa]. Therefore, results of two properly conducted tests on cores sampled from the same hardened concrete (where a single test is defined as the average of two observations (cores), each made on separate adjacent drilled 4-in. [100-mm] diameter cores) and tested by two different laboratories should not differ from each other by more than 13 %[7] of their average.

8.11 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

9. Cores for Splitting Tensile Strength

9.1 *Test Specimens*—The specimens shall conform to the dimensional requirements in 8.1, 8.2, 8.4.1, and 8.4.2. Ends are not to be capped.

9.2 *Moisture Conditioning*—Condition the specimens as described in 8.3, or as directed by the specifier of the tests.

9.3 *Bearing Surfaces*—The line of contact between the specimen and each bearing strip shall be straight and free of any projections or depressions higher or deeper than 0.01 in. [0.2 mm]. When the line of contact is not straight or contains projections or depressions having heights or depths greater than 0.01 in [0.2 mm], grind or cap the specimen so as to produce bearing lines meeting these requirements. Do not test specimens with projections or depressions greater than 0.1 in. [2 mm]. When capping is employed, the caps shall be as thin as practicable and shall be formed of high-strength gypsum cement.

NOTE 9—Fig. 1 illustrates a device suitable for applying caps to the bearing surfaces of core specimens.

9.4 *Testing*—Test the specimens in accordance with Test Method C496/C496M.

9.5 *Calculation and Report*—Calculate the splitting tensile strength and report the results as required in Test Method C496/C496M. When grinding or capping of the bearing surfaces is required, measure the diameter between the finished surfaces. Indicate that the specimen was a core and provide the moisture conditioning history as in 8.9.5.

9.6 *Precision*

9.6.1 The precision of splitting tensile strength of shotcrete cores measured by this test method has not been established, but is believed to be similar to that of concrete cores.[8] Therefore, the following provisional statements taken from the Test Method C42/C42M are provided until an inter-laboratory study of shotcrete cores is completed.

9.6.2 The within-laboratory single operator coefficient of variation for splitting tensile strength between 520 psi [3.6 MPa] and 590 psi [4.1 MPa] of cores has been found to be 5.3 %.[9] Therefore, results of two properly conducted tests by the same operator in the same laboratory on the same sample of material should not differ by more than 14.9 %[9] of their average.

9.6.3 The multi-laboratory coefficient of variation for splitting tensile strength between 520 psi [3.6 MPa] and 590 psi [4.1 MPa] of cores has been found to be 15 %.[9] Therefore, results of two properly conducted tests on the same sample of material of hardened concrete and tested by two different laboratories should not differ from each other by more than 42.3 %[9] of their average.

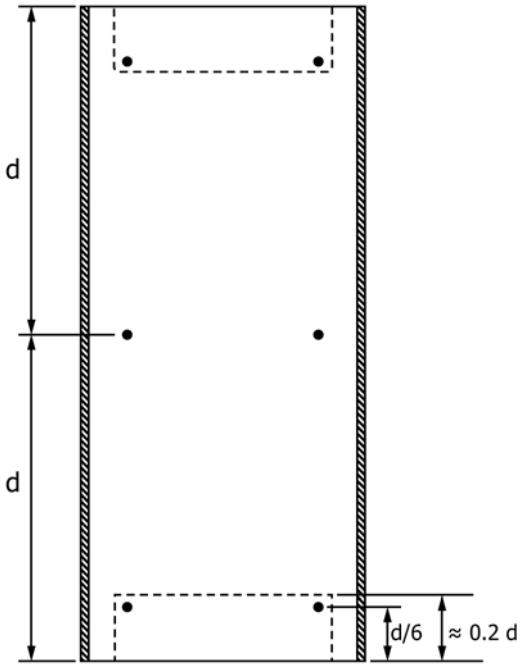
9.7 *Bias*—Since there is no accepted reference material suitable for determining the bias of the procedure in this test method, no statement on bias is being made.

[6] Bollin, G. E., "Development of Precision and Bias Statements for Testing Drilled Cores in Accordance with ASTM C42," *Journal of Cement, Concrete, and Aggregates*, Vol 15, No. 1, 1993.

[7] These numbers represent, respectively, the (1s %) and (d2s %) limits as described in ASTM Practice C670.

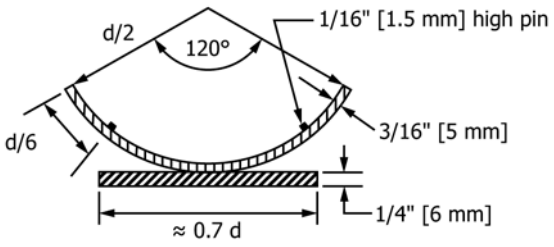
[8] Steele, G. W., "Portland Cement Concrete Core Proficiency Sample Program," Strategic Highway Research Program, SHHP-P-636, National Research Council, Washington D.C., 1993.

[9] These numbers represent, respectively, the (1s %) and (d2s %) limits a described in ASTM Practice C670.



PLAN

d = nominal core diameter



ELEVATION

FIG. 1 Suitable Capping Device for Splitting Tensile Strength Test

10. Keywords

10.1 compressive strength; core; shotcrete; splitting tensile strength