Designation: C192/C192M − 16a

Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory[1]

This standard is issued under the fixed designation C192/C192M; 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 U.S. Department of Defense.

1. Scope*

1.1 This practice covers procedures for making and curing test specimens of concrete in the laboratory under accurate control of materials and test conditions using concrete that can be consolidated by rodding or vibration as described herein.

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning—**Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to exposed skin and tissue upon prolonged exposure.[2])

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C70 Test Method for Surface Moisture in Fine Aggregate
C125 Terminology Relating to Concrete and Concrete Aggregates
C127 Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
C128 Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate
C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C172/C172M Practice for Sampling Freshly Mixed Concrete
C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C231/C231M Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C330/C330M Specification for Lightweight Aggregates for Structural Concrete
C403/C403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C470/C470M Specification for Molds for Forming Concrete Test Cylinders Vertically
C494/C494M Specification for Chemical Admixtures for Concrete
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C566 Test Method for Total Evaporable Moisture Content of Aggregate by Drying
C617/C617M Practice for Capping Cylindrical Concrete Specimens
C1064/C1064M Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
C1077 Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation

2.2 *American Concrete Institute Publications:*[4]

211.3 Practice for Selecting Proportions for No-Slump Concrete
309R Guide for Consolidation of Concrete

3. Significance and Use

3.1 This practice provides standardized requirements for preparation of materials, mixing concrete, and making and curing concrete test specimens under laboratory conditions.

[1] This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

Current edition approved June 1, 2016. Published June 2016. Originally approved in 1944. Last previous edition approved in 2016 as C192/C192M – 16. DOI: 10.1520/C0192_C0192M-16A.

[2] See section on Safety Precautions, *Manual of Aggregate and Concrete Testing*, *Annual Book of ASTM Standards*, Vol 04.02.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

***A Summary of Changes section appears at the end of this standard**

3.2 If specimen preparation is controlled as stipulated herein, the specimens may be used to develop information for the following purposes:

3.2.1 Mixture proportioning for project concrete,

3.2.2 Evaluation of different mixtures and materials,

3.2.3 Correlation with nondestructive tests, and

3.2.4 Providing specimens for research purposes.

NOTE 1—The concrete test results for concrete specimens made and cured using this practice are widely used. They may be the basis for acceptance testing for project concrete, research evaluations, and other studies. Careful and knowledgeable handling of materials, mixing concrete, molding test specimens, and curing test specimens is necessary. Many laboratories performing this important work are independently inspected or accredited. Practice C1077 identifies and defines the duties, responsibilities, and minimum technical qualification requirements of laboratory personnel and the minimum requirements for equipment used in testing concrete and concrete aggregates.

4. Apparatus

4.1 *Molds, General*—Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall conform to the dimensions and tolerances specified in the method for which the specimens are required. Molds shall hold their dimensions and shape under all conditions of use. Watertightness of molds during use shall be judged by their ability to hold water poured into them. Test procedures for watertightness are given in the section on Test Methods for Elongation, Absorption, and Watertightness of Specification C470/C470M. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax, shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

4.2 *Cylinder Molds:*

4.2.1 *Molds for Casting Specimens Vertically* shall conform to the requirements of 4.1 and Specification C470/C470M.

4.2.2 *Horizontal Molds for Creep Test Cylinders* shall conform to the requirements of 4.1 and to the requirements for symmetry and dimensional tolerance in the section on General Requirements except for verticality requirements of Specification C470/C470M. The use of horizontal molds is intended only for creep specimens that contain axially embedded strain gages. Molds for creep cylinders to be filled while supported in a horizontal position shall have a filling slot parallel to the axis of the mold which extends the full length to receive the concrete. The width of the slot shall be one half the diameter of the specimen. If necessary the edges of the slot shall be reinforced to maintain dimensional stability. Unless specimens are to be capped or ground to produce plane ends, the molds shall be provided with two machined metal end plates at least 25 mm [1 in.] thick and the working surfaces shall comply with the requirements for planeness and surface roughness given in the section on Capping Plates of Practice C617/C617M. Provision shall be made for fixing both end plates firmly to the mold. The inside surface of each end plate shall be provided with at least three lugs or studs approximately 25 mm [1 in.] long, firmly fastened to the plate for embedment in the concrete. One base plate shall be drilled from the inside at an angle to permit the lead wire from the strain gage to exit the specimen through the edge of the plate. Provision shall be made for accurately positioning the strain gage. All necessary holes shall be as small as possible to minimize disturbance to subsequent strain measurements and shall be sealed to prevent leakage.

4.3 *Beam and Prism Molds* shall be rectangular in shape (unless otherwise specified) and of the dimensions required to produce the desired specimen size. The inside surfaces of the molds shall be smooth and free from indentations. The sides, bottom, and ends shall be at right angles to each other and shall be straight and true and free of warpage. Maximum variation from the nominal cross section shall not exceed 3 mm [1⁄8 in.] for molds with depth or breadth of 150 mm [6 in.] or more, or 2 mm [1⁄16 in.] for molds of smaller depth or breadth. Except for flexure specimens, molds shall not vary from the nominal length by more than 2 mm [1⁄16 in.]. Flexure molds shall not be shorter than 2 mm [1⁄16 in.] of the required length, but may exceed it by more than that amount.

4.4 *Tamping Rod*—A round, smooth, straight, steel rod with a diameter conforming to the requirements in Table 2. The length of the tamping rod shall be at least 100 mm [4 in.] greater than the depth of the mold in which rodding is being performed, but not greater than 600 mm [24 in.] in overall length (see Note 2). The rod shall have the tamping end or both ends rounded to a hemispherical tip of the same diameter as the rod.

NOTE 2—A rod length of 400 mm [16 in.] to 600 mm [24 in.] meets the requirements of the following: Practice C31/C31M, Test Method C138/C138M, Test Method C143/C143M, Test Method C173/C173M, and Test Method C231/C231M.

4.5 *Mallets*—A mallet with a rubber or rawhide head weighing 0.6 ± 0.2 kg [1.25 ± 0.50 lb] shall be used.

4.6 *Vibrators:*

4.6.1 *Internal Vibrators*—The vibrator frequency shall be at least 9000 vibrations per minute [150 Hz] while the vibrator is operating in the concrete. The diameter of a round vibrator shall be no more than one fourth the diameter of the cylinder mold or one fourth the width of the beam or prism mold. Other shaped vibrators shall have a perimeter equivalent to the

TABLE 1 Number of Layers Required for Specimens

Specimen Type and Size	Mode of Consolidation	Numbers of Layers of Approximate Equal Depth
Cylinders:		
Diameter, mm [in.]		
75 to 100 [3 or 4]	rodding	2
150 [6]	rodding	3
225 [9]	rodding	4
up to 225 [9]	vibration	2
Prisms and horizontal creep Cylinders:		
Depth, mm [in.]		
up to 200 [8]	rodding	2
over 200 [8]	rodding	3 or more
up to 200 [8]	vibration	1
over 200 [8]	vibration	2 or more

TABLE 2 Diameter of Rod and Number of Roddings to be Used in Molding Test Specimens

	Cylinders	
Diameter of Cylinder, mm [in.]	Diameter of Rod mm [in.]	Number of Strokes/Layer
75 [3] to < 150 [6]	10 ± 2 [3⁄8 ± 1⁄16]	25
150 [6]	16 ± 2 [5⁄8 ± 1⁄16]	25
200 [8]	16 ± 2 [5⁄8 ± 1⁄16]	50
250 [10]	16 ± 2 [5⁄8 ± 1⁄16]	75
	Beams and Prisms	
Top Surface Area of Specimen, cm^2 [$in.^2$]	Diameter of Rod mm [in.]	Number of Roddings/Layer
160 [25] or less	10 ± 2 [3⁄8 ± 1⁄16]	25
165 to 310 [26 to 49]	10 ± 2 [3⁄8 ± 1⁄16]	one for each 7 cm^2 [1 $in.^2$] of surface
320 [50] or more	16 ± 2 [5⁄8 ± 1⁄16]	one for each 14 cm^2 [2 $in.^2$] of surface
	Horizontal Creep Cylinders	
Diameter of Cylinder mm [in.]	Diameter of Rod mm [in.]	Number of Roddings/Layer
150 [6]	16 ± 2 [5⁄8 ± 1⁄16]	50 total, 25 along both sides of axis

circumference of an appropriate round vibrator. The combined length of the vibrator shaft and vibrating element shall exceed the depth of the section being vibrated by at least 75 mm [3 in.]. The vibrator frequency shall be checked with a vibrating-reed tachometer or other suitable device at an interval not to exceed two years. If the vibrator manufacturer recommends a shorter verification interval or a verification procedure, the manufacturer's recommendation shall be followed.

NOTE 3—For information on size and frequency of various vibrators and method to check vibrator frequency, see ACI 309R.

4.6.2 *External Vibrators*—The two types of external vibrators permitted are either table or plank. The external vibrator frequency shall be 3600 vibrations per minute (60 Hz) or higher.

4.6.3 Provisions shall be made for clamping the mold securely to the apparatus for both types of vibrators.

NOTE 4—Vibratory impulses are frequently imparted to a table or plank vibrator through electromagnetic means, or by use of an eccentric weight on the shaft of an electric motor or on a separate shaft driven by a motor.

4.7 *Small Tools*—Tools and items such as shovels, pails, trowels, wood float, blunted trowels, straightedge, feeler gage, scoops, rulers, rubber gloves, and metal mixing bowls shall be provided.

4.8 *Slump Apparatus*—The apparatus for measurement of slump shall conform to the requirements of Test Method C143/C143M.

4.9 *Sampling and Mixing Pan*—The pan shall be flat-bottom and of heavy-gage metal, watertight, of convenient depth, and of sufficient capacity to allow easy mixing by shovel or trowel of the entire batch; or, if mixing is by machine, to receive the entire batch on discharge of the mixer and allow remixing in the pan by trowel or shovel.

4.10 *Wet-Sieving Equipment*—If wet-sieving is required, the equipment shall conform to the requirements of Practice C172/C172M.

4.11 *Air Content Apparatus*—The apparatus for measuring air content shall conform to the requirements of either Test Methods C231/C231M or C173/C173M.

4.12 *Scales*—Scales for determining the mass of batches of materials and concrete shall be accurate within 0.3 % of the test load at any point within the range of use.

NOTE 5—In general the mass of small quantities should not be determined on large capacity scales. In many applications the smallest mass determined on a scale should be greater than about 10 % of the maximum capacity of the scale; however, this will vary with the performance characteristics of the scale and the required accuracy of the determination. Acceptable scales used for determining the mass for concrete materials preferably should determine mass accurately to about 0.1 % of total capacity and the foregoing precaution is applicable. However, certain analytical and precision balances are exceptions to this rule and should weigh accurately to 0.001 %. Particular care must be exercised in measuring small quantities of material by determining the difference between two much larger masses.

4.13 *Temperature Measuring Device*—The temperature measuring device shall conform to the requirements of Test Method C1064/C1064M.

4.14 *Concrete Mixer*—A power-driven concrete mixer shall be a revolving drum, tilting mixer, or suitable revolving pan or revolving-paddle mixer capable of thoroughly mixing batches of the prescribed sizes at the required slump.

NOTE 6—A pan mixer is usually more suitable for mixing concrete with less than 25 mm [1 in.] slump than a revolving drum mixer. The rate of rotation, degree of tilt, and rated capacity of tilting mixers are not always suitable for laboratory mixed concrete. It may be found desirable to reduce the rate of rotation, decrease the angle of tilt from the horizontal, and use the mixer at somewhat less than the manufacturer's rated capacity.

5. Specimens

5.1 *Cylindrical Specimens*—Cylinder dimensions shall be as stipulated in the specification, test method or practice for the laboratory studies being performed and shall meet the requirements of 5.4. If dimensions are not stipulated in a specification, test method, or practice, the specimen selected shall have a length that is twice the diameter and meet the requirements of 5.4.

NOTE 7—The same cylinder size should be used for the reference (control) concrete mixture and test concrete mixtures when conducting comparative studies such as those required in Specification C494/C494M. For mixture proportioning of project concrete, it is preferable for the cylinder size in the laboratory to be the same as that specified for acceptance testing.

NOTE 8—When molds in SI units are required and not available, equivalent inch-pound unit size mold should be permitted.

5.1.1 Cylindrical specimens for tests other than creep shall be molded and allowed to harden with the axis of the cylinder vertical.

5.1.2 Cylindrical creep specimens may be cast with the cylindrical axis either vertical or horizontal and allowed to harden in the position in which cast.

5.2 *Prismatic Specimens*—Beams for flexural strength, prisms for freezing and thawing, bond, length change, volume change, etc., shall be formed with their long axes horizontal, unless otherwise required by the method of test in question, and shall conform in dimension to the requirements of the specific test method.

5.3 *Other Specimens*—Other shapes and sizes of specimens for particular tests may be molded as desired following the general procedures set forth in this practice.

5.4 *Specimen Size versus Aggregate Size*—The diameter of a cylindrical specimen or minimum cross-sectional dimension of a rectangular section shall be at least three times the nominal maximum size of the coarse aggregate in the concrete as defined in Terminology C125. When the nominal maximum size of the coarse aggregate exceeds 50 mm [2 in.], the sample shall be treated by wet sieving through a 50 mm (2 in.) sieve as described in Practice C172/C172M, unless otherwise stipulated.

5.5 *Number of Specimens*—The number of specimens and the number of test batches are dependent on established practice and the nature of the test program. Guidance is usually given in the test method or specification for which the specimens are made. Usually three or more specimens are molded for each test age and test condition unless otherwise specified (Note 9). Specimens involving a given variable should be made from three separate batches mixed on different days. An equal number of specimens for each variable should be made on any given day. When it is impossible to make at least one specimen for each variable on a given day, the mixing of the entire series of specimens should be completed in as few days as possible, and one of the mixtures should be repeated each day as a standard of comparison.

NOTE 9—Test ages often used are 7 and 28 days for compressive strength tests, or 14 and 28 days for flexural strength tests. Specimens containing Type III cement are often tested at 1, 3, 7, and 28 days. For later test ages, 3 months, 6 months, and 1 year are often used for both compressive and flexural strength tests. Other test ages may be required for other types of specimens.

6. Preparation of Materials

6.1 *Temperature*—Before mixing the concrete, bring the concrete materials to room temperature in the range from 20 to 30°C [68 to 86°F], except when the temperature of the concrete is stipulated. When a concrete temperature is stipulated, the method proposed to obtain the concrete temperature needs approval of the stipulator.

6.2 *Cement*—Store the cement in a dry place, in moisture-proof containers, preferably made of metal. The cement shall be thoroughly mixed to provide a uniform supply throughout the tests. It shall be passed through a 850-μm (No. 20) or finer sieve to remove all lumps, remixed on a plastic sheet, and returned to sample containers.

6.3 *Aggregates*—In order to preclude segregation of a coarse aggregate, separate into individual size fractions and for each batch recombine in the proper proportions to produce the desired grading.

NOTE 10—Only rarely is a coarse aggregate batched as a single size fraction. The number of size fractions will generally be between 2 and 5 for aggregate smaller than 60 mm [2½ in.]. When a size fraction to be batched is present in amounts in excess of 10 %, the ratio of the opening of the larger to the smaller sieve should not exceed 2.0. More closely sized groups are sometimes advisable.

6.3.1 Unless fine aggregate is separated into individual size fractions, maintain it in a damp condition or restore to a damp condition until use, to prevent segregation, unless material uniformly graded is subdivided into batch size lots using a sample splitter with proper size openings. If unusual gradings are being studied, the fine aggregate may need to be dried and separated into individual sizes. In this instance, if the total quantity of fine aggregate required is larger than can be efficiently blended in a single unit, then the individual size fractions should be determined in a mass required for each individual batch. When the total quantity of fine aggregate needed for the complete investigation is such that it can be thoroughly mixed, blended, and maintained in a damp condition, then it should be handled in that manner. Determine the specific gravity and absorption of aggregates in accordance with either Test Methods C127 or C128.

6.3.2 Before incorporating in concrete, prepare the aggregate to ensure a definite and uniform condition of moisture. Determine the weight of aggregate to be used in the batch by one of the following procedures:

6.3.2.1 Determine the mass of low-absorption aggregates (absorption less than 1.0 %) in the room-dry condition with allowance made for the amount of water that will be absorbed from the unset concrete (Note 11). This procedure is particularly useful for coarse aggregate which must be batched as individual sizes; because of the danger of segregation it can be used for fine aggregate only when the fine aggregate is separated into individual size fractions.

NOTE 11—When using aggregates with low absorption in room-dry condition the amount of water that will be absorbed by the aggregates before the concrete sets may be assumed to be 80 % of the difference between the 24-h absorption of the aggregates determined by Test Methods C127 or C128, and the amount of water in the pores of the aggregates in their room-dry state, as determined by Test Method C566.

6.3.2.2 Weigh the individual size fractions of aggregate separately, recombine them into a tared container in the amounts required for the batch, and immerse them in water for at least 24 h prior to use. After the immersion period, decant the excess water and determine the combined weight of aggregate and mixing water. Allowance shall be made for the amount of water absorbed by the aggregate. Determine the moisture content of the aggregates in accordance with Test Method C70 or Test Method C566.

6.3.2.3 Bring the aggregate to a saturated condition and maintain it in this condition, with surface moisture contained in sufficiently small amounts to preclude loss by draining, at least 24 h prior to use. When this method is used, the moisture content of the aggregate must be determined to permit calculation of proper quantities of the damp aggregate. The quantity of surface moisture present must be counted as a part of the required amount of mixing water. Determine the surface moisture in fine aggregate in accordance with Test Method C70 or Test Method C566, making due allowance for the amount of water absorbed. The method outlined here (moisture content slightly exceeding absorption) is particularly useful for fine aggregate. It is used less frequently for coarse aggregate because of the difficulty of accurately determining the moisture content, but if used, each size fraction must be handled separately to ensure that the proper grading is obtained.

6.3.2.4 Bring the aggregate, fine or coarse, to a saturated surface-dry condition and maintain it in this condition until batched for use. This method is used primarily to prepare material for batches not exceeding 0.007 m^3 [¼ ft^3] in volume. Care must be taken to prevent drying during weighing and use.

6.4 *Lightweight Aggregates*—The procedures for specific gravity, absorption, and preparation of aggregates mentioned in this practice pertain to materials with normal absorption values. Lightweight aggregates, air-cooled slag, and certain highly porous or vesicular natural aggregate may be so absorptive as to be difficult to treat as described. The moisture content of lightweight aggregate at the time of mixing may have important effects on properties of freshly mixed and hardened concretes such as slump loss, compressive strength, and resistance to freezing and thawing.

6.5 *Admixtures*—Powdered admixtures that are entirely or largely insoluble, that do not contain hygroscopic salts and are to be added in small quantities, should be mixed with a portion of the cement before introduction into the batch in the mixer so as to ensure thorough distribution throughout the concrete. Essentially insoluble materials which are used in amounts exceeding 10 % by mass of cement, such as pozzolans, should be handled and added to the batch in the same manner as cement. Powdered admixtures which are largely insoluble but contain hygroscopic salts may cause balling of cement and should be mixed with the sand. Water-soluble and liquid admixtures should be added to the mixer in solution in the mixing water. The quantity of such solution used shall be included in the calculation of the water content of the concrete. Admixtures, incompatible in concentrated form, such as solutions of calcium chloride and certain air-entraining and set-retarding admixtures, should not be intermixed prior to their addition to concrete. The time, sequence, and method of adding some admixtures to a batch of concrete can have important effects on concrete properties such as time of set and air content. The method selected must remain unchanged from batch to batch.

NOTE 12—The mixing apparatus and accessories shall be thoroughly cleaned to ensure that chemical additions or admixtures used in dissimilar batches of concrete do not affect subsequent batches.

7. Procedure

7.1 *Mixing Concrete:*

7.1.1 *General*—Mix concrete in a suitable mixer or by hand in batches of such size as to leave about 10 % excess after molding the test specimens. Hand-mixing procedures are not applicable to air-entrained concrete or concrete with no measurable slump. Hand mixing should be limited to batches of 0.007 m^3 [¼ ft^3] volume or less. Mixing procedures are given in 7.1.2 and 7.1.3. However, other procedures may be used when it is desired to simulate special conditions or practices, or when the procedures specified are impracticable. A machine-mixing procedure suitable for drum-type mixers is described. It is important not to vary the mixing sequence and procedure from batch to batch unless the effect of such variation is under study.

7.1.2 *Machine Mixing*—Prior to starting rotation of the mixer add the coarse aggregate, some of the mixing water, and the solution of admixture, when required, in accordance with 6.5. When feasible, disperse the admixture in the mixing water before addition. Start the mixer, then add the fine aggregate, cement, and water with the mixer running. If it is impractical for a particular mixer or for a particular test to add the fine aggregate, cement, and water while the mixer is running, these components may be added to the stopped mixer after permitting it to turn a few revolutions following charging with coarse aggregate and some of the water (Note 13). Mix the concrete, after all ingredients are in the mixer, for 3 min followed by a 3-min rest, followed by a 2-min final mixing. Cover the open end or top of the mixer to prevent evaporation during the rest period. Take precautions to compensate for mortar retained by the mixer so that the discharged batch, as used, will be correctly proportioned (Note 14). To eliminate segregation, deposit machine-mixed concrete in the clean, damp mixing pan and remix by shovel or trowel until it appears to be uniform.

NOTE 13—An experienced operator may add water incrementally during mixing to adjust to the desired slump.

NOTE 14—It is difficult to recover all of the mortar from mixers. To compensate for this difficulty one of the following procedures may be used to ensure the correct final proportions in the batch:

(1) "Buttering" the Mixer—Just prior to mixing the test batch, the mixer is "buttered" by mixing a batch proportioned to simulate closely the test batch. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch.

(2) "Over-Mortaring" the Mix—The test mix is proportioned by the use of an excess mortar, the amount established in advance, to compensate for that which, on the average, adheres to the mixer. In this case the mixer is cleaned before mixing the test batch.

7.1.3 *Hand Mixing*—Mix the batch in a watertight, clean (Note 12), damp, metal pan or bowl, with a bricklayer's blunted trowel, using the following procedure when aggregates have been prepared in accordance with 6.3.2.1, 6.3.2.3, and 6.3.2.4.

7.1.3.1 Mix the cement, powdered insoluble admixture, if used, and fine aggregate without addition of water until they are thoroughly blended.

7.1.3.2 Add the coarse aggregate and mix the entire batch without addition of water until the coarse aggregate is uniformly distributed throughout the batch.

7.1.3.3 Add water, and the admixture solution if used, and mix the mass until the concrete is homogeneous in appearance and has the desired consistency. If prolonged mixing is necessary because of the addition of water in increments while adjusting the consistency, discard the batch and make a new batch in which the mixing is not interrupted to make trial consistency tests.

7.1.4 *Mixed Concrete*—Select the portions of the batch of mixed concrete to be used in tests for molding specimens so as to be representative of the actual proportions and condition of the concrete. When the concrete is not being remixed or sampled cover it to prevent evaporation.

7.2 *Slump, Air Content, Yield, and Temperature:*

7.2.1 *Slump*—Measure the slump of each batch of concrete immediately after mixing in accordance with Test Method C143/C143M.

NOTE 15—The slump test is unsuitable for concrete so dry that it slumps less than 6 mm [¼ in.]. Methods for measuring the consistency of no-slump concrete are described in ACI 211.3.

7.2.2 *Air Content*—Determine the air content, when required, in accordance with either Test Methods C173/C173M or C231/C231M. Test Method C231/C231M shall not be used with concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. Discard the concrete used for the determination of air content.

7.2.3 *Yield*—Determine the yield of each batch of concrete, if required, in accordance with Test Method C138/C138M. Concrete used for slump and yield tests may be returned to the mixing pan and remixed into the batch.

7.2.4 *Temperature*—Determine the temperature of each batch of concrete in accordance with Test Method C1064/C1064M.

7.3 *Making Specimens:*

7.3.1 *Place of Molding*—Mold specimens as near as practicable to the place where they are to be stored during the first 24 h. If it is not practicable to mold the specimens where they will be stored, move them to the place of storage immediately after being struck off. Place molds on a rigid surface free from vibration and other disturbances. Avoid jarring, striking, tilting, or scarring of the surface of the specimens when moving the specimens to the storage place.

7.3.2 *Placing*—Place the concrete in the molds using a scoop, blunted trowel, or shovel. Select each scoopful, trowelful, or shovelful of concrete from the mixing pan to ensure that it is representative of the batch. It may be necessary to remix the concrete in the mixing pan with a shovel or trowel to prevent segregation during the molding of specimens. Move the scoop or trowel around the top edge of the mold as the concrete is discharged in order to ensure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate within the mold. Further distribute the concrete by use of a tamping rod prior to the start of consolidation. In placing the final layer the operator shall attempt to add an amount of concrete that will exactly fill the mold after compaction. Do not add nonrepresentative samples of concrete to an underfilled mold.

7.3.2.1 *Number of Layers*—Make specimens in layers as indicated in Table 1.

7.4 *Consolidation:*

7.4.1 *Methods of Consolidation*—Preparation of satisfactory specimens requires different methods of consolidation. The methods of consolidation are rodding, and internal or external vibration. Base the selection of the method on the slump, unless the method is stated in the specifications under which the work is being performed. Rod or vibrate concrete with slump greater than or equal to 25 mm [1 in.]. Vibrate concrete with slump less than 25 mm [1 in.] (Note 16). Do not use internal vibration for cylinders with a diameter less than 100 mm [4 in.], and for beams or prisms with breadth or depth less than 100 mm [4 in.].

NOTE 16—Concrete of such low water content that it cannot be properly consolidated by the methods described herein is not covered by this practice. Provisions for specimens and methods of testing will be found in the standards concerned. There are concretes that can be consolidated by external vibration, but additional forces on the surface are required to embed the coarse aggregate thoroughly and consolidate the mixture. For such mixtures the following procedures may be followed: using external vibration fill 150 by 300-mm [6 by 12-in.] cylinder molds in 75 mm [3 in.] lifts using a 4.5-kg [10-lb] cylindrical surcharge, or 75 by 150-mm [3 by 6-in.] cylinder molds in 50 mm [2 in.] lifts using a 1-kg [2.5-lb] cylindrical surcharge. The surcharge should have a diameter 6 mm [¼ in.] less than the inside of the mold. Simultaneously each lift should be compacted by external vibration with the surcharge on the top surface of the concrete, until the mortar begins to ooze around the bottom of the surcharge.

7.4.2 *Rodding*—Place the concrete in the mold, in the required number of layers of approximately equal volume. Rod each layer with the rounded end of the rod using the number of strokes and size of rod specified in Table 2. Rod the bottom layer throughout its depth. Distribute the strokes uniformly over the cross section of the mold and for each upper layer allow the rod to penetrate through the layer being rodded and into the layer below about 25 mm [1 in.]. After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. Use an open hand to tap light-gage single-use molds which are susceptible to damage if tapped with a mallet. After tapping, spade the concrete along the sides and ends of beam and prism molds with a trowel or other suitable tool.

7.4.3 *Vibration*—Maintain a uniform duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and large air bubbles cease to break through the top surface. Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 17). Fill the molds and vibrate in the required number of approximately equal layers (Table 2). Place all the concrete for each layer in the mold before starting vibration of that layer. When placing the final layer, avoid overfilling by more than 6 mm [¼ in.]. When the finish is applied after vibration, add only enough concrete with a trowel to overfill the mold about 3 mm [⅛ in.], work it into the surface and then strike it off.

NOTE 17—Generally, no more than 5 s of vibration should be required for each insertion to adequately consolidate the concrete with a slump greater than 75 mm [3 in.]. Longer times may be required for lower slump concrete, but the vibration time should rarely have to exceed 10 s per insertion. Overvibration may cause segregation.

7.4.3.1 *Internal Vibration*—In compacting the specimen insert the vibrator slowly and do not allow the vibrator to rest on or touch the bottom or sides of the mold or strike embedded items such as strain meters. Slowly withdraw the vibrator so that no large air pockets are left in the specimen.

7.4.3.2 *Cylinders*—The number of insertions of the vibrator is given in Table 3. When more than one insertion per layer is required, distribute the insertions uniformly within each layer. Allow the vibrator to penetrate into the layer below about 25 mm. [1 in]. After each layer is vibrated, tap the outside of the mold at least 10 times with the mallet to close the holes that

TABLE 3 Number of Vibrator Insertions per Layer

Specimen Type and Size	Number of Insertions per Layer
Cylinder: Diameter, mm [in.]	
100 [4]	1
150 [6]	2
225 [9]	4

remain and to release entrapped air voids. Use an open hand to tap cardboard or single-use metal molds that are susceptible to damage if tapped with a mallet.

7.4.3.3 *Beams, Prisms, and Horizontal Creep Cylinders*—Insert the vibrator at intervals not exceeding 150 mm [6 in.] along the center line of the long dimension of the specimen, or along both sides but not in contact with the strain gage in the case of creep cylinders. For specimens wider than 150 mm [6 in.], use alternating insertions along two lines. Allow the shaft of the vibrator to penetrate into the bottom layer about 25 mm [1 in.]. After each layer is vibrated, tap the outsides of the mold sharply at least 10 times with the mallet to close holes left by vibrating and to release entrapped air voids.

7.4.4 *External Vibration*—When external vibration is used, take care to ensure that the mold is rigidly attached to or securely held against the vibrating element or vibrating surface (Note 16).

7.5 *Finishing*—After consolidation by any of the methods, strike off the surface of the concrete and float or trowel it in accordance with the method concerned. If no finish is specified, finish the surface with a wood or magnesium float. Perform all finishing with the minimum manipulation necessary to produce a flat even surface that is level with the rim or edge of the mold and which has no depressions or projections larger than 3 mm [⅛ in.].

7.5.1 *Cylinders*—After consolidation finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits, or with a wood float or trowel. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste which is permitted to harden and cure with the specimen. See the section on Capping Materials of Practice C617/C617M.

7.5.2 *Horizontally Cast Creep Cylinders*—After consolidation strike off the specimen with a trowel or float, then trowel the minimum amount required to form the concrete in the opening concentrically with the rest of the specimen. Use a screed curved to the radius of the specimen to more precisely shape and finish the concrete in the opening.

8. Curing

8.1 *Initial Curing*—To prevent evaporation of water from unhardened concrete, cover the specimens immediately after finishing, preferably with a nonabsorptive, nonreactive plate or a sheet of tough, durable impervious plastic. Specimens shall be stored immediately after finishing until the removal of the molds to prevent loss of moisture from the specimens. Select an appropriate procedure or combination of procedures that will prevent moisture loss and is nonabsorptive and nonreactive with the concrete. When wet burlap is used for covering, the burlap must not be in contact with the fresh concrete surface and care must be exercised to keep the burlap wet until the specimens are removed from the molds. Placing a sheet of plastic over the burlap will facilitate keeping it wet. To prevent damage to specimens, protect the outside of cardboard molds from contact with wet burlap or other sources of water until the molds are removed. Record the maximum and minimum ambient temperatures during the initial curing.

8.2 *Removal from Molds*—Remove the specimens from the molds 24 ± 8 h after casting. For concrete with prolonged setting time, molds shall not be removed until 20 ± 4 h after final set. If needed, determine the setting times in accordance with Test Method C403/C403M.

8.3 *Curing Environment*—Unless otherwise specified all specimens shall be moist cured at 23.0 ± 2.0°C [73.5 ± 3.5°F] from the time of molding until the moment of test (Note 18). Storage during the first 48 h of curing shall be in a vibration-free environment. As applied to the treatment of demolded specimens, moist curing means that the test specimens shall have free water maintained on the entire surface area at all times. This condition is met by using water storage tanks or a moist room in accordance with the requirements of Specification C511. Cure structural lightweight concrete cylinders in accordance with Specification C330/C330M.

NOTE 18—The temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

8.4 *Flexural Strength Test Specimens*—Cure the flexural strength test specimens in accordance with 8.1 and 8.2 except that while in storage for a minimum period of 20 h immediately prior to testing they shall be immersed in water saturated with calcium hydroxide at 23.0 ± 2.0°C [73.5 ± 3.5°F]. At the end of the curing period, between the time the specimen is removed from curing until testing is completed, drying of the surfaces shall be prevented.

NOTE 19—Relatively small amounts of drying of the surface of flexural strength specimens will induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9. Precision and Bias

9.1 Data to establish precision statements for various testing required by this standard were obtained in the Concrete Proficiency Sample Program of the Cement and Concrete Reference Laboratory.

9.2 The single-operator standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 0.7 in., 0.9 lb/ft^3, 0.3 %, and 203 psi, respectively; therefore the results of properly conducted tests on two trial batches made in the same laboratory should not differ by more than 2.0 in., 2.5 lb/ft^3, 0.8 %, and 574 psi, respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a constant water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 50 mm [2 in.] or over 150 mm [6 in.], or concrete made with other than normal weight aggregate or aggregate larger than 25 mm [1 in.] nominal maximum size.

9.3 The multilaboratory standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 1.0 in., 1.4 lb/ft^3 0.4 %, and 347 psi, respectively; therefore, the results of properly conducted tests on single trial batches made in two different laboratories should not differ by more than 2.8 in., 4.0 lb/ft^3, 1.1 %, and 981 psi, respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a prescribed water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 50 mm [2 in.] or over 150 mm [6 in.], or concrete made with other than normal weight aggregate or aggregate larger than 25 mm [1 in.] nominal maximum size.

9.4 *Bias*—The procedures for the test methods in 9.3 have no bias because the values obtained from each of those test methods are defined only in terms of the test method.

10. Keywords

10.1 concrete; cylinders; laboratory; prisms; strength testing

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C192/C192M – 16) that may impact the use of this standard. (Approved June 1, 2016.)

(1) Corrected SI value in Table 3.

Committee C09 has identified the location of selected changes to this standard since the last issue (C192/C192M – 15) that may impact the use of this standard. (Approved Feb. 1, 2016.)

(1) Revised 6.3.2.2 – 6.3.2.4.

Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression[1]

This standard is issued under the fixed designation C469/C469M; 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 determination of (*1*) chord modulus of elasticity (Young's) and (*2*) Poisson's ratio of molded concrete cylinders and diamond-drilled concrete cores when under longitudinal compressive stress. Chord modulus of elasticity and Poisson's ratio are defined in Terminology E6.

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
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
C174/C174M Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C617 Practice for Capping Cylindrical Concrete Specimens
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E83 Practice for Verification and Classification of Extensometer Systems
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

2.2 *ASTM Adjuncts:*

Compressometers (two drawings) and Extensometers (two drawings)[3]

3. Significance and Use

3.1 This test method provides a stress to strain ratio value and a ratio of lateral to longitudinal strain for hardened concrete at whatever age and curing conditions may be designated.

3.2 The modulus of elasticity and Poisson's ratio values, applicable within the customary working stress range (0 to 40 % of ultimate concrete strength), are used in sizing of reinforced and nonreinforced structural members, establishing the quantity of reinforcement, and computing stress for observed strains.

3.3 The modulus of elasticity values obtained will usually be less than moduli derived under rapid load application (dynamic or seismic rates, for example), and will usually be greater than values under slow load application or extended load duration, given other test conditions being the same.

4. Apparatus

4.1 *Testing Machine*—Use a testing machine capable of imposing a load at the rate and of the magnitude prescribed in 6.4. The machine shall conform to the requirements of Practices E4 (Constant-Rate of-Traverse CRT-Type Testing Machines section). The spherical head and bearing blocks shall conform to the Apparatus Section of Test Method C39/C39M.

4.2 *Compressometer*[3]—For determining the modulus of elasticity use a bonded (Note 1) or unbonded sensing device that measures to the nearest 5 millionths the average deformation of two diametrically opposite gauge lines, each parallel to the axis, and each centered about midheight of the specimen.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

Current edition approved March 1, 2014. Published April 2014. Originally approved in 1961. Last previous edition approved in 2010 as C469–10. DOI: 10.1520/C0469_C0469M-14.

[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 ASTM International Headquarters. Order Adjunct No. ADJC0469.

***A Summary of Changes section appears at the end of this standard**

The effective length of each gauge line shall be not less than three times the maximum size of the aggregate in the concrete nor more than two thirds the height of the specimen; the preferred length of the gauge line is one half the height of the specimen. Either use gauge points embedded in or cemented to the specimen, and read deformation of the two lines independently; or use a compressometer (such as is shown in Fig. 1) consisting of two yokes, one of which (see *B*, Fig. 1) is rigidly attached to the specimen and the other (see *C*, Fig. 1) attached at two diametrically opposite points so that it is free to rotate. At one point on the circumference of the rotating yoke, midway between the two support points, use a pivot rod (see *A*, Fig. 1) to maintain a constant distance between the two yokes. At the opposite point on the circumference of the rotating yoke, the change in distance between the yokes (that is, the gauge reading) is equal to the sum of the displacement due to specimen deformation and the displacement due to rotation of the yoke about the pivot rod (see Fig. 2).

4.2.1 Measure deformation by a dial gauge used directly or with a lever multiplying system, by a wire strain gauge, or by a linear variable differential transformer. If the distances of the pivot rod and the gauge from the vertical plane passing through the support points of the rotating yoke are equal, the deformation of the specimen is equal to one-half the gauge reading. If these distances are not equal, calculate the deformation as follows:

$$d = ge_r/(e_r+e_g) \tag{1}$$

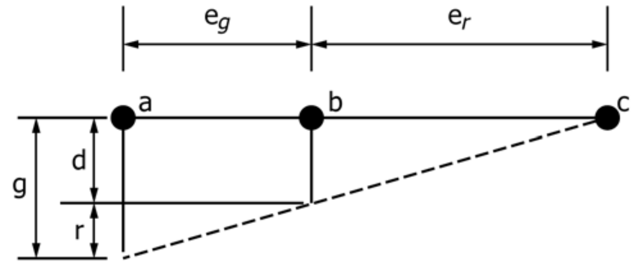
where:

d = total deformation of the specimen throughout the effective gauge length, µm [µin.],
g = gauge reading, µm [µin.],
e_r = the perpendicular distance, measured to the nearest 0.2 mm [0.01 in.] from the pivot rod to the vertical plane passing through the two support points of the rotating yoke, and
e_g = the perpendicular distance, measured to the nearest 0.2 mm [0.01 in.] from the gauge to the vertical plane passing through the two support points of the rotating yoke.

Procedures for calibrating strain-measuring devices are given in Practice E83.

NOTE 1—Although bonded strain gauges are satisfactory on dry specimens, they may be difficult, if not impossible, to mount on specimens continually moist-cured until tested.

4.3 *Extensometer*[3]—If Poisson's ratio is desired, the transverse strain shall be determined (*1*) by an unbonded extensometer capable of measuring to the nearest 0.5 µm [25 µin.] the change in diameter at the midheight of the specimen, or (*2*) by two bonded strain gauges (Note 1) mounted circumferentially at diametrically opposite points at the midheight of the specimen and capable of measuring circumferential strain to the nearest 5 millionths. A combined compressometer and extensometer (Fig. 3) is a convenient unbonded device. This apparatus shall contain a third yoke (consisting of two equal segments) located halfway between the two compressometer yokes and attached to the specimen at two diametrically opposite points. Midway between these points use a short pivot rod (*A*', see Fig. 3), adjacent to the long pivot rod, to maintain a constant distance between the bottom and middle yokes. Hinge the middle yoke at the pivot point to permit rotation of the two segments of the yoke in the horizontal plane. At the opposite point on the circumference, connect the two segments



d = displacement due to specimen deformation
r = displacement due to rotation of the yoke about the pivot rod
a = location of gauge
b = support point of the rotating yoke
c = location of pivot rod
g = gauge reading

FIG. 2 Diagram of Displacements

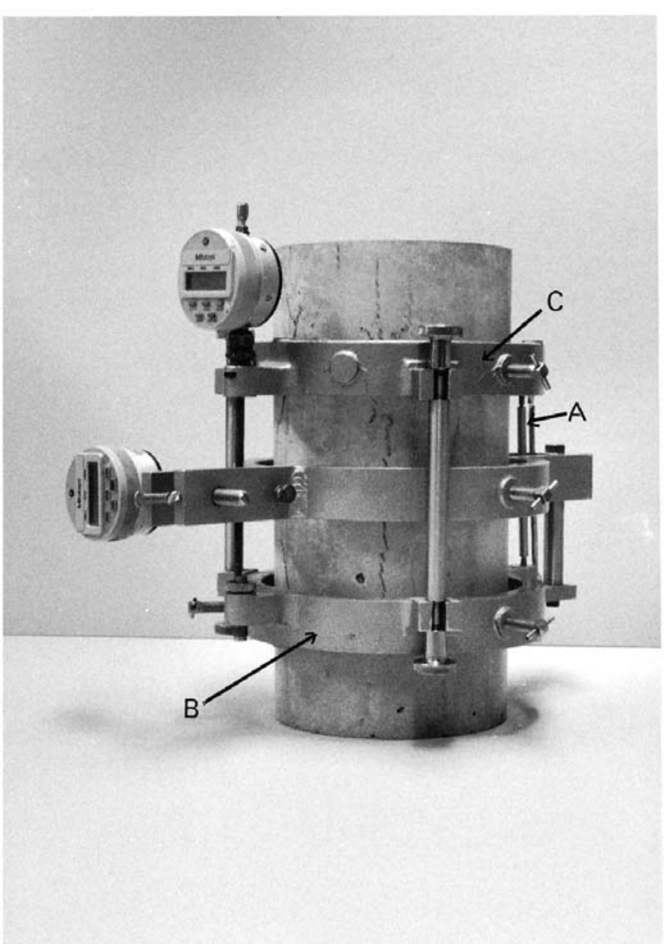


FIG. 1 Suitable Compressometer

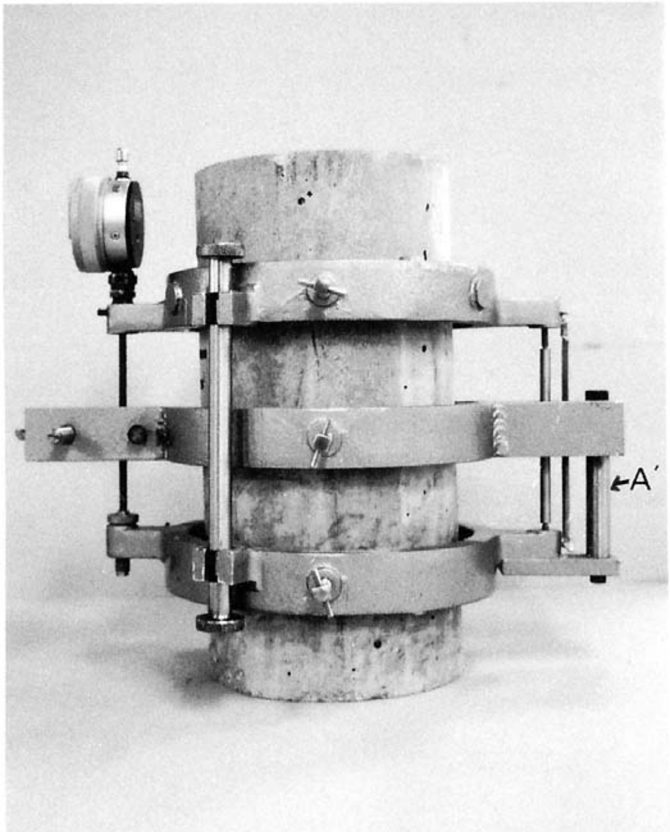


FIG. 3 Suitable Combined Compressometer-Extensometer

through a dial gauge or other sensing device capable of measuring transverse deformation to the nearest 1.27 µm [50 µin.]. If the distances of the hinge and the gauge from the vertical plane passing through the support points of the middle yoke are equal, the transverse deformation of the specimen diameter is equal to one-half the gauge reading. If these distances are not equal, calculate the transverse deformation of the specimen diameter in accordance with Eq 2.

$$d' = g'e'_h/(e'_h+e'_g) \qquad (2)$$

where:

d' = transverse deformation of the specimen diameter, µm [µin.],
g' = transverse gauge reading, µm [µin.],
e'_h = the perpendicular distance, measured to the nearest 0.2 mm [0.01 in.] from the hinge to the vertical plane passing through the support points of the middle yoke, and
e'_g = the perpendicular distance, measured to the nearest 0.2 mm [0.01 in.] from the gauge to the vertical plane passing through the support points of the middle yoke.

4.4 *Balance or Scale,* accurate to 50 g [0.1 lb] shall be used if necessary.

5. Test Specimens

5.1 *Molded Cylindrical Specimens*—Mold test cylinders in accordance with the requirements for compression test specimens in Practice C192/C192M, or in Practice C31/C31M. Subject specimens to the specified curing conditions and test at the age for which the elasticity information is desired. Test specimens within 1 h after removal from the curing or storage room. Specimens removed from a moist room for test shall be kept moist by a wet cloth covering during the interval between removal and test.

5.2 *Drilled Core Specimens*—Cores shall comply with the requirements for drilling, and moisture conditioning applicable to compressive strength specimens in Test Method C42/C42M, except that only diamond-drilled cores having a length-to-diameter ratio greater than 1.50 shall be used. Requirements relative to storage and to ambient conditions immediately prior to test shall be the same as for molded cylindrical specimens.

5.3 The ends of the test specimens shall be made perpendicular to the axis ±0.001 rad [±0.5°] and plane within 0.05 mm [0.002 in.]. If the specimen as cast does not meet the planeness requirements, planeness shall be accomplished by capping in accordance with Practice C617, or by lapping, or by grinding. It is not prohibited to repair aggregate popouts that occur at the ends of specimens, provided the total area of popouts does not exceed 10 % of the specimen area and the repairs are made before capping or grinding is completed (Note 2). Planeness will be considered within tolerance when a 0.05 mm [0.002 in.] feeler gauge will not pass between the specimen surface and a straight edge held against the surface.

NOTE 2—Repairs may be made by epoxying the dislodged aggregate back in place or by filling the void with capping material and allowing adequate time for it to harden.

5.4 Measure the diameter of the test specimen by caliper to the nearest 0.2 mm [0.01 in.] by averaging two diameters measured at right angles to each other near the center of the length of the specimen. Use this average diameter to calculate the cross-sectional area. Measure and report the length of a molded specimen, including caps, to the nearest 2 mm [0.1 in.]. Measure the length of a drilled specimen in accordance with Test Method C174/C174M; report the length, including caps, to the nearest 2 mm [0.1 in.].

6. Procedure

6.1 The temperature surrounding the specimen shall not vary by more than 2°C [4°F] during a test.

6.2 Except as provided in 6.5, use at least two companion specimens to determine the compressive strength in accordance with Test Method C39/C39M prior to the test for modulus of elasticity.

6.3 Place the specimen, with the strain-measuring equipment attached, on the lower platen or bearing block of the testing machine. Carefully align the axis of the specimen with the center of thrust of the spherically-seated upper bearing block. Note the reading on the strain indicators. Before applying the load on the specimen, tilt the movable portion of the spherically seated block by hand so that the bearing face appears to be parallel to the top of the test specimen based on visual observation.

6.4 Load the specimen at least three times. Do not record any data during the first loading. Base calculations on the average of the results of the subsequent loadings.

6.4.1 Apply the load continuously and without shock. Set testing machines of the screw type so that the moving head travels at a rate of about
1 mm/min [0.05 in./min] when the machine is running idle. In hydraulically operated machines, apply the load at a constant rate within the range 250 ± 50 kPa/s [35 ± 7 psi/s]. Load the specimen until the applied load is 40 % of the average ultimate load of the companion specimens. This is the maximum load for the modulus of elasticity test.

6.4.2 During the first loading, observe the performance of the gauges (Note 3). Correct any attachment or alignment defects that may be causing erratic readings prior to the second loading. For the second and subsequent loadings, obtain each set of readings as follows: Record, without interruption of loading, the applied load and longitudinal strain at the point (*1*) when the longitudinal strain is 50 microstrain and (*2*) when the applied load is equal to 40 % of the ultimate load of the companion specimens (see 6.5). Longitudinal strain is defined as the measured longitudinal deformation of the specimen divided by the effective gauge length.

NOTE 3—The first loading is primarily for the seating of the gauges. If a dial gauge is used to measure longitudinal deformation, it is convenient to set the gauge before each loading so that the indicator will pass the zero point at a longitudinal strain of 50 microstrain.

6.4.3 If Poisson's ratio is to be determined, record the transverse strain at the same points. The transverse strain is the measured change in specimen diameter divided by the original diameter.

6.4.4 If a stress-strain curve is to be determined, take readings at two or more intermediate points without interruption of loading; or use an instrument that makes a continuous record of the gauge readings.

6.4.5 Upon reaching the maximum load, except on the final loading, reduce the load to zero at the same rate at which it was applied.

6.5 It is not prohibited to obtain the modulus of elasticity and strength on the same loading provided that the gauges are expendable, removable, or adequately protected so that it is possible to comply with the requirement for continuous loading given in Test Method C39/C39M. In this case, record several intermediate readings to obtain a stress-strain curve up to at least 40 % of the ultimate load and determine the strain value at 40 % of the ultimate by interpolation.

6.6 If intermediate readings are taken, plot the results of each of the tests with the longitudinal strain as the abscissa and the compressive stress as the ordinate. Calculate the compressive stress by dividing the testing machine load by the cross-sectional area of the specimen calculated from the diameter determined in accordance with 5.4.

7. Calculation

7.1 Calculate the modulus of elasticity, to the nearest 200 MPa [50,000 psi] as follows:

$$E = (S_2 - S_1)/(\varepsilon_2 - 0.000050) \quad (3)$$

where:

E = chord modulus of elasticity, MPa [psi],
S_2 = stress corresponding to 40 % of ultimate load,
S_1 = stress corresponding to a longitudinal strain, ε_1, of 50 millionths, MPa [psi], and
ε_2 = longitudinal strain produced by stress S_2.

7.2 Calculate Poisson's ratio, to the nearest 0.01, as follows:

$$\mu = (\varepsilon_{t2} - \varepsilon_{t1})/(\varepsilon_2 - 0.000050) \quad (4)$$

where:

μ = Poisson's ratio,
ε_{t2} = transverse strain at midheight of the specimen produced by stress S_2, and
ε_{t1} = transverse strain at midheight of the specimen produced by stress S_1.

8. Report

8.1 Report the following information:
8.1.1 Specimen identification number,
8.1.2 Dimensions of specimen, in millimetres [inches],
8.1.3 Curing and environmental histories of the specimen,
8.1.4 Age of the specimen,
8.1.5 Strength of the concrete, if determined,
8.1.6 Unit weight of the concrete, if determined,
8.1.7 Stress-strain curves, if plotted,
8.1.8 Chord modulus of elasticity, and
8.1.9 Poisson's ratio, if determined.

9. Precision and Bias

9.1 *Precision*—The single-operator-machine multibatch precision is ±4.25 % (R1S %) max, as defined in Practice E177, over the range from 17 to 28 GPa [2.5 to 4×10^6 psi]; therefore, the results of tests of duplicate cylinders from different batches should not depart more than 5 % from the average of the two.

9.2 *Bias*—This test method has no bias because the values determined can only be defined in terms of the test method.

10. Keywords

10.1 compression testing; concrete; modulus of elasticity; Poisson's ratio

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C469/C469M – 10) that may impact the use of this standard. (Approved March 1, 2014)

(1) Section 6 was revised extensively. Three loading cycles is mandatory.

Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete[1]

This standard is issued under the fixed designation C157/C157M; 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 U.S. Department of Defense.

ε[1] NOTE—Editorial corrections were made in November 2014.

1. Scope*

1.1 This test method covers the determination of the length changes that are produced by causes other than externally applied forces and temperature changes in hardened hydraulic-cement mortar and concrete specimens made in the laboratory and exposed to controlled conditions of temperature and moisture.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. An exception is with regard to sieve sizes and nominal size of aggregate, in which the SI values are the standard as stated in Specification E11. Within the text, the SI 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 non-conformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C172 Practice for Sampling Freshly Mixed Concrete
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
C490 Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C596 Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement
C1437 Test Method for Flow of Hydraulic Cement Mortar
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

3. Terminology

3.1 *Definitions*—The terms used in this test method are defined in Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *length change, n*—an increase or decrease in the length of a test specimen that has been caused to change by any factor other than externally applied forces and temperature changes.

4. Significance and Use

4.1 Measurement of length change permits assessment of the potential for volumetric expansion or contraction of mortar or concrete due to various causes other than applied force or temperature change. This test method is particularly useful for comparative evaluation of this potential in different hydraulic-cement mortar or concrete mixtures.

4.2 This test method provides useful information for experimental purposes or for products that require testing under nonstandard mixing, placing, handling, or curing conditions,

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.68 on Volume Change.

Current edition approved Oct. 1, 2014. Published November 2014. Originally approved in 1940. Last previous edition approved in 2008 as C157/C157M – 08ε1. DOI: 10.1520/C0157_C0157M-08R14E01.

[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.

*A Summary of Changes section appears at the end of this standard

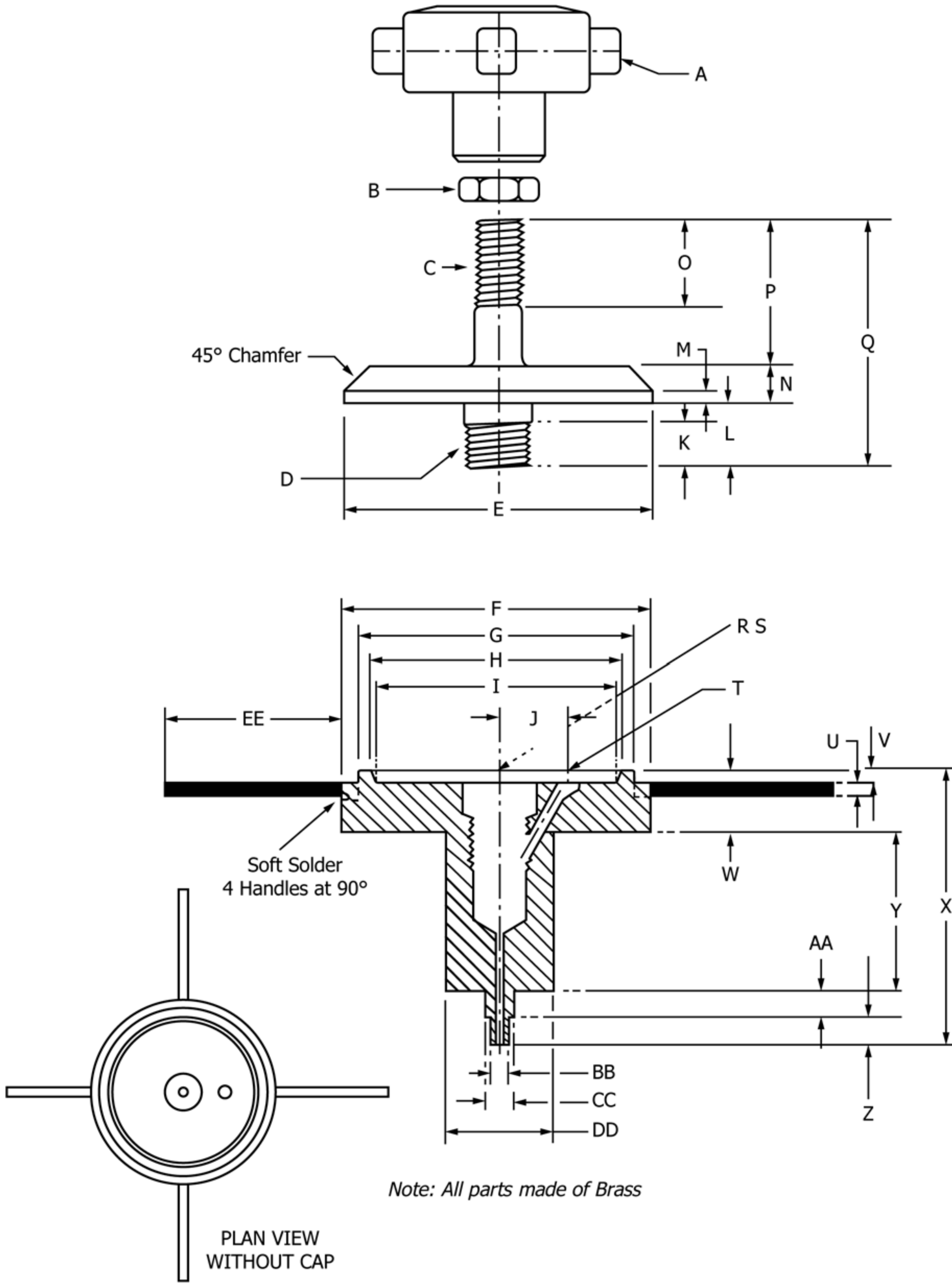


FIG. 1 Atmometer

such as high product workability or different demolding times. Standard conditions are described in 5.4.1.

4.3 If conditions for mixing, curing, sampling, and storage other than specified in this test method are required, they shall be reported but are not to be considered as standard conditions of this test method. Nonstandard conditions and the reasons for departure from standard conditions shall be reported clearly and prominently with comparator values.

5. Apparatus

5.1 *Molds and Length Comparator*—The molds for casting test specimens and the length comparator for measuring length change shall conform to the requirements of Practice C490.

5.2 *Tamper*—The tamper shall be made of a nonabsorptive, nonabrasive material such as medium-hard rubber or seasoned oak wood rendered nonabsorptive by immersion for 15 min in paraffin at approximately 392 °F [200 °C], and shall have a cross section of ½ by 1.0 in. [13 by 25 mm] and a convenient length of about 6 in. [150 mm]. The tamping face of the tamper shall be flat and at right angles to the length of the tamper.

5.3 *Tamping Rod*—The tamping rod shall be a straight steel rod ⅜ in. [10 mm] in diameter and not less than 10 in. [250 mm] in length, having at least the tamping end rounded to a hemispherical tip of the same diameter.

5.4 *Drying Room and Controls*—A drying room with suitable racks shall be provided when storing specimens in air. The racks shall be designed for free circulation of air around specimens, except for necessary supports, and shall be so situated with respect to the nearest wall or other obstruction that air circulation is not restricted in the intervening space. The supports shall be horizontal and shall consist of two nonabsorptive members not deeper than 1 in. [25 mm] and having a bearing area of not more than ¼ in. [6 mm] in width. Conditioned air shall be circulated into and out of the room in a uniform manner so that the specified rate of evaporation is attained adjacent to all specimens.

5.4.1 The air in the room shall be maintained at a temperature of 73 ± 3 °F [23 ± 2 °C] and a relative humidity of 50 ± 4 %. The air movement past all specimens shall be such that the rate of evaporation is 77 ± 30-mL/24 h from an atmometer or 13 ± 5-mL/24 h from a 400-mL Griffin low-form beaker filled to ¾ in. [20 mm] from the top. The temperature and relative humidity of the air in the room shall be measured with either a sling or Assmann psychrometer at least twice each working day. The psychrometer shall comply with Test Method E337, except that thermometers having an overall length of 10 in. [250 mm] and marked in subdivisions of 0.5 °F [0.25 °C] are permitted. The room shall be equipped with a means of measuring and recording wet- and dry-bulb temperatures continuously. Correction factors as indicated by the sling or Assmann psychrometer shall be applied to the recorded data. The rate of evaporation within the room shall be determined daily by the use of the atmometer or by the loss of mass of water from a 400-mL Griffin low-form beaker filled initially to ¾ in. [20 mm] from the top.

5.5 *Atmometer*—The atmometer shall be constructed as shown in Fig. 1.

5.5.1 *Mounting*—Fig. 2 shows a suggested arrangement for operating the atmometer. Punch a central hole ½ in. [13 mm] in diameter in a filter paper, place it on the atmometer, and secure it in place while dry, by turning the torque handle only, until it just starts to slip. Mount the atmometer on a stand with the filter paper in a horizontal position. Mount a 100-mL glass graduate so that the 100-mL mark is from 1 to 3 in. [25 to 75 mm] below the level of the filter paper. Stopper the graduate so that entrance is provided for two short glass tubes not extending to the water level and one long tube extending to the bottom of the graduate. Connect the glass tubing leading from the bottom of the graduate to the inlet of the atmometer by means of clear plastic tubing.

5.5.2 *Operation*—Use clear plastic tubing to connect a squeeze bottle containing distilled or deionized water to one of the short glass tubes into the graduate. Force water into the graduate until it is about half full and then close the remaining glass tube into the graduate. Continue to force water through the graduate into the atmometer until the filter paper is saturated and there are no air bubbles in the system. Open the glass tube into the graduate and release pressure on the squeeze bottle gradually to avoid trapping air in the tube leading to the atmometer. Adjust the level of water in the graduate to approximately the 100-mL mark. If the atmometer is to be used under variable temperature conditions, disconnect the squeeze bottle after filling the graduate to avoid the possibility of additional water being forced into the graduate. Permit evaporation of water from the filter paper for 1 h before recording the time and initial reading of the graduate. It is not permitted to omit the waiting period during subsequent use of the atmometer provided the filter paper does not become dry. Change the filter paper whenever it shows signs of contamination but not less frequently than once every two weeks.

5.6 *Filter Paper*—The filter paper to be used with the atmometer shall be white with a smooth surface texture. It shall be 6 in. [152 mm] in diameter and 0.050 ± 0.003 in. [1.27 ± 0.08 mm] thick and shall have a cotton fiber content of not less than 75 weight %. The density shall be between 0.400 and 0.425 g/cm^3. The Mullen bursting strength shall not be less than 50 psi [345 kPa].

NOTE 1—E and D filter paper No. 625[3] has been found suitable.

[3] The sole source of supply of the apparatus known to the committee at this time is Ahlstrom Filtration Co., Mt. Holly Springs, PA 17065. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

FIG. 1 Atmometer

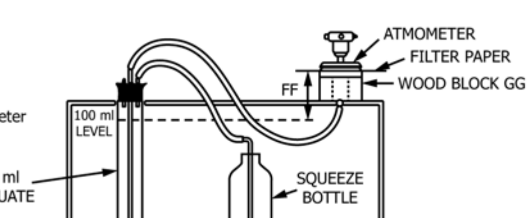
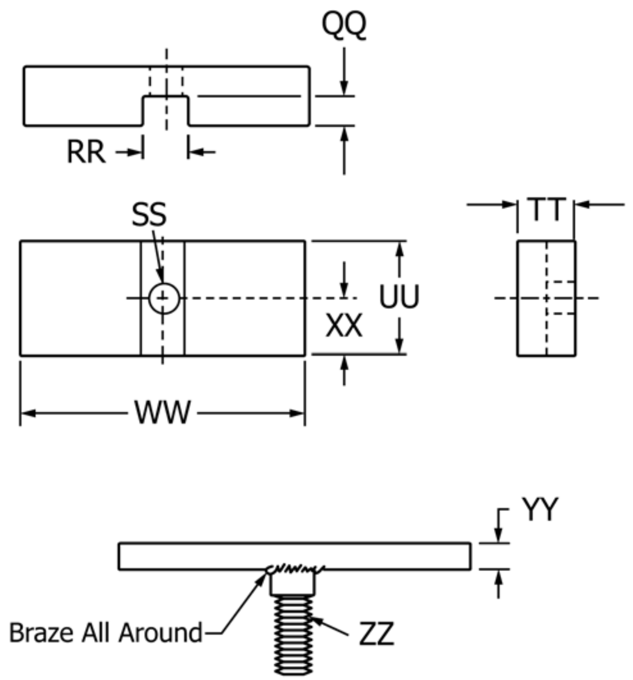
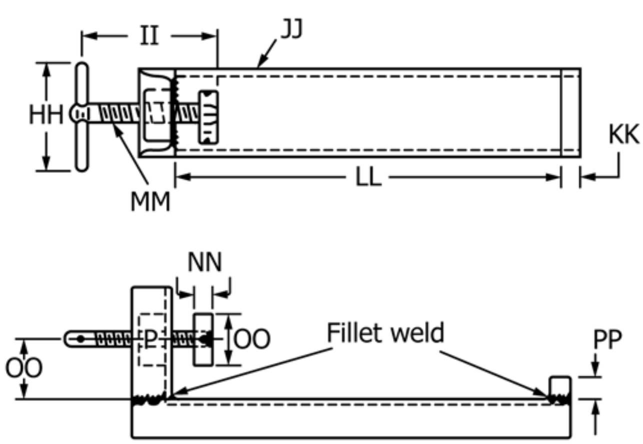


FIG. 2 Atmometer Assembly



Instructions for Use—Remove the end and the outer side plates leaving the base, center side plate, and gage stud holders in place. Engage the machine screw in the drilled and tapped end of the center side plate. Turn the thumbscrew to loosen the bars.

FIG. 3 Device for Detaching 1-in. [25-mm] Square by 11¼-in. [285-mm] Bars from Center Side Plate of Double Molds



NOTE 1—Dimensions shown are appropriate for one design of mold for 3-in. [75-mm] square specimens. Change dimensions as required for other molds.

FIG. 4 Device for Demolding Specimens from Single Molds

5.7 *Apparatus for Demolding Specimens*—It is useful to construct an apparatus for demolding specimens molded in double molds as detailed in Fig. 3 or to a different design that serves the same purpose. When this device is to be used, the center side plate of the double mold must be appropriately drilled and tapped to receive the 8-32 by ⅝ in. [4.5-0.74 IMC by 16 mm] machine screw of the demolding thumbscrew. Fig. 4 shows the details of a suitable apparatus for demolding specimens molded in single molds.

ASTM C157 FIGURES

Figure Dimensions	SI Units	Inch-Pound Units
A	Adjustable torque handle 1.4–1.7 Nm	Adjustable torque handle 12–15 in.lb
B	Jam nut 10–15 IMC	Jam nut ⅜-in.–16 NC
C	10-mm diameter 1.5 IMC Thd.	⅜-in. dia–16 NC Thd.
D	12-mm diameter 1.5 IMC Thd.	½-in. dia–20 NC Thd.
E	64-mm diameter	2.50-in. diameter
F	64-mm diameter	2.50-in. diameter
G	57-mm diameter	2.25-in. diameter
H	52-mm diameter	2.06-in. diameter
I	51-mm diameter	2.00-in. diameter
J	14 mm	0.56 in.
K	8 mm	0.31 in.
L	13 mm	0.50 in.
M	3 mm	0.125 in.
N	8 mm	0.31 in.
O	19 mm	0.75 in.
P	32 mm	1.25 in.
Q	53 mm	2.06 in.
R	1.5-mm drill through 11.5-mm C' drill	1⁄16-in. drill through 29⁄64-in. C' drill
	32-mm deep tap 12-mm 1.5-mm IMF Thd	1¼-in. deep tap ½-in.–20 Thd
S	19 mm deep 16 mm C' bore 6 mm deep	¾-in. deep ⅝-in. C' bore ¼ in. deep
T	5-mm drill 3-mm deep C' drill at 60° as shown through to center tapped hole	3⁄16-in. drill ⅛-in. deep C' drill at 60° as shown through to center tapped hole
U	3 mm	0.12 in. diameter
V	2 mm	0.09 in.
W	10 mm	0.40 in.
X	60 mm	2.36 in.
Y	35 mm	1.37 in.
Z	6 mm	0.25 in.
AA	6 mm	0.25 in.
BB	4 mm	0.15 in.
CC	6 mm	0.25 in.
DD	23 mm	0.87 in.
EE	38 mm	1.50 in.
FF	25 to 75 mm	1 to 3 in.
GG	35 mm high	1.37 in. high
HH	100 mm	4 in.
II	130 mm	5 in.
JJ	8 cm–6.1 kg/m channel	3 in.–4.1 lb/ft channel
KK	20 mm	¾ in.
LL	330 mm	13 in.
MM	14–2.0 IMC Thd.	½ in.–12 Thd.
NN	20 mm	¾ in.
OO	50 mm	2 in.
PP	20 mm	¾ in.
QQ	60 mm	¼ in.
RR	10 mm	⅜ in.
SS	Drill Cl. hole for 4.5–0.75 IMC machine screw	Drill Cl. hole for 8–32 in. machine screw
TT	13 mm	½ in.
UU	25 mm	1 in.
VV	30 mm	1-3⁄16 in.
WW	60 mm	2-⅜ in.
XX	12.5 mm	½ in.
YY	6-mm diameter steel rod	¼-in. diameter steel rod
ZZ	4.5–0.75 IMC × 16-mm machine screw	8–32 × ⅝-in. machine screw

6. Sampling

6.1 Take samples according to the applicable provisions of Practice C192/C192M from batches of hydraulic-cement mortar or concrete made in the laboratory (Note 2).

NOTE 2—When collecting samples in nonstandard conditions, such as field concrete, it is suggested that Practice C172 be followed. Field cast specimens can show up to twice as much drying shrinkage as laboratory cast specimens from the same materials and proportions.

7. Test Specimens

7.1 *Mortar*—The test specimen for mortar shall be a prism of 1-in. [25-mm] square cross-section and approximately 11¼ in. [285 mm] in length. Three specimens shall be prepared for each test condition.

7.2 *Concrete*—The test specimen for concrete, in which all of the aggregate passes a 2-in. [50-mm] sieve, shall be a prism of 4-in. [100-mm] square cross-section and approximately 11¼ in. [285 mm] long. However, a prism of 3-in. [75-mm] square cross-section shall be used if all of the aggregate passes a 1-in. sieve [25.0-mm]. Three specimens shall be prepared for each test condition. Since length change is capable of being influenced by the size of the specimen, specimens to be compared shall have the same dimensions, and any specification limit based upon this method shall be applied to a specified size of specimen.

8. Procedure for Mixing Mortars and Concrete

8.1 If the mortar or concrete to be tested is made in accordance with requirements other than those given in one of the following paragraphs, samples shall be taken and specimens molded as described in the sections on sampling and on molding specimens.

8.2 Bring all materials to a temperature between 65 and 75 °F [18 and 24 °C] before using to make mortar or concrete. Proportion solid materials by mass (that is, not by volume). It is permissible to batch water and liquid admixtures either by mass or by volume. For calculation of batch quantities, assume aggregates to be saturated and surface-dry; if they are not in this condition at the time of use, apply appropriate corrections, as necessary, to batch quantities to compensate for absorption or free moisture.

8.3 *Mortar*—Mix mortar in a mechanical mixer as described in Practice C305. The clearances between paddle and bowl specified in Practice C305 are suitable only for mortars made with fine aggregates that are finer than the 2.36 mm (No. 8) sieve. Mortars made with aggregates containing particles coarser than this sieve require special clearances or a different type of paddle to permit the mixer to operate freely and to avoid damage to the paddle and bowl. The sequence of mixing shall be in accordance with the applicable provisions of Practice C305. Determine the flow of the mortar in accordance with the applicable provisions of Test Method C1437, and use sufficient mixing water to produce a flow of 110 ± 5 %.

8.4 *Concrete*—Mix concrete in a suitable laboratory mixer in accordance with the applicable provisions of Practice C192/C192M. Determine the slump of the concrete using Test Method C143/C143M, and use sufficient mixing water to produce a slump of 3.5 ± ½ in. [90 ± 15 mm].

9. Procedure for Molding Specimens

9.1 *Mortar Specimens*—Place the mortar in the mold in two approximately equal layers. Compact each layer with the tamper. Work the mortar into the corners, around the gage studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, strike off the mortar flush with the top of the mold, and smooth the surface with a few strokes of a trowel. Immediately after completion of molding, loosen the device by holding the gage studs in position at each end of the mold in order to prevent any restraint of the gage studs during initial shrinkage of the specimen.

9.2 *Concrete Specimens*—Place the concrete in the mold in two approximately equal layers in accordance with the general instructions for placing concrete in specimens given in Practice C192/C192M. Consolidate each layer by rodding, except use external vibration if the slump is less than 3 in. [75 mm] in accordance with the instructions for consolidation of flexure test specimens given in Practice C192/C192M. The same method of consolidation is to be used for all specimens to be compared. In addition, as the top layer is being placed, work the concrete thoroughly around each gage stud with the fingers. The top layer shall slightly overfill the mold. After consolidation is complete, strike off the excess material with a straightedge. Immediately after completion of molding, loosen the device by holding the gage studs in position at each end of the mold in order to prevent any restraint of the gage studs before the test specimens are demolded.

10. Procedure for Curing of Specimens

10.1 Cure the test specimens in the molds in a moist cabinet or room in accordance with Specification C511. Protect specimens from dripping water.

10.2 Remove specimens from the molds at an age of 23½ ± ½ h after the addition of water to the cement during the mixing operation. In order to avoid damage during removal from the molds, it is not permitted, especially in the case of certain slow-hardening cements, to allow specimens to remain in the molds for more than 24 h. When this is found necessary the moist curing schedule shall be extended, but all specimens that are to be directly compared with each other shall be subjected to the same conditions of moist-curing and shall have their initial comparator reading made within ±½ h of the same age. It is permitted to use the demolding device to remove specimens without striking or jarring and with particular care not to exert pressure directly against the gage studs. The gage stud holder shall remain attached to the stud during this operation. Marks placed on the specimens for identification or positioning are only to be made by graphite applied either by a soft pencil or as a liquid that deposits essentially graphite without binder or made with waterproof indelible ink. Upon removal of the specimens from the molds, place them in lime-saturated water maintained at 73 ± 1 °F [23 ± 0.5 °C] for a minimum of 15 min in the case of 1-in. [25-mm] square cross-section specimens, and for a minimum of 30 min in the case of 3-in. [75-mm] or 4-in. [100-mm] square cross section specimens before being measured for length. This is to minimize variation in length due to variation in temperature. At an age of 24 ± ½ h after the addition of water to the cement during the mixing operation, remove the specimens from water storage one at a time, wipe with a damp cloth, and immediately take the initial comparator reading.

10.3 After the initial comparator reading, store the specimens in lime-saturated water at 73 ± 3 °F [23 ± 2 °C] until they have reached an age of 28 days, including the period in the molds. At the end of the curing period, take a second comparator reading after the specimens have been brought to a more closely controlled temperature as was done prior to the earlier reading and in the manner described above.

NOTE 3—To determine the drying shrinkage of concrete subjected to elevated temperature curing in the laboratory, a modification of the previous method is necessary. Where concrete is cured with elevated (non-autoclave) temperatures, the curing cycle for this test method shall be that to be used for the project structural members. The elevated temperature curing cycle consists of pre-steam, steam cure, and post-steam periods. To avoid measuring thermal volume change, after the molds are stripped, cool drying-shrinkage specimens at laboratory temperature until they reach equilibrium (approximately 6 h for 4 by 4 by 11-in. [100 by 100 by 280-mm] bars). Then place them in lime-saturated water prior to the initial reading (see 10.2).

11. Procedure for Storage of Specimens

11.1 After measurement at the end of the curing period, store the specimens as described in either of the following:

11.1.1 *Water Storage*—Immerse the specimens in lime-saturated water storage in accordance with Specification C511. Take comparator readings of each specimen when it has reached an age, including the curing period of 8, 16, 32, and 64 weeks. Make these readings immediately after the specimens have been subjected to storage in water at 73 ± 1 °F [23 ± 0.5 °C] for at least 15 min in the case of 1-in. [25-mm] specimens or 30 min in the case of 3-in. [75-mm] or 4-in. [100-mm] specimens.

11.1.2 *Air Storage*—Store the specimens in the drying room, so that the specimens have a clearance of at least 1 in. or 25 mm on all sides. Take comparator readings of each specimen after periods of air storage after curing of 4, 7, 14, and 28 days, and after 8, 16, 32, and 64 weeks. Preferably, take these readings in a room maintained at a relative humidity of 50 ± 4 % while the specimens are at a temperature of 73 ± 3 °F [23 ± 2 °C].

12. Procedure for Calculating Length Change

12.1 *Comparator Reading*—Read the comparator dial with the test specimen in the comparator; then read the comparator dial with the reference bar in the comparator. Calculate the difference between the two readings as described in Practice C490.

12.2 *Length Change*—Calculate the length change of any specimen at any age after the initial comparator reading as follows:

$$\Delta L_x = \frac{CRD - \text{initial } CRD}{G} \times 100 \quad (1)$$

where:

ΔL_x = length change of specimen at any age, %,

CRD = difference between the comparator reading of the specimen and the reference bar at any age, and

G = the gage length (10 in. [250 mm]) (see Note 4).

NOTE 4—In Practice C490, the comparator dial gage specified for use with 10-in. gage length specimens shall be graduated in fractions of an inch; the comparator dial gage specified for use with 250-mm gage length specimens shall be graduated in fractions of a millimetre.

13. Report

13.1 Report the following information:

13.1.1 Identification as mortar or concrete specimens, number of specimens for each condition, and date molded,

13.1.2 Source and identification of each material employed,

13.1.3 Type, maximum size, moisture condition, and grading of the aggregate,

13.1.4 Size of specimens,

13.1.5 Mortar or concrete mixture data at time of mixing, including flow or slump and temperature of mixture,

13.1.6 Description of consolidation of concrete, specifying whether rodding or external vibration was used,

13.1.7 Conditions and periods of moist curing prior and subsequent to removal of molds, if different from those specified,

13.1.8 Description of storage condition, including temperature and humidity, either by indicating whether the water or air storage was followed or by giving the details of any procedure not conforming to either of these conditions,

13.1.9 Total elapsed time of storage and total age of specimen, or total elapsed time of curing and storage if the same condition was used for both,

13.1.10 Length change data, reported as percent increase or decrease in linear dimension to the nearest 0.001 % of the gage length based on the initial measurement made at the time of removal from the molds, and

13.1.11 Any other pertinent information.

14. Precision and Bias

14.1 *Precision:*

14.1.1 When this test method was used for the purpose of determining drying shrinkage of mortar as affected by the choice of portland cement used in making it, the precision was found to be as reported in Test Method C596.

14.1.1.1 The following single-laboratory, multiple-operator precision applies to concrete specimens measured at 180 days.

14.1.1.2 For specimens stored in water, the standard deviation (1s) among specimens is 0.0045 %. When three replicate specimens are tested, the maximum range among them is not expected to exceed 0.0266 % in 95 % of the sets tested. When a test result represents the mean of three specimens, the 1s is 0.0026 %. The difference between two such means is not expected to exceed 0.0074 % in 95 % of such duplicate tests performed.

14.1.1.3 For specimens stored in air, the standard deviation (1s) among specimens is 0.0084 %. When three replicate specimens are tested, the maximum range among them is not expected to exceed 0.0496 % in 95 % of the sets tested. When a test result represents the mean of 3 specimens, the 1s is 0.0048 %. The difference between two such means is not expected to exceed 0.0137 % in 95 % of such duplicate tests performed.

NOTE 5—These precision values were calculated from data taken on specimens described on p. 47 of STP 205,[4] representing 193 concrete mixtures; two specimens made from each of three batches made on separate days, one of each two specimens stored in water, the other stored at nominal 50 % relative humidity.

[4] Mather, Bryant, "The Partial Replacement of Portland Cement in Concrete," *Cement and Concrete, ASTM STP 205*, ASTM, 1958.

14.2 *Bias*—No statement on bias is being made since there is no accepted reference material suitable for determining the bias of these procedures.

15. Keywords

15.1 length change; mortar concrete

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C157/C157M – 08ε1, that may impact the use of this test method. (Approved Oct. 1, 2014.)

(1) Replaced Test Method C1347 with correct designation Test Method C1437 in Section 2 and 8.3.

Designation: C642 – 13

Standard Test Method for Density, Absorption, and Voids in Hardened Concrete[1]

This standard is issued under the fixed designation C642; 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 the determinations of density, percent absorption, and percent voids in hardened concrete.

1.2 The text of this test method references notes and footnotes which provide explanatory information. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

1.3 The values stated in SI units are to be regarded as the standard.

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. Significance and Use

2.1 This test method is useful in developing the data required for conversions between mass and volume for concrete. It can be used to determine conformance with specifications for concrete and to show differences from place to place within a mass of concrete.

3. Apparatus

3.1 *Balance,* sensitive to 0.025 % of the mass of the specimen.

3.2 *Container,* suitable for immersing the specimen and suitable wire for suspending the specimen in water.

4. Test Specimen

4.1 Whenever possible, the sample shall consist of several individual portions of concrete, each to be tested separately. The individual portions may be pieces of cylinders, cores, or beams of any desired shape or size, except that the volume of each portion shall be not less than 350 cm^3 (or for normal weight concrete, approximately 800 g); and each portion shall be free from observable cracks, fissures, or shattered edges.

5. Procedure

5.1 *Oven-Dry Mass*—Determine the mass of the portions, and dry in an oven at a temperature of 110 ± 5°C for not less than 24 h. After removing each specimen from the oven, allow it to cool in dry air (preferably in a desiccator) to a temperature of 20 to 25°C and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass closely agrees with the first, consider it dry. If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24 h and again determine the mass. If the third value checks the second, consider the specimen dry. In case of any doubt, redry the specimen for 24-h periods until check values of mass are obtained. If the difference between values obtained from two successive values of mass exceeds 0.5 % of the lesser value, return the specimens to the oven for an additional 24-h drying period, and repeat the procedure until the difference between any two successive values is less than 0.5 % of the lowest value obtained. Designate this last value *A*.

5.2 *Saturated Mass After Immersion*—Immerse the specimen, after final drying, cooling, and determination of mass, in water at approximately 21°C for not less than 48 h and until two successive values of mass of the surface-dried sample at intervals of 24 h show an increase in mass of less than 0.5 % of the larger value. Surface-dry the specimen by removing surface moisture with a towel, and determine the mass. Designate the final surface-dry mass after immersion *B*.

5.3 *Saturated Mass After Boiling*—Place the specimen, processed as described in 5.2, in a suitable receptacle, covered with tap water, and boil for 5 h. Allow it to cool by natural loss of heat for not less than 14 h to a final temperature of 20 to 25°C. Remove the surface moisture with a towel and determine the mass of the specimen. Designate the soaked, boiled, surface-dried mass *C*.

5.4 *Immersed Apparent Mass*—Suspend the specimen, after immersion and boiling, by a wire and determine the apparent mass in water. Designate this apparent mass *D*.

6. Calculation

6.1 By using the values for mass determined in accordance with the procedures described in Section 5, make the following calculations:

---

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.66 on Concrete's Resistance to Fluid Penetration.

Current edition approved Feb. 1, 2013. Published February 2013. Originally approved in 1969. Last previous edition approved in 2006 as C642 – 06. DOI: 10.1520/C0642-13.

***A Summary of Changes section appears at the end of this standard**

$$\text{Absorption after immersion, \%} = [(B - A)/A] \times 100 \quad (1)$$

$$\text{Absorption after immersion and boiling, \%} = [(C - A)/A] \times 100 \quad (2)$$

$$\text{Bulk density, dry} = [A/(C - D)] \cdot \rho = g_1 \quad (3)$$

$$\text{Bulk density after immersion} = [B/(C - D)] \cdot \rho \quad (4)$$

$$\text{Bulk density after immersion and boiling} = [C/(C - D)] \cdot \rho \quad (5)$$

$$\text{Apparent density} = [A/(A - D)] \cdot \rho = g_2 \quad (6)$$

$$\text{Volume of permeable pore space (voids), \%} = (g_2 - g_1)/g_2 \times 100 \quad (7)$$

$$\text{or } (C - A)/(C - D) \times 100$$

where:

A = mass of oven-dried sample in air, g
B = mass of surface-dry sample in air after immersion, g
C = mass of surface-dry sample in air after immersion and boiling, g
D = apparent mass of sample in water after immersion and boiling, g
g_1 = bulk density, dry, Mg/m^3 and
g_2 = apparent density, Mg/m^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3.

7. Example

7.1 Assume a sample having the following characteristics:

7.1.1 Mass of the solid part of the specimen = 1000 g.

7.1.2 Total volume of specimen (including solids, "permeable" voids, and "impermeable" voids) = 600 cm^3.

7.1.3 Absolute density of solid part of specimen = 2.0 Mg/m^3.

7.1.4 Void space in specimen contains initially only air (no water).

7.2 Then, it follows that there are 500 cm^3 of solids and 100 cm^3 of voids making up the specimen, and the void content is ⅙ = 16.67 %.

7.3 Assume that on immersion 90 mL of water is absorbed.

7.4 Assume that after immersion and boiling 95 mL of water is absorbed.

7.5 Based on the assumptions given in 7.1 – 7.4 above, the data that would be developed from the procedures given in Section 5 would be as follows:

7.5.1 Oven-dry mass, A = 1000 g.

7.5.2 Mass in air after immersion, B = 1090 g.

7.5.3 Mass in air after immersion and boiling, C = 1095 g.

7.5.4 Apparent mass in water after immersion and boiling, D = 495 g.

NOTE 1—Since loss of mass in water is equal to mass of displaced water, and volume of specimen = 600 cm^3, mass of specimen in water after immersion and boiling is 1095 – 600 = 495 g.

7.6 By using the data given above to perform the calculations described in Section 6, the following results will be obtained (Note 2):

$$\text{Absorption after immersion, \%} = [(B - A)/A] \times 100 = [(1090 - 1000)/1000] \times 100 = 9.0 \quad (8)$$

$$\text{Absorption after immersion and boiling, \%} = [(C - A)/A] \times 100 = [(1095 - 1000)/1000] \times 100 = 9.5 \quad (9)$$

$$\text{Bulk density, dry} = [A/(C - D)] \cdot \rho = [1000/(1095 - 495)] \times 1 = 1.67\ Mg/m^3 = g_1 \quad (10)$$

$$\text{Bulk density after immersion} = [B/(C - D)] \cdot \rho = [1090/(1095 - 495)] \times 1 = 1.82 \quad (11)$$

$$\text{Bulk density after immersion and boiling} = [C/(C - D)]\ \rho = [1095/(1095 - 495)] \times 1 = 1.83\ Mg/m^3 \quad (12)$$

$$\text{Apparent density} = [A/(A - D)]\ \rho = [1000/(1000 - 495)] \times 1 = 1.98\ Mg/m^3 = g_2 \quad (13)$$

$$\text{Volume of permeable voids, \%} \quad (14)$$

$$= [(g_2 - g_1)/g_2] \times 100 = [(1.98 - 1.67)/1.98] \times 100$$

$$= 15.8, \text{ or } [(C - A)/(C - D)] \times 100$$

$$= [(1095 - 1000)/(1095 - 495)] \times 100 = 15.7$$

NOTE 2—This test method does not involve a determination of absolute density. Hence, such pore space as may be present in the specimen that is not emptied during the specified drying or is not filled with water during the specified immersion and boiling or both is considered "impermeable" and is not differentiated from the solid portion of the specimen for the calculations, especially those for percent voids. In the example discussed it was assumed that the absolute density of the solid portion of the specimen was 2.0 Mg/m^3, the total void space was 16.67 %, and the impermeable void space was 5 cm^3. The operations, if performed, and the calculations, if performed as described, have the effect of assuming that there are 95 cm^3 of pore space and 505 cm^3 of solids, and indicate that the solid material, therefore, has an apparent density of 1.98 rather than the absolute density of 2.00 Mg/m^3 and the specimen has a percentage of voids of 15.8 rather than 16.67.

Depending on the pore size distribution and the pore entry radii of the concrete and on the purposes for which the test results are desired, the procedures of this test method may be adequate, or they may be insufficiently rigorous. In the event that it is desired to fill more of the pores than will be filled by immersion and boiling, various techniques involving the use of vacuum treatment or increased pressures may be used. If a rigorous measure of total pore space is desired, this can only be obtained by determining absolute density by first reducing the sample to discrete particles, each of which is sufficiently small so that no impermeable pore space can exist within any of the particles. If the absolute density were determined and designated g_3, then:

$$\text{Total void volume, \%} = (g_3 - g_1)/g_3 \times 100 \quad (15)$$

$$= (2.00 - 1.67)/2.00 \times 100 = 16.5$$

8. Precision and Bias

8.1 *Precision*—At present there are insufficient data available to justify attempting to develop a precision statement for this test method.

8.2 *Bias*—Bias for this test method cannot be determined since there is no reference standard available for comparison.

9. Keywords

9.1 absorption; concrete-hardened; density; voids

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C642 – 06, that may impact the use of this test method. (Approved February 1, 2013.)

(*1*) Added new 1.4.

(*2*) Modified 5.1.

Designation: C900 – 15

Standard Test Method for Pullout Strength of Hardened Concrete[1]

This standard is issued under the fixed designation C900; 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 determination of the pullout strength of hardened concrete by measuring the force required to pull an embedded metal insert and the attached concrete fragment from a concrete test specimen or structure. The insert is either cast into fresh concrete or installed in hardened concrete. This test method does not provide statistical procedures to estimate other strength properties.

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

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

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.[2])

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C125 Terminology Relating to Concrete and Concrete Aggregates

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

E4 Practices for Force Verification of Testing Machines

E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminology C125.

4. Summary of Test Method

4.1 A metal insert is either cast into fresh concrete or installed into hardened concrete. When a measure of the in-place pullout strength is desired, the insert is pulled by means of a jack reacting against a bearing ring. The pullout strength is determined by measuring the maximum force required to pull the insert from the concrete mass. Alternatively, the insert is loaded to a specified load to verify whether a minimum level of in-place pullout strength has been attained.

5. Significance and Use

5.1 For a given concrete and a given test apparatus, pullout strengths can be related to compressive strength test results. Such strength relationships are affected by the configuration of the embedded insert, bearing ring dimensions, depth of embedment, and the type of aggregate (lightweight or normal weight). Before use, the relationships must be established for each test system and each new concrete mixture. Such relationships are more reliable if both pullout test specimens and compressive strength test specimens are of similar size, consolidated to similar density, and cured under similar conditions.

NOTE 1—Published reports **(1-17)**[4] by different researchers present their experiences in the use of pullout test equipment. Refer to ACI 228.1R **(14)** for guidance on establishing a strength relationship and interpreting test results. The Appendix provides a means for comparing pullout strengths obtained using different configurations.

5.2 If a strength relationship has been established experimentally and accepted by the specifier of tests, pullout tests are used to estimate the in-place strength of concrete to establish whether it has reached a specified level so that, for example:

(1) post-tensioning may proceed;
(2) forms and shores may be removed;
(3) structure may be placed into service; or
(4) winter protection and curing may be terminated.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

Current edition approved May 1, 2015. Published June 2015. Originally approved in 1978. Last previous edition approved in 2014 as C900 – 14. DOI: 10.1520/C0900-15.

[2] Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The boldface numbers refer to the list of references at the end of this test method.

***A Summary of Changes section appears at the end of this standard**

In addition, post-installed pullout tests may be used to estimate the strength of concrete in existing construction.

5.3 When planning pullout tests and analyzing test results, consideration should be given to the normally expected decrease of concrete strength with increasing height within a given concrete placement in a structural element.

5.4 The measured pullout strength is indicative of the strength of concrete within the region represented by the conic frustum defined by the insert head and bearing ring. For typical surface installations, pullout strengths are indicative of the quality of the outer zone of concrete members and can be of benefit in evaluating the cover zone of reinforced concrete members.

5.5 Cast-in-place inserts require that their locations in the structure be planned in advance of concrete placement. Post-installed inserts can be placed at any desired location in the structure provided the requirements of 7.1 are satisfied.

5.6 This test method is not applicable to other types of post-installed tests that, if tested to failure, do not involve the same failure mechanism and do not produce the same conic frustum as for the cast-in-place test described in this test method (**16**).

6. Apparatus

6.1 The apparatus requires three basic sub-systems: a pullout insert, a loading system, and a load-measuring system (Note 2). For post-installed inserts, additional equipment includes a core drill, a planing tool to prepare a flat bearing surface, a grinding tool to undercut a groove to engage the insert, and an expansion tool to expand the insert into the groove.

Note 2—A center-pull hydraulic jack with a pressure gauge that has been standardized according to Annex A1 and that reacts against a bearing ring has been used satisfactorily.

6.1.1 Cast-in-place inserts shall be made of metal that does not react with the constituents of the concrete. The insert shall consist of a cylindrical head and a shaft to fix embedment depth. The shaft shall be attached firmly to the center of the head (see Fig. 1). The insert shaft shall be threaded to the insert head so that it can be removed and replaced by a stronger shaft to pullout the insert, or it shall be an integral part of the insert and also function as the pullout shaft. Metal components of cast-in-place inserts and attachment hardware shall be of similar material to prevent galvanic corrosion. Post-installed inserts shall be designed so that they will fit into the drilled holes, and can be expanded subsequently to fit into the grooves that are undercut at a predetermined depth (see Fig. 2).

Note 3—A successful post-installed system uses a split ring that is coiled to fit into the core hole and then expanded into the groove.

6.1.2 The loading system shall consist of a bearing ring to be placed against the hardened concrete surface (see Figs. 1 and 2) and a tensile loading apparatus, with a load-measuring device that can be attached to the pullout shaft.

6.1.3 The test apparatus shall include centering features to ensure that the bearing ring is concentric with the insert, and that the applied load is axial to the pullout shaft, perpendicular to the bearing ring, and uniform on the bearing ring.

6.2 Equipment dimensions shall be determined as follows (see Fig. 1):

6.2.1 The diameter of the insert head (d_2) is the basis for defining the test geometry. The thickness of the insert head and the yield strength of the metal shall be sufficient to prevent

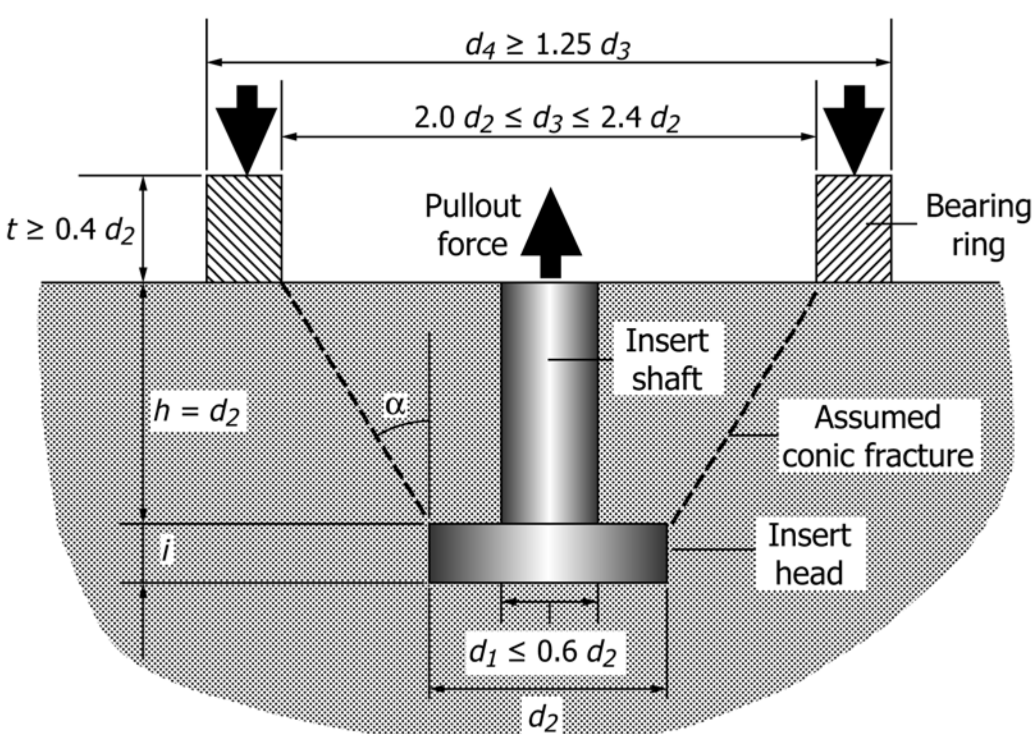


FIG. 1 Schematic Cross Section of Cast-in-Place Pullout Test

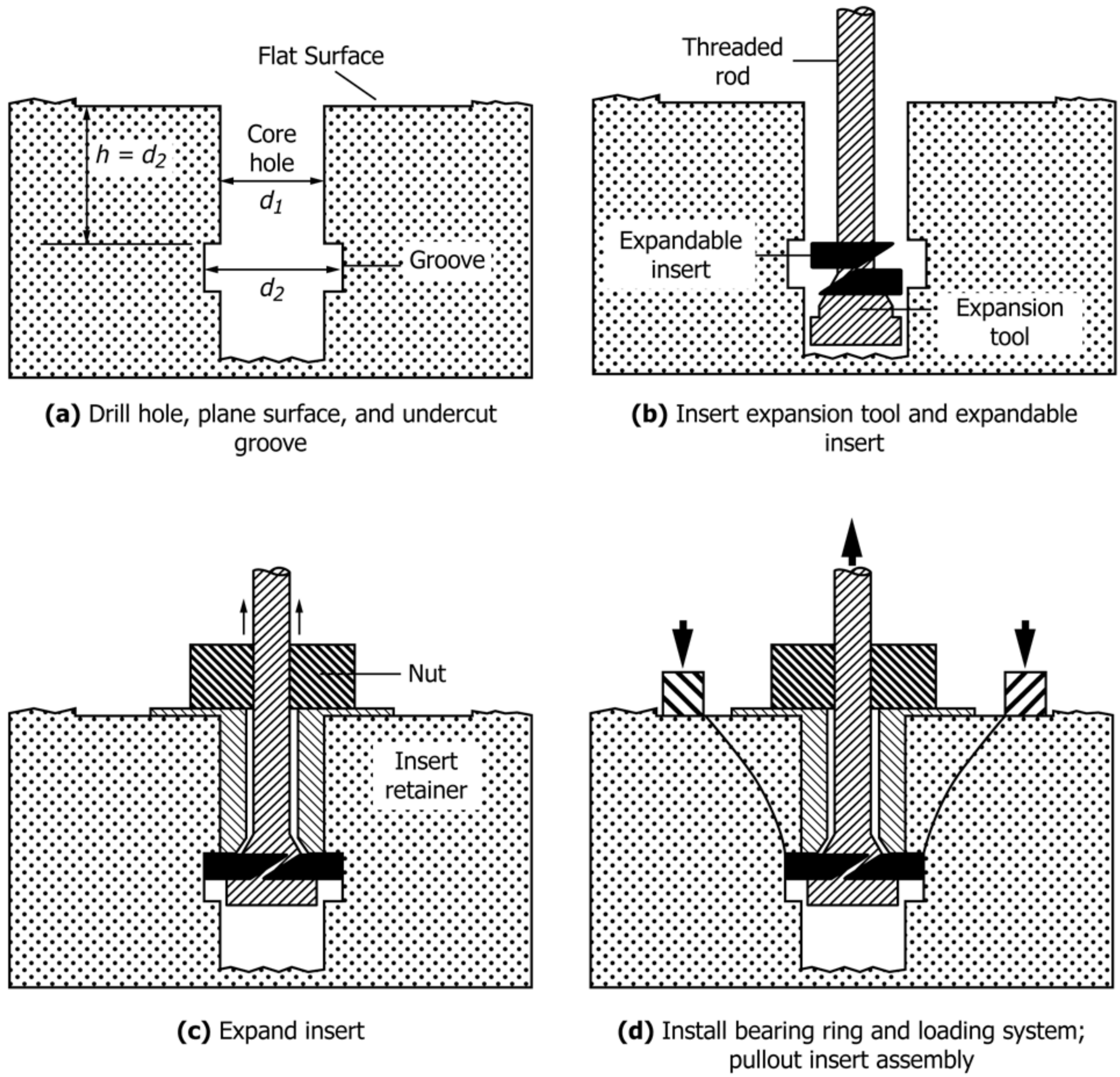


FIG. 2 Schematic of Procedure for Post-Installed Pullout Test

yielding of the insert during test. The sides of the insert head shall be smooth (see Note 5). The insert head diameter shall be at least ⅔ of the nominal maximum size of aggregate.

NOTE 4—Typical insert diameters are 25 and 30 mm, but larger diameters have been used (**1, 3**). Tests (**15**) have shown that nominal maximum aggregate sizes up to 1.5 times the head diameter do not have significant effects on the strength relationships. Larger aggregate sizes may result in increased scatter of the test results because the large particles can interfere with normal pullout of the conic frustum.

NOTE 5—Cast-in–place inserts may be coated with a release agent to minimize bonding with the concrete, and they may be tapered to minimize side friction during testing. The insert head should be provided with the means, such as a notch, to prevent rotation in the concrete if the insert shaft has to be removed prior to performing the test. As a further precaution against rotation of the insert head, all threaded hardware should be checked prior to installation to ensure that it is free-turning and can be easily removed. A thread-lock compound is recommended to prevent loosening of the insert head from the shaft during installation and during vibration of the surrounding concrete.

6.2.2 For cast-in–place inserts, the distance from the insert head to the concrete surface (h) shall equal the diameter of the insert head (d_2). The diameter of the insert shaft at the head (d_1) shall not exceed 0.60 d_2.

6.2.3 For post-installed inserts, the groove to accept the expandable insert shall be cut so that the distance between the bearing surface of the groove and concrete surface equals the insert diameter after expansion (d_2). The difference between the diameters of the undercut groove (d_2) and the core hole (d_1) shall be sufficient to prevent localized failure and ensure that a conic frustum of concrete is extracted during the test (see Note 6). The expanded insert shall bear uniformly on the entire bearing area of the groove.

NOTE 6—A core hole diameter of 18 mm and an undercut groove diameter of 25 mm have been used successfully.

6.2.4 The bearing ring shall have an inside diameter (d_3) of 2.0 to 2.4 times the insert head diameter (d_2), and shall have an outside diameter (d_4) of at least 1.25 times the inside diameter. The thickness of the ring (t) shall be at least 0.4 times the pullout insert head diameter. For a given test system, the same bearing ring dimensions shall be used.

6.2.5 Tolerances for dimensions of the pullout test inserts, bearing ring and embedment depth shall be ±2 % within a given system.

NOTE 7—The limits for dimensions and configurations for pullout test inserts and apparatus are intended to accommodate various systems.

6.2.6 The loading apparatus shall have sufficient capacity to provide the loading rate prescribed in 8.4.

NOTE 8—Hydraulic pumps that permit continuous loading may give more uniform test results than pumps that apply load intermittently.

6.2.7 The gauge to measure pullout force is permitted to be of the analog or digital type. Analog gauges shall be designed so that the pullout force can be estimated to the nearest 0.5 kN. Digital gauges shall display the pullout force to the nearest 0.1 kN.

6.2.8 The force gauge shall have a means to preserve the maximum value of the load during a test.

6.2.9 Pullout apparatus shall be standardized in accordance with Annex A1 at least once a year and after all repairs. Standardize the pullout apparatus using a testing machine verified in accordance with Practices E4 or using a Class A load cell as defined in Practice E74. The indicated pullout force based on the developed relationship shall be within ±2 % of the force measured by the testing machine or load cell.

7. Sampling

7.1 Pullout test locations shall be separated so that the clear spacing between inserts is at least seven times the pullout insert head diameter. Clear spacing between the inserts and the edges of the concrete shall be at least 3.5 times the head diameter. Inserts shall be placed so that reinforcement is outside the expected conical failure surface by more than one bar diameter, or the maximum size of aggregate, whichever is greater.

NOTE 9—A reinforcement locator is recommended to assist in avoiding reinforcement when planning the locations of post-installed tests. Follow the manufacturer's instructions for proper operation of such devices.

7.2 When pullout test results are used to assess the in-place strength in order to allow the start of critical construction operations, such as formwork removal or application of post tensioning, at least five individual pullout tests shall be performed as follows:

7.2.1 For every 115 m^3, or a fraction thereof, of a given placement; or

7.2.2 For every 470 m^2 , or a fraction thereof, of the surface area of one face of a slab or wall.

NOTE 10—More than the minimum number of inserts should be provided in case a test result is not valid or testing begins before adequate strength has developed.

7.2.3 Inserts shall be located in those portions of the structure that are critical in terms of exposure conditions and structural requirements.

7.3 When pullout tests are used for other purposes, the number of tests shall be determined by the specifier of the test.

8. Procedure

8.1 *Cast-in-Place Inserts:*

8.1.1 Attach the pullout inserts to the forms using bolts or by other methods that firmly secure the insert in its proper location prior to concrete placement. All inserts shall be embedded to the same depth. The axis of each shaft shall be perpendicular to the formed surface.

8.1.2 Alternatively, when instructed by the specifier of tests, manually place inserts into unformed horizontal concrete surfaces. The inserts shall be embedded into the fresh concrete by means that ensure a uniform embedment depth and a surface to support the bearing ring that is plane and perpendicular to the axis of the insert shaft. Installation of inserts shall be performed or supervised by personnel trained by the manufacturer or manufacturer's representative.

NOTE 11—Experience indicates that pullout strengths are of lower value and more variable for manually-placed surface inserts than for inserts attached to formwork (12).

8.1.3 When pullout strength of the concrete is to be measured, remove all hardware used for securing the pullout inserts in position. Before mounting the loading system, remove any debris or surface abnormalities to ensure a flat bearing surface that is perpendicular to the axis of the insert.

8.2 *Post-Installed Inserts:*

8.2.1 The selected test surface shall be flat to provide a suitable working surface for drilling the core and undercutting the groove. Drill a core hole perpendicular to the surface to provide a reference point for subsequent operations and to accommodate the expandable insert and associated hardware. The use of an impact drill is not permitted.

8.2.2 If necessary, use a surface planing tool to prepare a flat surface so that the base of the tool for cutting the groove is supported firmly and so that the bearing ring is supported uniformly during testing. The prepared surface shall be perpendicular to the axis of the core hole.

8.2.3 Use the grinding tool in accordance with the manufacturer's instructions to undercut a groove of the correct diameter and at the correct depth in the core hole. The groove shall be concentric with the core hole.

NOTE 12—To control the accuracy of these operations, a support system should be used to hold the apparatus in the proper position during these steps.

8.2.4 If water is used as a coolant, remove free-standing water from the hole at the completion of the drilling, planing, and undercutting operations. Protect the hole from ingress of additional water until completion of the test.

NOTE 13—Penetration of water into the failure zone could affect the measured pullout strength.

8.2.5 Use the expansion tool to position the expandable insert into the groove and expand the insert to its proper size in accordance with the manufacturer's instructions.

8.3 *Bearing Ring*—Place the bearing ring around the pullout insert shaft, connect the pullout shaft to the hydraulic ram, and tighten the pullout assembly snugly against the bearing surface.

Ensure that the bearing ring is centered around the shaft and flush against the concrete.

8.4 *Loading Rate*—Apply load at a uniform rate so that the nominal normal stress on the assumed conical fracture surface increases at a rate of 70 ± 30 kPa/s (Note 14). If the insert is to be tested to rupture of the concrete, load at the specified uniform rate until rupture occurs. Record the maximum gauge reading to the nearest 0.5 kN for analog gauges and to the nearest 0.1 kN for digital gauges. If the insert is to be tested only to a specified load to verify whether a minimum in-place pullout strength has been attained, load at the specified uniform rate until the specified pullout load is reached. Maintain the specified load for at least 10 s.

NOTE 14—The loading rate is specified in terms of a nominal stress rate to accommodate different sizes of pullout test systems. See Appendix X1 for the formula relating the nominal normal stress and the pullout load. For a commonly used pullout test system in which d_2 = 25 mm and d_3 = 55 mm, the specified stress rate corresponds to a loading rate of approximately 0.5 ± 0.2 kN/s. If this system is used, the ranges of the times to complete a test for different anticipated ultimate pullout loads would be as follows:

Anticipated Pullout Load, kN	Minimum Time, s	Maximum Time, s
10	14	33
20	29	67
30	43	100
40	57	133
50	71	167
60	86	200
70	100	233
80	114	267
90	129	300
100	143	333

8.4.1 Do not test frozen concrete.

8.5 *Rejection*—Reject a test result if one or more of the following conditions are encountered:

8.5.1 The large end of the conic frustum is not a complete circle of the same diameter as the inside diameter of the bearing ring;

8.5.2 The distance from the surface to the insert head (*h* in Fig. 1 or Fig. 2) is not equal to the insert diameter;

8.5.3 The diameter of the groove in a post-installed test is not equal to the manufacturer's design value;

8.5.4 The expanded insert diameter in a post-installed test is not equal to the manufacturer's design value; or,

8.5.5 A reinforcing bar is visible within the failure zone after the conic frustum is removed.

9. Calculation

9.1 Convert gauge readings to pullout force on the basis of relationship developed in accordance with Annex A1.

9.2 Compute the average and standard deviation of the pullout forces that represent tests of a given concrete placement.

10. Report

10.1 Report the following information:

10.1.1 Dimension of the pullout insert and bearing ring (sketch or define dimensions),

10.1.2 Identification by which the specific location of the pullout test can be identified,

10.1.3 Date and time when the pullout test was performed.

10.1.4 For tests to failure, maximum pullout load of individual tests, average, and standard deviation, kN. For tests to a specified load, the pullout load applied in each test, kN.

10.1.5 Description of any surface abnormalities beneath the reaction ring at the test location,

10.1.6 Abnormalities in the ruptured specimen and in the loading cycle,

10.1.7 Concrete curing methods used and moisture condition of the concrete at time of test, and

10.1.8 Other information regarding unusual job conditions that may affect the pullout strength.

11. Precision and Bias

11.1 *Single Operator Precision*—Based on the data summarized in ACI 228.1 R (**14**) for cast-in-place pullout tests with embedment of about 25 mm, the average coefficient of variation for tests made on concrete with maximum aggregate of 19 mm by a single operator using the same test device is 8 %.[5] Therefore, the range in individual test results, expressed as a percentage of the average, should not exceed the following:

Number of Tests	Acceptable range, (percent of average)
5	31 %
7	34 %
10	36 %

Similar values of within-test variability have been reported for post-installed pullout tests of the same geometry as cast-in-place tests (**15**).

NOTE 15—If the range of tests results exceeds the acceptable range, further investigation should be carried out. Abnormal test results could be due to improper procedures or equipment malfunction. The user should investigate potential causes of outliers and disregard those test results for which reasons for the outlying results can be identified positively. If there are no obvious causes of the extreme values, it is probable that there are real differences in concrete strength at different test locations. These differences could be due to variations in mixture proportions, degree of consolidation, or curing conditions.

11.2 *Multi-Operator Precision*—Test data are not available to develop a multi-operator precision statement.

11.3 *Bias*—The bias of this test method cannot be evaluated since pullout strength can only be determined in terms of this test method.

12. Keywords

12.1 concrete strength; in-place strength; in-place testing; pullout test

[5] This number represents the (1s%) limit as described in Practice C670.

ANNEX

(Mandatory Information)

A1. STANDARDIZATION OF PULLOUT-HYDRAULIC LOADING SYSTEM

A1.1 The objective of the procedure in this annex is to establish a relationship between the reading of the pullout force measuring system and the tensile force in the shaft used to pullout the insert. This relationship is established using alternative approaches as indicated in Fig. A1.1. In general, standardization is achieved by correlating the gauge reading of the pullout loading system with the force measured by a testing machine that has been verified in accordance with Practices E4 or measured with a Class A load cell that has been calibrated in accordance with Practice E74. The time interval between testing machine verifications or load cell calibrations shall be as defined in Practices E4 or E74.

A1.2 Position the pullout loading system on the force measurement apparatus. Align all components so that the pullout force is concentric with the loading system and the force measurement system. Use spherical seats or other similar means to minimize bending effects in the loading system.

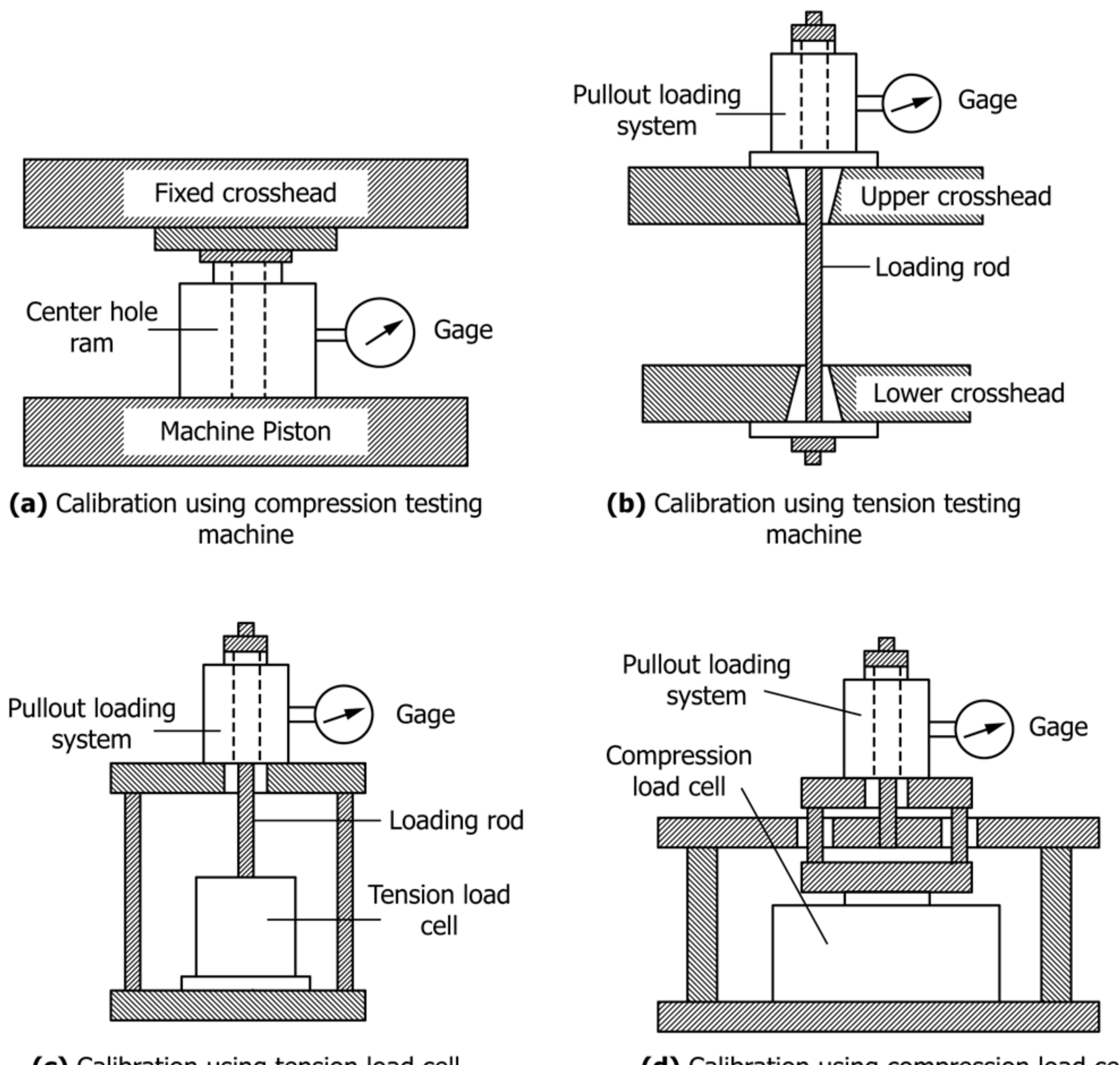


FIG. A1.1 Schematics of Acceptable Methods to Standardize Pullout Load Measuring System

NOTE A1.1—When a compression-testing machine is used to measure the force, the bearing blocks should be protected against damage. Cold-rolled steel plate at least 13 mm thick is recommended.

A1.3 Using the pullout loading system, apply increasing loads over the operating range, and record the gauge reading and the corresponding force measured by the testing machine or load cell. Take readings at approximately 10 load levels distributed over the operating range of the pullout loading system.

NOTE A1.2—Low values of force should be avoided in the standardization process because the effects of friction may introduce significant errors. The manufacturer should provide the operating range of the pullout loading system.

A1.4 Use the readings obtained in A1.3 to calculate an appropriate regression equation using the least-squares curve-fitting method.

NOTE A1.3—Appendix X2 provides an example to illustrate the development of the regression equation. Additional information is provided in Practice E74.

A1.5 The difference between the force based on the regression equation and the force measured by the testing machine or the load cell shall not be greater than ±2 % of the measured force over the operating range. If this tolerance is not met, the pullout loading system shall not be used until this requirement is satisfied.

APPENDIXES

(Nonmandatory Information)

X1. STRESS CALCULATION

X1.1 When a stress calculation is desired, compute a nominal normal stress on the assumed conical fracture surface by dividing the pullout force by the area of the frustum and multiplying by the sine of one-half the apex angle (see Fig. 1). Use the following equations:

$$f_n = \frac{P}{A} \sin\alpha \tag{X1.1}$$

$$\sin\alpha = \frac{d_3 - d_2}{2S} \tag{X1.2}$$

$$A = \pi S \frac{d_3 + d_2}{2} \tag{X1.3}$$

$$S = \sqrt{h^2 + \left(\frac{d_3 - d_2}{2}\right)^2} \tag{X1.4}$$

where:

f_n = nominal normal stress, MPa,
P = pullout force, N,
α = ½ the frustum apex angle, or $\tan^{-1} (d_3 - d_2)/2h$,
A = fracture surface area, mm^2 ,
d_2 = diameter of pullout insert head, mm,
d_3 = inside diameter of bearing ring or large base diameter of assumed conic frustum, mm,
h = height of conic frustum, from insert head to large-base surface, mm , and
S = slant length of the frustum, mm.

X1.2 The above calculation gives the value of the average normal stress on the assumed failure surface shown in Fig. 1. Because the state of stress on the conic frustum is not uniform, the calculated normal stress is a fictitious value. The calculated normal stress is useful when comparing pullout strengths obtained with different test geometries that fall within the limits of this test method.

X2. EXAMPLE TO ILLUSTRATE STANDARIZATION PROCESS

X2.1 This appendix provides an example to illustrate the development of the regression equation to convert the gauge reading of the pullout loading system to the force acting on the insert. Table X2.1 shows data that were obtained using the procedure in the annex. The first column shows the gauge reading and the second column shows the measured force.

X2.2 Fig. X2.1 shows a plot of the data in Table X2.1 along with the best-fit straight line to the data. A straight line was fitted using a commercial computer program for graphing and statistical analysis. The equation of the line is shown in the table of results on the graph and is as follows:

$$P\ (\text{kN}) = -0.55 + 1.089\ G\ (\text{kN}) \tag{X2.1}$$

TABLE X2.1 Example of Gauge Reading Versus Force Data and Residuals After Fitting Regression Equation

Gauge Reading, kN	Measured Force, kN	Residuals, kN
2.0	1.6	0.03
5.0	4.8	0.09
10.0	10.5	−0.16
15.0	15.8	−0.02
20.0	21.2	0.03
25.0	26.7	−0.03
30.0	32.0	0.12
35.0	37.4	0.16
40.0	42.8	0.21
45.0	48.6	−0.14
50.0	54.2	−0.30
55.0	59.4	−0.06
60.0	64.5	0.29

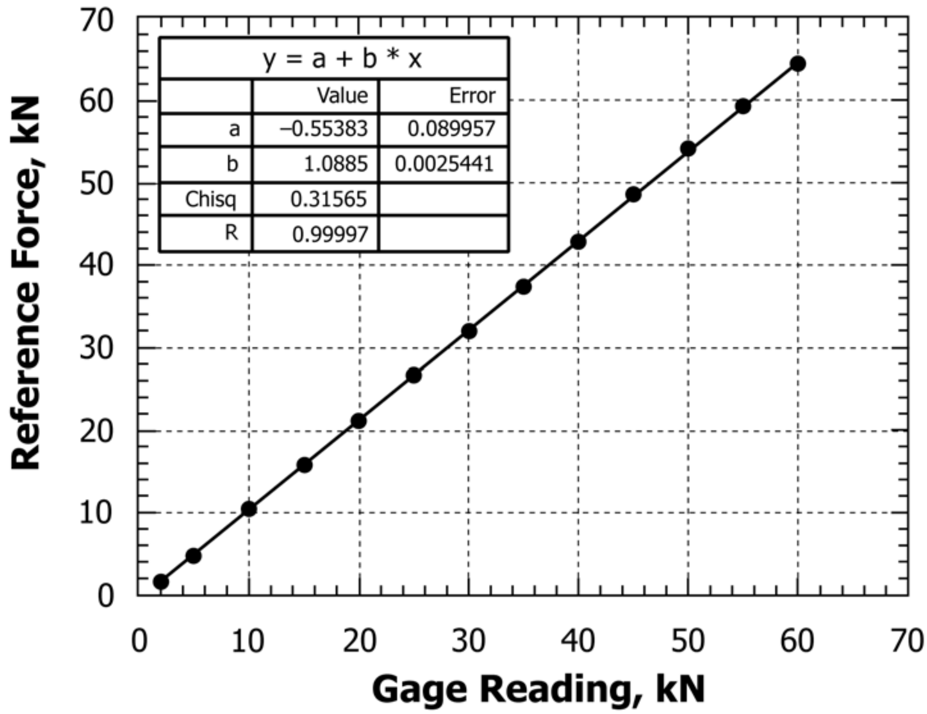


FIG. X2.1 Plot of Data from Table X2.1 and Best-Fit Straight Line

where:

P = estimated pullout force, kN, and
G = pullout force indicated by gauge of pullout loading system, kN.

The column labeled "error" in the table shown within Fig. X2.1 represents the standard deviations of the estimated intercept and slope. The low values of these standard deviations relative to the slope and intercept indicate that the intercept is not zero and that the slope is not equal to 1.00.

X2.3 Fig. X2.2 is a plot of the residuals of the best-fit line as a function of the measured force. These residuals are shown in the third column of Table X2.1, and they are the differences between the estimated force based on the best-fit equation and the measured force (Column 2 in Table X2.1). Also shown in Fig. X2.2 are the ±2 % limits required in accordance with 6.2.9. It is seen that, with the exception of the first three points, the residuals are well within the permitted tolerance. Thus, the regression equation for this particular apparatus satisfies the requirements of 6.2.9 provided that the pullout force is greater than about 10 kN.

X2.4 Fig. X2.2 shows that the residuals are not randomly distributed but appear to have a periodic variation with the level of force. This indicates that the true regression equation is not a straight line. However, because the residuals are well below the ±2 % limits, it is not necessary to try to fit a higher order (polynomial) equation, and the straight line is adequate. Additional discussion on fitting higher order equations is provided in Practice E74.

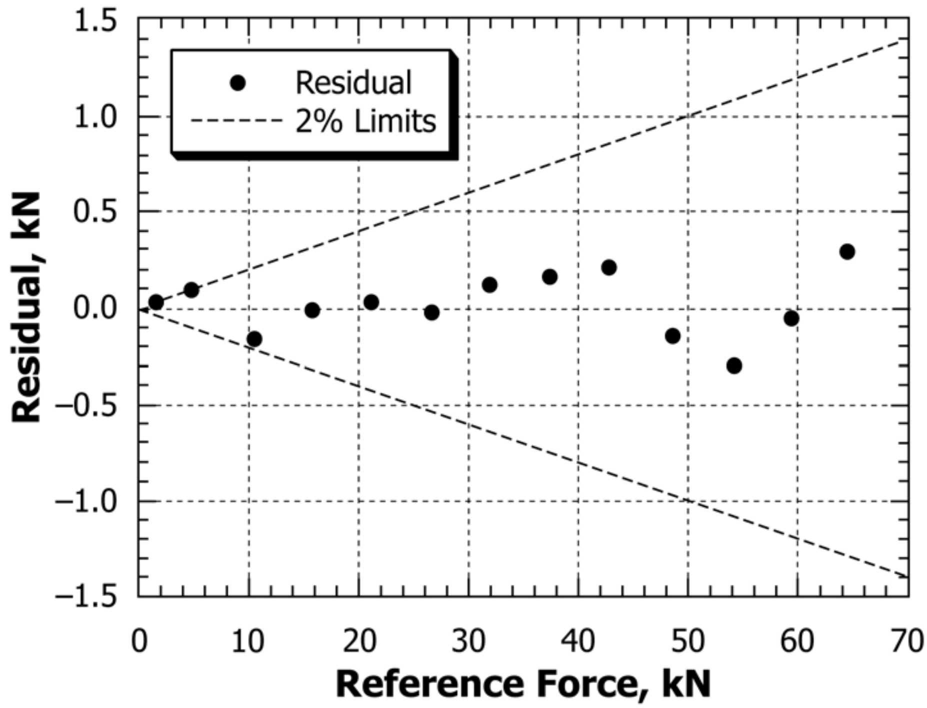


FIG. X2.2 Residuals of Best-Fit Equation as a Function of Measured Force

REFERENCES

(1) Richards, O., "Pullout Strength of Concrete," *Reproducibility and Accuracy of Mechanical Tests*, *ASTM STP 626*, ASTM 1977, pp. 32–40.

(2) Kiekegaard-Hansen, P., *Lok-Strength*, Saertryk af Nordisk Betong 3: 1975.

(3) Malhotra, V. M., and Carrette, G., "Comparison of Pullout Strength of Concrete with Compressive Strength of Cylinders and Cores, Pulse Velocity and Rebound Number," *Journal*, American Concrete Institute, Vol 77, No. 3, May–June 1980, pp. 161–170.

(4) Bickley, J. A., "The Variability of Pullout Tests and In-Place Concrete Strength," *Concrete International*, American Concrete Institute, Vol 4, No. 4, April 1982, pp. 44–51.

(5) Dilly, R. L., and Ledbetter, W. B., "Concrete Strength Based on Maturity and Pullout," *ASCE Journal of Structural Engineering*, American Society of Civil Engineers, Vol 110, No. 2, Feb. 1984, pp. 354–369.

(6) Stone, W. C., and Giza, B. J., "The Effect of Geometry and Aggregate on the Reliability of the Pullout Test," *Concrete International*, American Concrete Institute, Vol 7, No. 2, Feb. 1985, pp. 27–36.

(7) Hindo, K. R., and Bergstrom, W. R., "Statistical Evaluation of the In-Place Compressive Strength of Concrete," *Concrete International*, American Concrete Institute, Vol 7, No. 2, Feb. 1985, pp. 44–48.

(8) Yener, M., and Chen, W. F., "On In-Place Strength of Concrete and Pullout Tests," Cement, Concrete, and Aggregates, CCAGDP, Vol 6, No. 2, Winter 1984, pp. 90–99.

(9) Bickley, J. A., "The Evaluation and Acceptance of Concrete Quality by In-Place Testing," *In Situ/Nondestructive Testing of Concrete*, American Concrete Institute, 1984, pp. 95–109.

(10) Carrette, G. G., and Malhotra, V. M., "In Situ Tests: Variability and Strength Prediction of Concrete at Early Ages," *In Situ/Nondestructive Testing of Concrete*, American Concrete Institute, 1984, pp. 111–141.

(11) Khoo, L. M., "Pullout Technique—An Additional Tool for In Situ Concrete Strength Determination," *In Situ/Nondestructive Testing of Concrete*, American Concrete Institute, 1984, pp. 143–159.

(12) Vogt, W. L., Beizai, V., and Dilly, R. L., "In Situ Strength of Concrete with Inserts Embedded by 'Finger Placing'," *In Situ/Nondestructive Testing of Concrete*, American Concrete Institute, 1984, pp. 161–175.

(13) Parsons, T. J., and Naik, T. R., "Early Age Concrete Strength Determination Pullout Testing and Maturity," *In Situ/Nondestructive Testing of Concrete*, American Concrete Institute, 1984, pp. 177–199.

(14) ACI228.1R-03, "In-Place Methods to Estimate Concrete Strength," American Concrete Institute, Farmington Hills, MI, www.concrete.org, 44 pp.

(15) Petersen, C.G., "LOK-TEST and CAPO-TEST Pullout Testing, Twenty Years Experience," *Proceedings of Conference on Nondestructive Testing in Civil Engineering*, J.H. Bungey, Ed., British Institute of Nondestructive Testing, U.K., Liverpool, 8–11 April 1997, pp. 77–96.

(16) Carino, N.J., "Pullout Test," Chapter 3 in *Handbook on Nondestructive Testing of Concrete*, 2nd Edition, V.M. Malhotra and N.J. Carino, Eds., CRC Press, Boca Raton, FL, and ASTM International, West Conshohocken, PA, www.astm.org, 2004.

(17) Soutsos, M.N., Bungey, J.H., and Long, A.E., "Pullout Test Correlations and In-Place Strength Assessment—The European Concrete Frame Building Project," *ACI Materials Journal*, Vol 12, No. 6, Nov-Dec 2005, pp 422–428.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C900 – 14, that may impact the use of this test method. (Approved May 1, 2015.)

(1) Revised 5.2.

Designation: C597 – 16

Standard Test Method for Pulse Velocity Through Concrete[1]

This standard is issued under the fixed designation C597; 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 U.S. Department of Defense.

1. Scope*

1.1 This test method covers the determination of the propagation velocity of longitudinal stress wave pulses through concrete. This test method does not apply to the propagation of other types of stress waves through concrete.

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates

C215 Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens

C823 Practice for Examination and Sampling of Hardened Concrete in Constructions

E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions*—Refer to Terminology C125 and the section related to ultrasonic examination in Terminology E1316 for definitions of terms used in this test method.

4. Summary of Test Method

4.1 Pulses of longitudinal stress waves are generated by an electro-acoustical transducer that is held in contact with one surface of the concrete under test. After traversing through the concrete, the pulses are received and converted into electrical energy by a second transducer located a distance L from the transmitting transducer. The transit time T is measured electronically. The pulse velocity V is calculated by dividing L by T.

5. Significance and Use

5.1 The pulse velocity, V, of longitudinal stress waves in a concrete mass is related to its elastic properties and density according to the following relationship:

$$V = \sqrt{\frac{E\,(1-\mu)}{\rho\,(1+\mu)(1-2\,\mu)}} \quad (1)$$

where:

E = dynamic modulus of elasticity,
μ = dynamic Poisson's ratio, and
ρ = density.

5.2 This test method is applicable to assess the uniformity and relative quality of concrete, to indicate the presence of voids and cracks, and to evaluate the effectiveness of crack repairs. It is also applicable to indicate changes in the properties of concrete, and in the survey of structures, to estimate the severity of deterioration or cracking. If used to monitor changes in condition over time, test locations are to be marked on the structure to ensure that tests are repeated at the same positions.

5.3 The degree of saturation of the concrete affects the pulse velocity, and this factor must be considered when evaluating test results (Note 1). In addition, the pulse velocity in saturated concrete is less sensitive to changes in its relative quality.

NOTE 1—The pulse velocity in saturated concrete may be up to 5 % higher than in dry concrete.[3]

5.4 The pulse velocity is independent of the dimensions of the test object provided reflected waves from boundaries do not complicate the determination of the arrival time of the directly transmitted pulse. The least dimension of the test object must exceed the wavelength of the ultrasonic vibrations (Note 2).

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

Current edition approved April 1, 2016. Published May 2016. Originally approved in 1967. Last previous edition approved in 2009 as C597 – 09. DOI: 10.1520/C0597-16.

[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] Bungey, J. H., Millard, S. G., and Grantham, M.G., 2006 *Testing of Concrete in Structures*, 4th ed., Taylor & Francis, 339 pp.

***A Summary of Changes section appears at the end of this standard**

NOTE 2—The wavelength of the vibrations equals the pulse velocity divided by the frequency of vibrations. For example, for a frequency of 54 kHz and a pulse velocity of 3500 m/s, the wavelength is 3500/54000 = 0.065 m.

5.5 The accuracy of the measurement depends upon the ability of the operator to determine precisely the distance between the transducers and of the equipment to measure precisely the pulse transit time. The received signal strength and measured transit time are affected by the coupling of the transducers to the concrete surfaces. Sufficient coupling agent and pressure must be applied to the transducers to ensure stable transit times. The strength of the received signal is also affected by the travel path length and by the presence and degree of cracking or deterioration in the concrete tested.

NOTE 3—Proper coupling can be verified by viewing the shape and magnitude of the received waveform. The waveform should have a decaying sinusoidal shape. The shape can be viewed by means of outputs to an oscilloscope or digitized display inherent in the device.

5.6 The measured quantity in this test method is transit time, from which an 'apparent' pulse velocity is calculated based on the distance between the transducers. Not all forms of deterioration or damage actually change the pulse velocity of the material, but they affect the actual path for the pulse to travel from transmitter to receiver. For example, load-induced cracking will increase the true path length of the pulse and thus increase the measured pulse transit time. The true path length cannot be measured. Because the distance from transmitting to receiving transducer is used in the calculation, the presence of the cracking results in a decrease in the 'apparent' pulse velocity even though the actual pulse velocity of the material has not changed. Many forms of cracking and deterioration are directional in nature. Their influence on transit time measurements will be affected by their orientation relative to the pulse travel path.

5.7 The results obtained by the use of this test method are not to be considered as a means of measuring strength nor as an adequate test for establishing compliance of the modulus of elasticity of field concrete with that assumed in the design. The longitudinal resonance method in Test Method C215 is recommended for determining the dynamic modulus of elasticity of test specimens obtained from field concrete because Poisson's ratio does not have to be known.

NOTE 4—If circumstances warrant, a velocity-strength (or velocity-modulus) relationship may be established by the determination of pulse velocity and compressive strength (or modulus of elasticity) on a number of specimens of a concrete. This relationship may serve as a basis for the estimation of strength (or modulus of elasticity) by further pulse-velocity tests on that concrete. Refer to ACI 228.1R[4] for guidance on the procedures for developing and using such a relationship.

5.8 The procedure is applicable in both field and laboratory testing regardless of size or shape of the specimen within the limitations of available pulse-generating sources.

NOTE 5—Presently available test equipment limits path lengths to approximately 50-mm minimum and 15-m maximum, depending, in part, upon the frequency and intensity of the generated signal. The upper limit of the path length depends partly on surface conditions and partly on the characteristics of the interior concrete under investigation. A preamplifier at the receiving transducer may be used to increase the maximum path length that can be tested. The maximum path length is obtained by using transducers of relatively low resonant frequencies (20 to 30 kHz) to minimize the attenuation of the signal in the concrete. (The resonant frequency of the transducer assembly determines the frequency of vibration in the concrete.) For the shorter path lengths where loss of signal is not the governing factor, it is preferable to use resonant frequencies of 50 kHz or higher to achieve more accurate transit-time measurements and hence greater sensitivity.

5.9 Because the pulse velocity in steel is up to double that in concrete, the pulse-velocity measured in the vicinity of the reinforcing steel will be higher than in plain concrete of the same composition. If possible, avoid measurements close to steel parallel to the direction of pulse propagation.

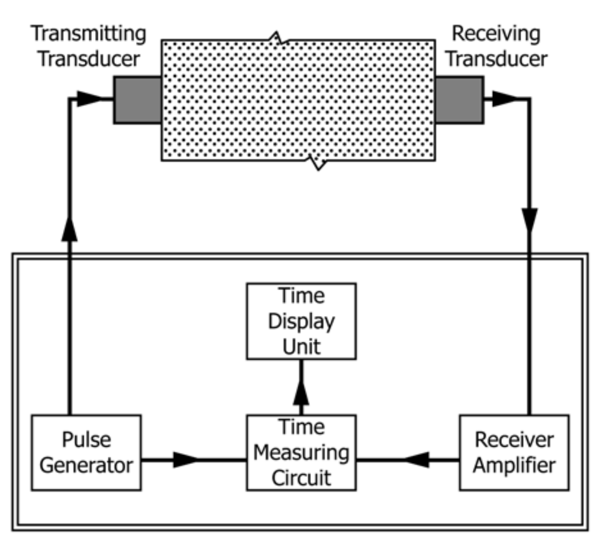
6. Apparatus

6.1 The testing apparatus, shown schematically in Fig. 1, consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measuring circuit, a time display unit, and connecting cables.

6.1.1 *Pulse Generator and Transmitting Transducer*—The pulse generator shall consist of circuitry for generating pulses of voltage (Note 6). The transducer for transforming these electronic pulses into wave bursts of mechanical energy shall have a resonant frequency in the range from 20 to 100 kHz (Note 7). The pulse generator shall produce repetitive pulses at a rate of at least 3 pulses per second. The time interval between pulses shall exceed the decay time for the transmitting transducer. The transducer shall be constructed of piezoelectric, magnetostrictive, or other voltage-sensitive material, and housed for protection. A triggering pulse shall be produced to start the time measuring circuit.

NOTE 6—The pulse voltage affects the transducer power output and the maximum penetration of the longitudinal stress waves. Voltage pulses of 500 to 1000 V have been used successfully.

NOTE 7—Transducers with higher resonant frequencies have been used successfully in relatively small laboratory specimens.



NOTE 1—It is advantageous to incorporate the pulse generator, time measuring circuit, receiver amplifier, and time display into one unit.

FIG. 1 Schematic of Pulse Velocity Apparatus

[4] "In-Place Methods to Estimate Concrete Strength," ACI 228.1R, American Concrete Institute, Farmington Hills, MI.

6.1.2 *Receiving Transducer and Amplifier*—The receiving transducer shall be similar to the transmitting transducer. The voltage generated by the receiver shall be amplified as necessary to produce triggering pulses to the time-measuring circuit. The amplifier shall have a flat response between one half and three times the resonant frequency of the receiving transducer.

6.1.3 *Time-Measuring Circuit*—The time-measuring circuit and the associated triggering pulses shall be capable of providing an overall time-measurement resolution of at least 1 µs. Time measurement is initiated by a triggering voltage from the pulse generator, and the time measuring circuit shall operate at the repetition frequency of the pulse generator. The time-measuring circuit shall provide an output when the received pulse is detected, and this output shall be used to determine the transit time displayed on the time-display unit. The time-measuring circuit shall be insensitive to operating temperature in the range from 0 to 40°C and voltage changes in the power source of ±15 %.

6.1.4 *Display Unit*—A display unit shall indicate the pulse transit time to the nearest 0.1 µs.

6.1.5 *Reference Bar*—For units that use manual zero-time adjustment, provide a bar of metal or other durable material for which the transit time of longitudinal waves is known. The transit time shall be marked permanently on the reference bar. The reference bar is optional for units that perform automatic zero-time adjustment.

6.1.6 *Connecting Cables*—Where pulse-velocity measurements on large structures require the use of long interconnecting cables, use low-capacitance, shielded, coaxial cables.

6.1.7 *Coupling Agent*—A viscous material (such as oil, petroleum jelly, water soluble jelly, moldable rubber, or grease) to ensure efficient transfer of energy between the concrete and the transducers. The function of the coupling agent is to eliminate air between the contact surfaces of the transducers and the concrete. Water is an acceptable coupling agent if ponded on the surface, or for underwater testing.

7. Procedure

7.1 *Functional Check of Equipment and Zero-time Adjustment*—Verify that the equipment is operating properly and perform a zero-time adjustment.

7.1.1 *Units with Automatic Zero-Time Adjustment*—Follow the manufacturer's instructions for performing zero-time adjustments.

NOTE 8—A reference bar may be used to verify that the zero-time adjustment has been performed correctly.

7.1.2 *Units with Manual Zero-Time Adjustment*—Apply coupling agent to the ends of the reference bar, and press the transducers firmly against the ends of the bar until a stable transit time is displayed. Adjust the zero reference until the displayed transit time agrees with the value marked on the bar.

7.1.3 Check the zero adjustment on an hourly basis during continuous operation of the instrument, and every time a transducer or connecting cable is changed. If zero-time adjustment cannot be accomplished, do not use the instrument until it has been repaired.

7.2 *Determination of Transit Time:*

7.2.1 For testing existing construction, select test locations in accordance with Practice C823, or follow the requirements of the party requesting the testing, whichever is applicable.

7.2.2 For best results, locate the transducers directly opposite each other. Because the beam width of the vibrational pulses emitted by the transducers is large, it is permissible to measure transit times across corners of a structure but with some loss of sensitivity and accuracy. Measurements along the same surface shall not be used unless only one face of the structure is accessible because such measurements may be indicative only of surface layers, and calculated pulse velocities will not agree with those obtained by through transmission (Note 9).

NOTE 9—One of the sources of uncertainty in surface tests is the lengths of the actual travel paths of the pulses. Hence, individual readings are of little value. Surface tests, however, have been used to estimate the depth of a lower quality surface layer by making multiple measurements of transit time with varying distances between the transducers. From the plot of travel time versus spacing, it may be possible to estimate the depth of the lower quality concrete.[5]

7.2.3 Apply an appropriate coupling agent (such as water, oil, petroleum jelly, grease, moldable rubber, or other viscous materials) to the transducer faces or the test surface, or both. Press the faces of the transducers firmly against the surfaces of the concrete until a stable transit time is displayed, and measure the transit time (Note 10). Determine the straight-line distance between centers of transducer faces.

NOTE 10—The quality of the coupling is critically important to the accuracy and maximum range of the method. Inadequate coupling will result in unstable and inaccurate time measurements, and will significantly shorten the effective range of the instrument. Repeat measurements should be made at the same location to minimize erroneous readings due to poor coupling.

8. Calculation

8.1 Calculate the pulse velocity as follows:

$$V = L/T \tag{2}$$

where:

V = pulse velocity, m/s,
L = distance between centers of transducer faces, m, and
T = transit time, s.

9. Report

9.1 Report at least the following information:

9.1.1 Location of test or identification of specimen.

9.1.2 Location of transducers.

9.1.3 Distance between centers of transducer faces, reported to a precision of at least 0.5 % of the distance.

9.1.4 Transit time, reported to a resolution of at least 0.1 µs.

9.1.5 Pulse velocity reported to the nearest 10 m/s.

10. Precision and Bias

10.1 *Precision:*

[5] Chung, H. W., and Law, K. S., "Assessing Fire Damage of Concrete by the Ultrasonic Pulse Technique," *Cement, Concrete, and Aggregates*, CCAGDP, Vol 7, No. 2, Winter, 1985, pp. 84–88.

10.1.1 Repeatability of results have been investigated using devices with CRT displays. It is expected that the repeatability with digital display devices will be better than stated as follows.

10.1.2 Tests involving three test instruments and five operators have indicated that for path lengths from 0.3 to 6 m through sound concrete, different operators using the same instrument or one operator using different instruments will achieve repeatability of test results within 2 %. For longer path lengths through sound concrete, attenuation of the signal will decrease the absolute repeatability of the transit-time measurement, but the longer transit time involved will result in a calculation of velocity having the same order of accuracy.

10.1.3 In the case of tests through badly cracked or deteriorated concrete, the variation of the results are substantially increased. Attenuation is affected by the nature of the deterioration and the resonant frequency of the transducers. Differences between operators or instruments may result in differences in test results as large as 20 %. In such cases, however, calculated velocities will be sufficiently low as to indicate clearly the presence of distress in the concrete tested.

10.2 *Bias*—Bias of this test method has not been determined.

11. Keywords

11.1 concrete; longitudinal stress wave; nondestructive testing; pulse velocity; ultrasonic testing

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C597 – 09) that may impact the use of this standard. (Approved April 1, 2016.)

(1) Revised 5.2, 5.9, 6.1.7, 7.2.2, and Note 4 for editorial purposes.
(2) Revised 7.1.1 to reflect the current and future equipment requirements.
(3) Added new Subsection 5.6 and renumbered subsequent sections.
(4) Updated reference in Footnote 3 to newer edition.

Standard Test Method for Rebound Number of Hardened Concrete[1]

This standard is issued under the fixed designation C805/C805M; 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 the determination of a rebound number of hardened concrete using a spring-driven steel hammer.

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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

C125 Terminology Relating to Concrete and Concrete Aggregates

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

E18 Test Methods for Rockwell Hardness of Metallic Materials

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology C125.

4. Summary of Test Method

4.1 A steel hammer impacts, with a predetermined amount of energy, a metal plunger in contact with a concrete surface. Either the distance that the hammer rebounds is measured or the hammer speeds before and after impact are measured. The test result is reported as a dimensionless rebound number.

5. Significance and Use

5.1 This test method is applicable to assess the in-place uniformity of concrete, to delineate variations in concrete quality throughout a structure, and to estimate in-place strength if a correlation is developed in accordance with 5.4.

5.2 For a given concrete mixture, the rebound number is affected by factors such as moisture content of the test surface, the type of form material or type of finishing used in construction of the surface to be tested, vertical distance from the bottom of a concrete placement, and the depth of carbonation. These factors need to be considered in interpreting rebound numbers.

5.3 Different instruments of the same nominal design may give rebound numbers differing from 1 to 3 units. Therefore, tests should be made with the same instrument in order to compare results. If more than one instrument is to be used, perform comparative tests on a range of typical concrete surfaces so as to determine the magnitude of the differences to be expected in the readings of different instruments.

5.4 Relationships between rebound number and concrete strength that are provided by instrument manufacturers shall be used only to provide indications of relative concrete strength at different locations in a structure. To use this test method to estimate strength, it is necessary to establish a relationship between strength and rebound number for a given concrete and given apparatus (see Note 1). Establish the relationship by correlating rebound numbers measured on the structure with the measured strengths of cores taken from corresponding locations (see Note 2). At least two replicate cores shall be taken from at least six locations with different rebound numbers. Select test locations so that a wide range of rebound numbers in the structure is obtained. Obtain, prepare, and test cores in accordance with Test Method C42/C42M. If the rebound number if affected by the orientation of the instrument during testing, the strength relationship is applicable for the same orientation as used to obtain the correlation date (see Note 3). Locations where strengths are to be estimated using the developed correlation shall have similar surface texture and shall have been exposed to similar conditions as the locations

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

Current edition approved Dec. 15, 2013. Published January 2014. Originally approved in 1975. Last previous edition approved in 2013 as C805 – 13. DOI: 10.1520/C0805_C0805M-13a.

[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.

*A Summary of Changes section appears at the end of this standard where correlation cores were taken. The functionality of the rebound hammer shall have been verified in accordance with 6.4 before making the correlation measurements.

NOTE 1—See ACI 228.1R[3] for additional information on developing the relationship and on using the relationship to estimate in-place strength.

NOTE 2—The use of molded test specimens to develop a correlation may not provide a reliable relationship because the surface texture and depth of carbonation of molded specimens are not usually representative of the in-place concrete.

NOTE 3—The use of correction factors to account for instrument orientation may reduce the reliability of strength estimates if the correlation is developed for a different orientation than used for testing.

5.5 This test method is not suitable as the basis for acceptance or rejection of concrete.

6. Apparatus

6.1 *Rebound Hammer,* consisting of a spring-loaded steel hammer that, when released, strikes a metal plunger in contact with the concrete surface. The spring-loaded hammer must travel with a consistent and reproducible speed. The rebound number is based on the rebound distance of the hammer after it impacts the plunger, or it is based on the ratio of the hammer speed after impact to the speed before impact. Rebound numbers based on these two measurement principles are not comparable.

NOTE 4—Several types and sizes of rebound hammers are commercially available to accommodate testing of various sizes and types of concrete construction.

6.1.1 A means shall be provided to display the rebound number after each test.

NOTE 5—Methods of displaying rebound number include mechanical sliders and electronic displays. Instruments are available that will store the rebound numbers, which can then be transferred to a computer for analysis.

6.1.2 The manufacturer shall supply rebound number correction factors for instruments that require such a factor to account for the orientation of the instrument during a test. The correction factor is permitted to be applied automatically by the instrument. The manufacturer shall keep a record of test data used as the basis for applicable correction factors.

6.2 *Abrasive Stone,* consisting of medium-grain texture silicon carbide or equivalent material.

6.3 *Verification Anvil,* used to check the operation of the rebound hammer. An instrument guide is provided to center the rebound hammer over the impact area and keep the instrument perpendicular to the anvil surface. The anvil shall be constructed so that it will result in a rebound number of at least 75 for a properly operating instrument (see Note 6). The manufacturer of the rebound hammer shall stipulate the type of verification anvil to be used and shall provide the acceptable range of rebound numbers for a properly operating instrument. The anvil manufacturer shall indicate how the anvil is to be supported for verification tests of the instrument, and shall provide instructions for visual inspection of the anvil surface for surface wear.

NOTE 6—A suitable anvil has included an approximately 150 mm [6 in.] diameter by 150 mm [6 in.] tall steel cylinder with an impact area hardened to an HRC hardness value of 64 to 68 as measured by Test Methods E18.

6.4 *Verification*—Rebound hammers shall be serviced and verified annually and whenever there is reason to question their proper operation. Verify the functional operation of a rebound hammer using the verification anvil described in 6.3. During verification, support the anvil as instructed by the anvil manufacturer.

NOTE 7—Typically, a properly operating rebound hammer and a properly designed anvil should result in a rebound number of about 80. The anvil needs to be supported as stated by the anvil manufacturer to obtain reliable rebound numbers. Verification on the anvil does not guarantee that the hammer will yield repeatable rebound numbers at other points on the scale. At the user's option, the rebound hammer can be verified at lower rebound numbers by using blocks of polished stone having uniform hardness. Some users compare several hammers on concrete or stone surfaces encompassing the usual range of rebound numbers encountered in the field.

7. Test Area and Interferences

7.1 *Selection of Test Surface*—Concrete members to be tested shall be at least 100 mm [4 in.] thick and fixed within a structure. Smaller specimens must be rigidly supported. Avoid areas exhibiting honeycombing, scaling, or high porosity. Do not compare test results if the form material against which the concrete was placed is not similar (see Note 8). Troweled surfaces generally exhibit higher rebound numbers than screeded or formed finishes. If possible, test structural slabs from the underside to avoid finished surfaces.

7.2 *Preparation of Test Surface*—A test area shall be at least 150 mm [6 in.] in diameter. Heavily textured, soft, or surfaces with loose mortar shall be ground flat with the abrasive stone described in 6.2. Smooth-formed or troweled surfaces do not have to be ground prior to testing (see Note 8). Do not compare results from ground and unground surfaces. Remove free surface water, if present, before testing.

NOTE 8—Where formed surfaces were ground, increases in rebound number of 2.1 for plywood formed surfaces and 0.4 for high-density plywood formed surfaces have been noted.[4] Dry concrete surfaces give higher rebound numbers than wet surfaces. The presence of surface carbonation can also result in higher rebound numbers.[5] In cases of a thick layer of carbonated concrete, it may be necessary to remove the carbonated layer in the test area, using a power grinder, to obtain rebound numbers that are representative of the interior concrete. Data are not available on the relationship between rebound number and thickness of carbonated concrete. The user should exercise professional judgment when testing carbonated concrete.

7.3 Do not test frozen concrete.

NOTE 9—Moist concrete at 0 °C [32 °F] or less may exhibit high rebound values. Concrete should be tested only after it has thawed. The temperatures of the rebound hammer itself may affect the rebound number. Rebound hammers at -18 °C [0 °F] may exhibit rebound numbers

[3] ACI 228.1R, "In-Place Methods to Estimate Concrete Strength," American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, http://www.concrete.org.

[4] Gaynor, R. D., "In-Place Strength of Concrete—A Comparison of Two Test Systems," and "Appendix to Series 193," National Ready Mixed Concrete Assn., TIL No. 272, November 1969.

[5] Zoldners, N. G., "Calibration and Use of Impact Test Hammer," *Proceedings* , American Concrete Institute, Vol 54, August 1957, pp. 161–165.

reduced by as much as 2 or 3 units[6].

7.4 For readings to be compared, the direction of impact, horizontal, downward, upward, or at another angle, must be the same or established correction factors shall be applied to the readings.

7.5 Do not conduct tests directly over reinforcing bars with cover less than 20 mm [0.75 in.].

NOTE 10—The location of reinforcement may be established using reinforcement locators or metal detectors. Follow the manufacturer's instructions for proper operation of such devices.

8. Procedure

8.1 Hold the instrument firmly so that the plunger is perpendicular to the test surface. Record the orientation of the instrument with respect to horizontal to the nearest 45 degree increment. Use a positive angle if the instrument points upward and a negative angle if it points downward with respect to horizontal during testing (see Note 11). Gradually push the instrument toward the test surface until the hammer impacts. After impact, maintain pressure on the instrument and, if necessary, depress the button on the side of the instrument to lock the plunger in its retracted position. Read and record the rebound number to the nearest whole number. Take ten readings from each test area. The distances between impact points shall be at least 25 mm [1 in.], and the distance between impact points and edges of the member shall be at least 50 mm [2 in.]. Examine the impression made on the surface after impact, and if the impact crushes or breaks through a near-surface air void disregard the reading and take another reading.

NOTE 11—Digital angle gages are available that can be attached to the body of the instrument to allow quick measurement of the angle with respect to horizontal. The recorded orientation would be 0 degrees (horizontal), ±45 degrees (inclined), or ±90 (vertical). For example, if the instrument points vertically down during a test, the angle would be reported as –90 degrees. If the angle is measured to be 55 degrees upward from horizontal, the recorded angle to the nearest 45 degree increment would be +45 degrees.

9. Calculation

9.1 Discard readings differing from the average of 10 readings by more than 6 units and determine the average of the remaining readings. If more than 2 readings differ from the average by 6 units, discard the entire set of readings and determine rebound numbers at 10 new locations within the test area.

9.2 If necessary, apply the correction factor to the average rebound number so that the rebound number is for a horizontal orientation of the hammer. Interpolation is permitted if corrections factors are not given for ±45 degrees.

[6] National Ready Mixed Concrete Assn., TIL No. 260, April 1968.

10. Report

10.1 Report the following information, if known, for each test area.

10.1.1 General information:

10.1.1.1 Date of testing,

10.1.1.2 Air temperature and time of testing,

10.1.1.3 Age of concrete, and

10.1.1.4 Identification of test location in the concrete construction and the size of member tested.

10.1.2 Information about the concrete:

10.1.2.1 Mixture identification and type of coarse aggregate, and

10.1.2.2 Specified strength of concrete.

10.1.3 Description of test area:

10.1.3.1 Surface characteristics (trowelled, screeded. formed),

10.1.3.2 If applicable, type of form material used for test area,

10.1.3.3 If surface was ground and depth of grinding,

10.1.3.4 If applicable, curing conditions, and

10.1.3.5 Surface moisture condition (wet or dry).

10.1.4 Hammer information:

10.1.4.1 Hammer identification or serial number, and

10.1.4.2 Date of hammer verification.

10.1.5 Rebound number data:

10.1.5.1 Name of operator,

10.1.5.2 Orientation of hammer during test,

10.1.5.3 On vertical surfaces (walls, columns, deep beams), relative elevation of test region,

10.1.5.4 Individual rebound numbers,

10.1.5.5 Remarks regarding discarded readings,

10.1.5.6 Average rebound number,

10.1.5.7 If necessary, corrected rebound number for a horizontal orientation of the instrument, and

10.1.5.8 If applicable, description of unusual conditions that may affect test readings.

11. Precision and Bias

11.1 *Precision*—The single-specimen, single-operator, machine, day standard deviation is 2.5 units (1s) as defined in Practice C670. Therefore, the range of ten readings should not exceed 12.

11.2 *Bias*—The bias of this test method cannot be evaluated since the rebound number can only be determined in terms of this test method.

12. Keywords

12.1 concrete; in-place strength; nondestructive testing; rebound hammer; rebound number

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C805 – 13, that may impact the use of this test method. (Approved December 15, 2013)

(1) Revised 4.1 and 6.1.

(2) Added 6.1.1 and Note 5.

Committee C09 has identified the location of selected changes to this test method since the last issue, C805 – 08, that may impact the use of this test method. (Approved January 1, 2013)

(1) Revised 5.1, 6.3, and 8.1.

(2) Modified sections 5.2 and 5.3; previous section 5.2 moved to 5.4.

(3) New Notes 2, 3, 5, and 10 added.

(4) Added 6.1.1, 9.2, 10.1.5.1, and 10.1.5.7.

(5) Some information from previous 6.4 moved to 6.3.

Design of lightweight aggregate mixes

The influence of the water/cement ratio on strength applies to concrete made with lightweight aggregate in the same way as to normal aggregate concrete, and the same procedure of mix design can, therefore, be used when lightweight aggregate is employed. This is the approach in the UK and also in the US for semi-lightweight aggregate concrete (see page 349). However, it is very difficult to determine the SSD bulk specific gravity of lightweight aggregate because of its high absorption (up to 20 per cent), and also because the *rate* of absorption may vary considerably, in some cases the absorption continuing for several days. In consequence, it is difficult to calculate the free water/cement ratio at the time of mixing.

Lightweight aggregate produced artificially is usually bone-dry. If it is saturated before mixing, the strength of the resulting concrete is about 5 to 10 per cent lower than when dry aggregate is used, for the same cement content and workability, and, of course, with an appropriate allowance for the absorbed water in the calculation of the effective water/cement ratio. The explanation lies in the fact that, in the case of bone-dry aggregate, some of the mixing water is absorbed after mixing, but prior to setting, so that the effective water/cement ratio is further reduced. Furthermore, the density of concrete made with saturated aggregate is higher, and the resistance of such concrete to freezing and thawing is impaired. On the other hand, when aggregate with a high absorption is used without pre-soaking, it is difficult to obtain a sufficiently workable and yet cohesive mix. In general, aggregates with absorption of over 10 per cent should be pre-soaked, and air entrainment is recommended.

For many lightweight aggregates, the apparent specific gravity (see page 49) varies with the particle size, the finer particles being heavier than the large ones. Since proportioning is on a *mass* basis, but it is the *volumetric* proportions that govern the physical distribution of material, the percentage of finer material is greater than appears from calculations. Hence, the final volume of voids, the cement paste content and the workability of the mix are affected. We should bear this in mind. If we achieve a well-graded aggregate with a minimum volume of voids the concrete will require only a moderate amount of cement and will exhibit a comparatively small drying shrinkage and thermal movement. The grading limits of ASTM C 330–05 are given in Table 18.1.

The ACI 211.2–98 method of mix design is applicable to lightweight aggregate concrete with a compressive strength greater than 17 MPa (2500 psi) at 28 days and an air-dry density (unit weight) of not more than 1840 kg/m^3 (115 lb/ft^3). The method also applies to semi-lightweight aggregate concrete, provided the above requirements are met.

Trial mixes form the basis of design by either the cement content–strength method or the mass method. The former constitutes a volumetric approach and is applicable to both lightweight and semi-lightweight aggregate concrete, while the mass method is applicable to semi-lightweight aggregate concrete only. The mass method is similar in approach to the mix design of normal weight aggregate concrete, described earlier. The cement content–strength method will now be presented, and this will be followed by a worked example.

If the slump is not specified, an appropriate value for beams, reinforced concrete walls, building columns and floor slabs can be selected from Table 19.3; for trial mixes, the highest value should be used. The maximum size of aggregate should not exceed $\frac{1}{5}$ of the smallest dimension of the

Table 19.11: **Air content of air-entrained and non-air-entrained concrete as given by ACI 211.2–98 (Reapproved 2004)**

Level of exposure	**Recommended average *total* air content, per cent, for maximum size of aggregate**		
	10 mm ($\frac{3}{8}$ in.)	**12.5 ($\frac{1}{2}$ in.)**	**20 mm ($\frac{3}{4}$ in.)**
	(a) Air-entrained concrete		
Mild	4.5	4.0	4.0
Moderate	6.0	5.5	5.0
Extreme	7.5	7.0	6.0
	(b) Non-air-entrained concrete		
Approximate amount of entrapped air	3	2.5	2.0

Table 19.12: **Approximate relation between cement content and strength of lightweight and semi-lightweight aggregate concrete according to ACI 211.2–98 (Reapproved 2004)**

Compressive strength of standard cylinders		**Cement content, kg/m³ (lb/yd³)**	
MPa	**psi**	**All lightweight aggregate**	**Semi-lightweight aggregate**
17	2500	210–310 (350–520)	150–270 (250–460)
21	3000	240–325 (400–550)	190–310 (320–520)
28	4000	300–385 (500–650)	250–355 (420–600)
34	5000	355–445 (600–750)	300–415 (500–700)
41	6000	415–505 (700–850)	355–475 (600–800)

member, $\frac{1}{3}$ of the depth of the slab, or $\frac{3}{4}$ of the minimum spacing between reinforcing bars or bundles of bars.

Table 19.11 gives the volume of entrapped air to be expected in non-air-entrained concrete, and the recommended contents of entrained air for durability requirements.

The cement content can be roughly estimated from Table 19.12 but the aggregate producer may be able to provide a closer value.

To estimate the content of lightweight aggregate, it can be assumed that the total volume of aggregate will usually be from 1.0 to 1.2 m³ per cubic metre (27 to 32 ft³ per cubic yard) of concrete, as measured on a dry-loose basis. The proportion of fine aggregate is usually between 40 and 50 per cent. For closer estimates, it may again be useful to consult the aggregate supplier.

Knowing the dry-loose densities of fine and coarse aggregate, we calculate their masses on a dry basis, and then a trial mix is made using sufficient water to produce the required slump. This water consists of both added water and that absorbed by the aggregate. After measuring the density (unit weight) of the fresh concrete, the yield can be estimated so that the batch quantities can be calculated.

If the cement content of the trial mix turns out to be different from that specified but the other properties (such as air content, workability and cohesiveness) are satisfactory, the cement content should be adjusted. We assume that the volume of aggregate (dry-loose) should be increased by 0.0006 m^3 (0.01 ft^3) for each 1 kg (1 lb) decrease in cement content, and *vice versa*. This 'rule' applies only to small adjustments to the cement content so that the resulting small changes in the aggregate content will not significantly change the added water requirement.

As a first approximation, it may be assumed that the *total* water also remains unaffected by the adjustments. To allow for the total moisture contents of the aggregate, the dry quantities are simply multiplied by the appropriate total moisture contents, and this increase in the mass of the (wet) aggregates is deducted from the total water requirement to obtain the added water.

A more accurate method of adjusting the mix proportions is to use a so-called pycnometer *specific gravity factor*, *S*, which is defined as the ratio of the mass of the aggregate at mixing to the effective volume displaced by the aggregate (i.e. the volume of aggregate and its moisture). The mass of the aggregate thus includes any moisture, absorbed or free, at the time of placing the aggregate in the mixer. The pycnometer specific gravity factor differs from the bulk specific gravity (SSD) because it includes the free moisture (see page 53).

The value of *S* is given by (see page 50):

$$S = \frac{A'}{C - (B - A')}$$

where A' = mass of the aggregate tested (moist or dry),
B = mass of pycnometer with the aggregate and then filled with water (usually after 10 min of sample immersion), and
C = mass of pycnometer filled with water.

By this means, the specific gravity factors for both fine and coarse aggregate can be obtained for different total moisture contents (for example, see Fig. 19.5).

The above, more accurate, procedure for adjusting the mix proportions of lightweight and semi-lightweight aggregate concretes is based on the effective volume approach. For example, if a trial mix has satisfactory properties of workability and cohesiveness but the strength is too low, an increase in the cement content is necessary. The total water requirement and coarse aggregate content are assumed to remain unchanged but the fine aggregate content will have to be reduced. Knowing the specific gravity of cement and the specific gravity factor of coarse aggregate on a dry basis,

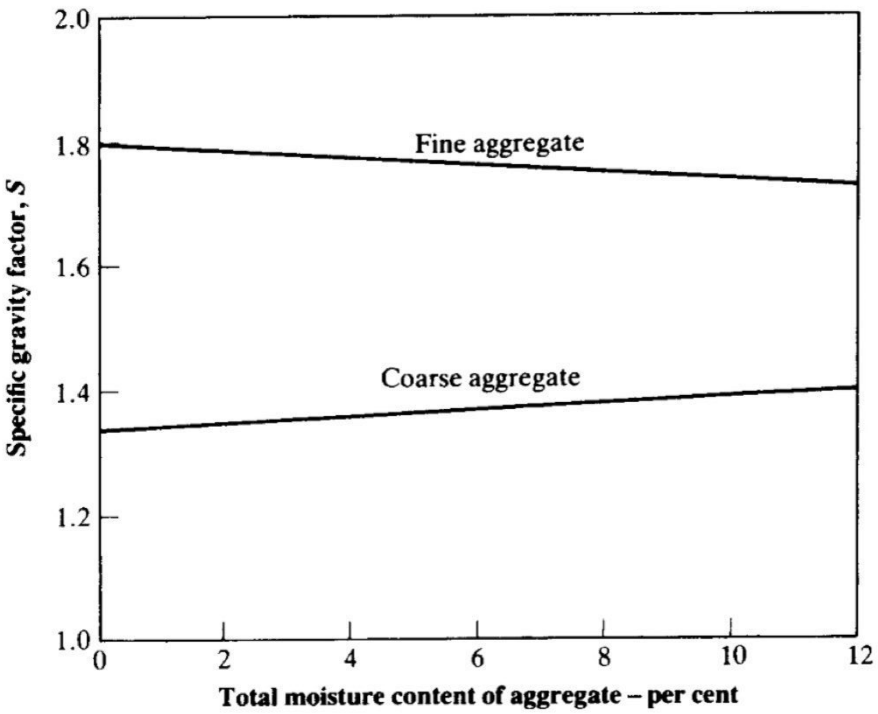


Fig. 19.5: Example of the relation between the pycnometer specific gravity factor S and the total moisture content of lightweight aggregate

the volume of fine aggregate can be estimated by deducting the sum of the volumes of cement, coarse aggregate, water and air from the total volume of concrete. Since we know the specific gravity factor (dry) of fine aggregate, the mass of this ingredient can be calculated. For semi-lightweight concrete, the mass of the normal weight fine aggregate is obtained by using its bulk specific gravity (SSD).

The above are dry quantities. However, for proportioning, we require the quantities on a wet basis, and the increases in the masses of lightweight fine and coarse aggregates are obtained simply by multiplying the dry masses by their respective total moisture contents; in the case of normal weight fine aggregate, the moisture content is used. Subsequently, the volume of added water is obtained by deducting the sum of the volumes of wet aggregates, cement and air from the total volume of concrete; the volume of added water multiplied by its density (in kg/m^3 or lb/ft^3) gives the mass of added water.

A trial mix should now be made. Density (unit weight), air content and slump should be measured. We should also check the finishing properties of the mix and verify that it does not segregate.

Batch quantities can then be calculated from the yield. When adjustments are required to fine aggregate, air content and slump, the following 'rules of thumb' are recommended:

(a) An increase in each percentage point of the fine to total aggregate ratio requires an increase in water content of approximately 2 kg/m^3 (3 lb/yd^3) of concrete. To maintain the strength, the cement content should be increased by approximately 1 per cent for each 2 kg/m^3 (3 lb/yd^3) increase in water content.

(b) An increase of 1 per cent in air content requires a decrease in water content of approximately 3 kg/m^3 (5 lb/yd^3) of concrete to maintain the same slump. This applies to air contents in the range of 4 to 6 per cent and to slumps of less than 150 mm (6 in). For higher air contents, a loss of strength may occur so that it would be necessary to increase the cement content.

(c) For an initial slump of approximately 75 mm (3 in.), an increase in slump of 25 mm (1 in.) requires an increase in the water content of approximately 6 kg/m^3 (10 lb/yd^3) of concrete. To maintain the strength, the cement content should be increased by approximately 3 per cent for each 6 kg/m^3 (10 lb/yd^3) increase in water.

With any of the above changes, adjustments to the mass of fine aggregate (and coarse aggregate in case (a)) are necessary to maintain the same total volume of concrete; these adjustments are carried out by the method described on page 373.

Example V

It is required to produce lightweight aggregate concrete with an average strength of 20 MPa (2900 psi) at 28 days, an air content of 5.5 per cent, a minimum cement content of 350 kg/m^3 (590 lb/yd^3) of concrete, and a slump of 75 mm (3 in.). The coarse aggregate has a dry-loose density of 720 kg/m^3 (44 lb/ft^3) and a total moisture content of 3 per cent. The fine aggregate has a dry-loose density of 900 kg/m^3 (56 lb/ft^3) and a total moisture content of 7 per cent.

The procedure for choosing the mix proportions is as follows.

Assuming that the total volume of the two aggregates, measured on a dry-loose basis, is 1.2 m^3 per cubic metre (32 ft^3 per cubic yard) of concrete, and that the coarse and fine aggregate volumes are equal, the trial mix quantities on a dry basis for 0.02 m^3 (0.026 yd^3) of concrete are as follows:

cement:	$350 \times 0.02 =$	7.00 kg	(15.40 lb)
fine aggregate:	$0.60 \times 900 \times 0.02 =$	10.80 kg	(23.76 lb)
coarse aggregate:	$0.60 \times 720 \times 0.02 =$	8.64 kg	(19.01 lb)
water:		5.00 kg	(11.00 lb)
Total:		31.44 kg	(69.17 lb).

The mass of water is that found to produce a slump of 75 mm (3 in.) for the air-entrained trial mix, and consists of the added water and the water absorbed by the aggregates.

The measured density of fresh concrete is found to be 1510 kg/m^3 (92.5 lb/ft^3). Hence, the yield is $\frac{31.44}{1510} = 0.0208$ m^3 (0.736 ft^3). The quantities on a dry basis in kg per cubic metre (lb per cubic yard) of concrete are as follows:

$$\text{cement:} \quad 7.00 \times \frac{1}{0.0208} = 336 \quad (567)$$

$$\text{fine aggregate:} \quad 10.80 \times \frac{1}{0.0208} = 519 \quad (874)$$

$$\text{coarse aggregate:} \quad 8.64 \times \frac{1}{0.0208} = 415 \quad (700)$$

$$\text{water:} \quad 5.00 \times \frac{1}{0.0208} = 240 \quad (405)$$

$$\text{Total:} \quad 1510 \quad (2546).$$

Now, the cement content in the trial mix is 14 kg/m^3 (24 lb/yd^3) less than that specified. Since the other properties of the mix, including strength, are satisfactory and only a small change in the cement content is required, we can decrease the volume of aggregate on a dry-loose basis by 0.0006 m^3 for each 1 kg increase in the cement content. Allocating the reduction equally to fine and coarse aggregates, the quantities of these become:

fine aggregate: $519 - \frac{1}{2}(14 \times 0.0006 \times 900) = 515$ kg/m^3 (868 lb/yd^3) of concrete.

coarse aggregate: $415 - \frac{1}{2}(14 \times 0.0006 \times 720) = 412$ kg/m^3 (694 lb/yd^3) of concrete.

For these small adjustments, the required amount of added water will not be changed appreciably.

To allow for the total moisture content of the aggregate, the quantities of fine and coarse aggregate have to be increased and the water content decreased by the same amount. Hence, the final adjusted quantities on a damp basis in kg per cubic metre (lb per cubic yard) of concrete are as follows:

cement:	$336 + 14 =$	350	(590)
fine aggregate:	$515 \times 1.07 =$	551	(928)
coarse aggregate:	$412 \times 1.03 =$	424	(715)
added water:	$240 - [(551 - 515) + (424 - 412)] =$	192	(323)
Total:		1517	(2556)

Example VI

The same example will be used but let us suppose that the average strength of 20 MPa (2900 psi) at 28 days was not reached using the required minimum cement content of 350 kg/m^3 (590 lb/yd^3) of concrete.

To achieve the required strength, we assume that an increase in cement content of 50 kg/m^3 (84 lb/yd^3) of concrete is necessary. To adjust the above mix so as to have a cement content of 400 kg/m^3 (674 lb/yd^3) of concrete, a more accurate method is necessary. Now, we assume that the total water requirement and the coarse aggregate content are unchanged. Since the increased amount of cement provides a fine material, the quantity of fine aggregate should be decreased. To estimate this quantity, we use the pycnometer specific gravity factors, defined on page 388. We need to determine these factors, both on a dry basis and at the total moisture content as shown, for example, in Fig. 19.5.

Let us assume that the specific gravity factors have been found to be 1.78 and 1.35 on a dry basis, and 1.75 and 1.36 on the wet basis, for the fine and coarse aggregate, respectively.

On a dry basis, the volume of concrete with a cement content of 350 kg/m³ (590 lb/yd³) of concrete is

$$\underset{\text{(cement)}}{\frac{350}{3.15 \times 1000}} + \underset{\text{(fine aggregate)}}{\frac{515}{1.78 \times 1000}} + \underset{\text{(coarse aggregate)}}{\frac{412}{1.35 \times 1000}} + \underset{\text{(water)}}{\frac{240}{1000}} + \underset{\text{(air)}}{0.055} = 1.000 \text{ m}^3 \ (1.308 \text{ yd}^3).$$

For a mix with a cement content of 400 kg/m³ (674 lb/yd³) of concrete, the sum of the volumes of cement, coarse aggregate, water and air on a dry basis is

$$\frac{400}{1000 \times 3.15} + \frac{412}{1000 \times 1.35} + \frac{240}{1000} + 0.055 = 0.727 \text{ m}^3 \ (0.951 \text{ yd}^3).$$

Hence, the volume of fine aggregate is 1.00 − 0.727 = 0.273 m³ (0.357 yd³). The mass of fine aggregate on a dry basis is now

$$0.273 \times 1000 \times 1.78 = 486 \text{ kg/m}^3 \ (819 \text{ lb/yd}^3) \text{ of concrete.}$$

To estimate the quantities on a wet basis, we allow for the total moisture contents of the aggregates as before so that, in kg per cubic metre (lb per cubic yard) of concrete, they become:

fine aggregate: $486 \times 1.07 = 520$ (876)
coarse aggregate: $412 \times 1.03 = 424$ (715).

Now, instead of simply deducting from the total water, the sum of the increase in the mass of the aggregates (from the dry to the wet basis), the added water is obtained more accurately deducting the sum of the volumes of cement, wet aggregate and air from the total volume of concrete, viz.:

$$\underset{\text{(concrete)}}{1.000} - \underset{\text{(cement)}}{\frac{400}{1000 \times 3.15}} - \underset{\text{(fine aggregate)}}{\frac{520}{1000 \times 1.75}} - \underset{\text{(coarse aggregate)}}{\frac{424}{1000 \times 1.36}} - \underset{\text{(air)}}{0.055} = 0.209 \text{ m}^3 \ (0.273 \text{ yd}^3).$$

(Note the use of wet specific gravity factors for the aggregates.) Therefore, the mass of added water is

$$1000 \times 0.209 = 209 \text{ kg/m}^3 \ (352 \text{ lb/yd}^3) \text{ of concrete.}$$

Summarizing, the quantities on a wet basis in kg per cubic metre (lb per cubic yard) of concrete are as follows:

cement:	400	(674)
fine aggregate:	520	(876)
coarse aggregate:	424	(715)
added water:	209	(352)
Total:	1553	(2617).

RESEARCH ARTICLE OPEN ACCESS

Design and Analysis of Foam Concrete

D.Kavitha [1], K.V.N Mallikarjunrao [2]
M.Tech student [1], Assistant Professor [2]
Department of Civil Engineering
Rise Krishna Sai Gandhi Group of Institutions, Ongole
India

ABSTRACT
The foam concrete name itself define the character of the concrete that being light weight concrete made out of a foaming agent which doesn't have coarse aggregate in it as a mixture, and could also termed as aerated mortar since it having air voids in it. The foaming agent is added separately to the cement paste which dilutes with water in forming foam when it is sprayed out of pump.

The mixture is having more water content in order to produce more bubbles with the foaming agent while the concrete mixture have enough strength to be in certain shape around the air voids to get stiff. The mixture should have enough water content added to it because of if the water content if excess, then the mixture couldn't hold the bubbles by separates bubbles form mixture and if it is lower then it gets stiffens. The water-cement (w/c) ratio of foam concrete used will be in 0.4 – 1.25 where as it varies according to the purpose of usage.

It is designed to have any density within the dry density range of 300-1850kg/m3. In this project foam concrete blocks are prepared according to the designed proportions to attain the maximum strength of 1900kg/m3.cubes are prepared by a designed mix and there by tested for their density and also compressive strength the results are reported

Keywords: Foam concrete, Light weight, Density and strength

I. INTRODUCTION

1.1 BACKGROUND:

Foam concrete is a type of porous concrete. According to its features and uses it is similar to aerated concrete. The synonyms are aerated concrete, lightweight concrete or porous concrete. The term foam concrete is containing no aggregates only sand, cement, water and stable foam to perform the concrete. This action incorporates small enclosed air bubbles within the mortar there by making the concrete lighter.

Basically, there are two method of producing foamed concrete such as prefoam method and inline method. The inline method can divided into wet method and dry method. To produces foamed concrete, aerated concrete(flow chart:1.1 aerated concrete) there are two type of foam will be used by wet foam and dry foam. A foamed concrete is described as having an air content of more than 25% which distinguishes it from highly air entrained materials. Foamed concrete may have density from as low 500kg/m^3 to 1600kg/m^3 and strength from less than 1N/mm^2 to 25N/mm^2.

1.2 CONSTITUENTS OF FOAM CONCRETE :

[Deijk, 1991]The essential components in foam concrete are binder, water and foam. Optionally, sand, fiber, filler and additives such as water-reducing agent, setting-controlling agent, etc. can be added according to the practical requirement.

1.1.1 BINDER

The most commonly used binder is cement, but other supplementary materials such as silica fume, fly ash, slag or waste, can also be included in as long as their acceptability has been demonstrated. The addition of supplementary materials as partial replacement to the binder can enrich the concrete with various desirable properties in its fresh and hardened states [Narayanan and Ramamurthy, 2000]. Binder can be even materials without cement. For example, the successful use of binder made of ground granulated blast furnace slag plus low value liquid glass **[Beljakova et al., 1998]**, and magnesite powder **[Vinogradov et al., 1998]** in foam concrete were reported.

1.1.1.1 Cement

ACI 523.1R-92 [American Concrete Institute, 1992] recommends the use of Portland cement or Portland blast furnace slag cement which conforms to the respective ASTM

Specifications:

C 150 [American Society for Testing and Materials, 1994], Type I or Type III;

Type IA or Type IIIA; C 595 [American Society for Testing and Materials, 1994] , Type IS or Type IS-A. It also points out that High-early-strength cements (Type III or IIIA) are often used to advantage the production of low density concrete. The practical use of finely-ground cement, high-early-strength Portland cement and rapid setting hydraulic cement were reported by **Fujiwara et al [1995], Johansson et al.[1999] and Hashimoto et al.[1976]**, respectively.

1.1.1.2 Supplementary material

Spinnery [1993], in his patent of producing non-shrinking foam concrete, has reported replacing cement with an equal amount of cementitious fines which can be fly ash (Type F and C), slag cement and kiln dust or non-cementitious fines which can be limestone, silica and granitic fines. **Fujiwara et al. [1995]** reported the use of binder comprising high-early-strength Portland cement, silica fume and ultra-fine silica stone powder to produce high-strength foam concrete. The mean particle size of ultra-fine silica stone powder of 2.4µm, is approximately the square root of the product of the mean particle size of the silica fume, 0.1µm, and that of cement, 20µm, which is expected to have densification effect and increase the strength of the resulting paste. His study also showed that the combination of 10% silica fume, 30% ultrafine silica stone powder and 60% cement resulted in the most satisfactory workability and compressive strength among all the trial mixes. The 28-day compressive strength of the foam concrete with wet density of 1500 kg/m^3 was around 50 MPa. **Kamaya et al. [1996]** pointed out that it is preferable to use non-organic materials, which have specific surface area higher than 7500 g/cm^2 as supplementary material, for the production of high-strength foam concrete, otherwise the strength of the resultant foam concrete will be drastically reduced.

Kearsley and Visagie [1999] reported that, using unclassified fly ash, of which around 40% of the particles have diameters exceeding 45 µm, the 56 day compressive strength of foam concrete with wet density of 1500 kg/m^3 could achieve around 45 MPa,. Although the compressive strength of foam concrete produced by Kearsley and Visagie is lower than what Fujiwara et al. have produced at the same density, the former is still significantly higher than the conventional foam concrete. Therefore, it seems that, without using ultra fine material such as silica fume or materials with fineness higher than 7500 g/cm^2, the production of high strength foam concrete is still possible.

II. MIXING WATER

According to ACI 523.3R-93 [American Concrete Institute, 1993], mixing water for foam concrete should be fresh, clean and drinkable. This is particularly important when using protein-based foaming agents as any organic contamination could have an adverse effect on the quality of the foam produced [British Cement Association, 1991]. Undrinkable water could also be used only if the resulting foam concrete has 7- and 28-day strengths equal to at least 90% of the strength of similar specimens made with water from a municipal supply. The strength comparison should be made on mortars, identical except for the mixing water, prepared and tested in accordance with ASTM C109 [American Society for Testing and Materials, 1993].

2.1.3 FOAM

The low specific gravity of foam concrete is achieved by introducing foam bubbles in the cement paste and the concrete produced. Foam bubbles are air voids enclosed by the wall of a solution of foaming agent. Common foaming agents are synthetic agents such as resin soap, and protein-based foaming agents such as hydrolyzed protein **[India Concrete Journal, 1989; Deijk, 1991]**. Preformed foam, as described by ACI 523.3R-93 [American Concrete Institute, 1993] is produced by blending the foaming agent, water and compressed air (generated by an air-compressor) in predetermined proportions in a foam generator calibrated for a discharge rate.

The quality of foam is affected by its density, the dilution ratio of the agent, the foaming process, the pressure of the compressed air, and the adding and blending process with the mortar. In addition, a suitable workability of the mortar is vital for the uniform introduction of foam **[Kamaya et al, 1996]**. This quality of foam is evident from the stability of the foam concrete and will consequently affect the strength and stiffness of the resultant foam concrete **[Beljakova et al., 1998]**. To ensure the quality of the foam, a minimum dilution ratio of foaming agent and a minimum air pressure must be achieved. Furthermore, the foam must be added immediately after it is produced, whilst it is still stiff. Method of improving the stability of foam by adding a foam stabilizing fluorinated surfactant into the foam concrete has been described in US patent no. 6153005 **[Welker et al., 2000]**.

2.1.4 FINE AGGREGATE

The most commonly used inorganic fine aggregate is sand. According to ACI 523.1R-92 [American Concrete Institute, 1992], sands conforming to ASTM C33 [American Society for Testing and Materials, 1993], Concrete Aggregates, and C 144 [American Society for Testing and Materials, 2002], Aggregate for Masonry Mortar, are acceptable for production of foam concrete. Sands of other gradations may be used where their acceptability has been demonstrated.

The British Cement Association [1991] recommends that building sand or concreting sand of 5mm maximum size may be used, and it is reported that, based on the research findings, for a given cement content, a higher strength was obtained using sand with maximum size of 2 mm and with 60 to 95% passing the 600 micron sieve. Waste sands, such as single-sized tailings and granite dust, have been used successfully, but the same restrictions on grading and maximum size still apply [British Cement Association, 1991]. Foam concrete with improved strength using ground quartz sand with specific surface at least 2900 g/cm^2 was reported by Votintsev and Mironova [1999]. Conclusively, the fineness of sand is important for the strength of foam concrete. The use of finer sand can improve the strength of resultant foam concrete. Fine aggregate can be not only natural or crushed sand, but also artificial fine particles as long as their usability can be proved.

Organic fine particles such as polystyrene pellet [**Rodgers, 1996**] and polymer micro-particles **[Hedberg and Berntsson, 1990]** can also be used to partially or totally replace the sand as fine aggregate in foam concrete. They normally have a lower specific gravity than that of sand and therefore help to further reduce the weight of foam concrete or improve the strength of foam concrete when its density is maintained. Some materials have not been reportedly used to produce foam concrete but the use of them may bring significant economical effect. One example is middle-east sand, which is generally considered not suitable to be used as concrete making material **[Kay et al., 1994, Fookes and Collis, 1975]**. Compared to normal sand, middle-east costal sand has poor grading and high content of chloride and sulphate salts. Bleeding, segregation, lower strength and poor durability of concrete have reportedly been encountered when it is used for producing normal mortar. However, inland dune sand which is a type of middle-east sand has low content of chloride and sulphate salts. Compared with commonly used sand, inland dune sand has smaller particle size, smoother surface texture and particle shape which is closer to spherical. These features make the use of inland dune sand in foam concrete possible.

2.1.5 FIBER

The use of fibers helps to reduce the non-load cracking of foam concrete at early ages [American Concrete Institute, 1993]. Fibers for this purpose must have a high modulus of elasticity and be of sufficient length, size and number to develop the required tensile resistance at any section. The introduction of fiber reinforcement can transform the basic material character of cellular concrete from brittle to ductile elasto-plastic behaviour. Fiber reinforcement contributes to the improved flexural strength, energy absorbing (toughness) capabilities and post cracking behavior **[Zollo and Hays, 1989]**. Fibers that can be used in foam concrete are: Glass fiber, synthetic fiber and carbon fiber. ACI committee 544 [American Concrete Institute, 2002] has reported the information on fiber types and sizes, and methods of handling, mixing, and placing concrete containing fibers. Glass fibers are often used in cellular concrete. Synthetic fibers such as polyamide fiber**[Morgun et al., 1999]**, polyvinyl alcohol fiber**[Kenji &Mitsuo, 1989]**, polypropylene fiber**[Castro and Moran, 2001]** have been successfully used to produce foam concrete. Carbon fiber can also be used but its cost could be too high. Steel fibers are not suitable to be used in foam concrete as they may settle to the bottom of the concrete mixture. The suitable fiber volume fraction is from 0 to about 3%. When fiber volume fraction ranged from 0.1 to 1%, the effect of restrain in shrinkage cracking became more significant **[Grzybowski and Shah, 1990].**

The size of fiber is generally expressed in the unit of denier, which is a weight-perunit-length measure of any linear material. Officially, it is the number of unit weights of 0.05 grams per 450-meter length. This is numerically equal to weight in gramsof 9,000 meters of the material. Denier is a direct numbering system in which the lower numbers represent the finer sizes and the higher numbers the coarser sizes.

2.1.6 WASTE OR RECYCLED MATERIAL

Many people have reported the successful use of waste or recycled materials, such as sewage sludge ash [cook and walker, 1999], crushed excavated material **[etherton, 2001]**, slaked lime **[masao et al., 1991]**, crushed broken ceramic bricks **[vinogradov et al., 1998]**, and the waste from the combustion of brown coal **[siejko and jatymowicz, 1978]**, as the constituent material of foam concrete.

2.1.7 ADMIXTURES OR ADDITIVES

Admixtures or additives may be used when a specific change in the properties of the freshly mixed or hardened concrete is desired. ACI 523.3R-93 [American Concrete Institute, 1993] specifies that admixtures should conform to ASTM C260 [American Society for Testing and Materials, 1994] and C494 [American Society for Testing and Materials, 1992]. Commonly used admixtures are: water-reducing agent, water repellents, retarders and accelerators. For foam concrete made by pre-foaming method, it is imperative to maintain a sufficient workability of the premixed mortar (or paste) without foam to ensure the successful introduction of foam.

Therefore, the addition of water-reducing agent would be necessary for the production of high-strength foam concrete which generally has low water/binder ratio. **Fujiwara et al. [1995]** described production of a high-strength foam concrete, of which the amount of water was only 0.19 that of the total mass of cement, silica fume and ultra-fine silica stone powder. To obtain a flow value of around 180mm, measured in accordance with JISR5201[Japanese Architectural Association, 1998], the dosage of super plasticizer was 3% by weight of the blended powder. Admixtures may react adversely with the foaming agent **[Deijk, 1991],** thus when any admixture is used in foam concrete, the compatibility of the admixture with the other constituents in the mix should be determined by tests [American Concrete Institute, 1993].

2.1.8 OTHERS

Foam concrete can be coated or impregnated **[Terajima and Harada, 1998, Jun et al., 1992]** with resin or polymer to acquire high strength and water resistance.

Coarse natural aggregates cannot be used because they will segregate in the lightweight foam concrete, but it is possible to use lightweight aggregate with a similar density to the foam concrete. This will avoid segregation, improve the strength for a given density and reduce the higher drying shrinkage associated with the lower density mixes [British Cement Association, 1991].

2.2 MIX PROPORTION OF FOAM CONCRETE

The variation in mix proportion has a strong effect on the material properties of foam concrete. Altering the cement content and/or the water/cement ratio with a constant density has an impact on the strength and stiffness. Increasing the aggregate and/or filler content with a constant density decreases the shrinkage and crack sensitivity and can improve the toughness.

The change in density has an enormous impact on the thermal insulation capacity, the strength, the stiffness and the water absorption of the material **[Deijk, 1991].** Therefore, mix proportion must be chosen according to the practical requirements such as strength, shrinkage, thermal conductivity, etc.

The early work reviewed by **Valore [1954]** and **Taylor et al. [1969]** indicated thatproportions were selected through trial mixes using three parameters: sand/cement ratio,water/cement ratio and density of the mix.

ACI 523.3R-93 [American Concrete Institute, 1993] reports that the mix proportioning begins with the selection of the unit weight of the plastic concrete (wet density), the cement content, and the water-cement ratio. The mix can then be proportioned by the method of absolute volumes. The sum of the absolute volumes of cement, water, and aggregate for one cubic meter of concrete determines the volume of air required per cubic meter of concrete. The relation between air volume and foam volume can be calculated according to the density of the foam measured, which has been explained in ASTM C-769 [American Society for Testing and Materials, 1993]. Lim [1984] obtained various mix proportions by fixing the cement content and altering the density and water to cement ratio. **Fujiwara et al. [1995]** first chose an optimal binder composition by studying the strength and workability of the resulting paste. A low water/binder ratio equal to 0.19 was adopted in the mixture. Thereafter the exact binder and water content were calculated based on the density of the foamed paste.

2.2.1 CEMENT OR BINDER CONTENT

The average cement content in conventional foam concrete with or without sand ranges from 250 to 500 kg per cubic meter of concrete [Indian Concrete Journal, 1989; American Concrete Institute, 1993; Valore, 1954; E-A-B Associates Bayley-Edge Limited; American Society for Testing and Materials, ASTM C796, 1993; Lim, 1984]. Cement contents for the most commonly used mixes are between 300 and 375 kg/m^3 [British Cement Association, 1991]. Binder content of 924.4 kg/m^3 and 1260.5 kg/m^3 were adopted for high strength foam concrete with density around 1100 kg/m^3 and 1500 kg/m^3 [Fujiwara, 1995].

2.2.2 WATER/BINDER RATIO

In Valore's [1954] work, for mixes with lower densities, higher water/cement ratios were used for each sand/cement ratio; but for mixes at the same density, the water/cement ratios were increased with the increased proportion of sand. He further noted that for cellular concretes in general, it is customary to gauge the proper amount of water in a mix by consistency rather than by a predetermined water/cement ratio.

For foam concrete without water reducing agent, the amount of water must be sufficient to ensure that the workability of the premixed paste or mortar is satisfactory for foam introduction [British Cement Association, 1991]. Otherwise the cement absorbs water from the foam, causing rapid degeneration of the foam [Kearsley, 1999]. Therefore for foam concrete with certain binder content and with certain type and gradation of sand, there is a minimum water/binder ratio for each density range [Lim, 1984]. On the other hand, the workability of the mortar should not be too high; otherwise the foam bubbles tend to separate, which brings about unfavourable bulk density difference between the upper part and the lower part of the shaped body [Narayanan, 1999, Masao et al., 1991]. In general, the optimum water/cement ratio for the premixed paste/mortar lies between 0.5 and 0.6 [British Cement Association, 1991].

The advent of superplasticizer makes it possible to produce foam concrete with not only very low water/binder ratio but satisfactory workability as well. Mortar or paste withwater/binder ratio of only 0.19 and 0.17 have been reported [Fujiwara et al., 1995, Kamaya et al., 1996] for the production of high-strength foam concrete. Instead of using the water/binder ratio of the foam concrete as one of the parameters, some researchers use the water/binder ratio of the paste before the introduction of the foam as one of the parameters [Fujiwara et al, 1995].

2.2.3 SAND/BINDER RATIO

Conventional foam concretes made in Europe generally have sand/binder proportions of 1:1 to 4:1. McCormick [1967] observed that the effect of varying the sand content appeared inconsequential with respect to compressive strength when the sand/cement ratio was ranged from 1.0 to 2.0.

In the mix design recommended by ACI committee 523 [American Concrete Institute, 1993], sand/cement ratio was obtained as a dependent variable after the mix density, the cement content and the water/cement ratio have been decided. The sand/cement ratio thus obtained ranged from 0.29 to 3.66 for mixes of densities ranging from 800 to 1920 kg/m^3 at various cement contents and water/cement ratios.

2.3 PROCESS OF PRODUCTION

2.3.1 MIXING

Component materials can be added into mixer by three different sequences:

i) dry material water with admixtures dissolved in foam [Valore, 1954]

ii) water with admixtures dissolved in dry material foam [American Concrete Institute, 1993]

iii) partial water partial dry materials partial water partial dry materials foam [E-A-B Associates Bayley-Edge Limited]

The density of the mortar before and after the introduction of foam shall be checked for the control of density of foam concrete [E-A-B Associates Bayley-Edge Limited]. Avariation from above mentioned sequences is also allowed if it can be shown to be advantageous.

Omni mixer [Fujiwara et al., 1995] and gravity type mixer [E-A-B Associates Bayley-Edge Limited] have been reportedly used for the production of foam concrete. ASTM C 796 [American Society for Testing and Materials, 1993] recommended that the mixer for mixing foam concrete in laboratory shall be a powder-driven paddle type mixer with a capacity of 0.12m^3, an operating speed of 40 to 45 rpm, and equipped with rubber wiper blades.

III. METHODOLOGY

Foresight groups around the world, future need for construction materials that are light, durable, and simple to use. The alternative material that has the potential to fulfill all these requirements is foamed concrete.

- Mix Design of Foam concrete
- Preparation and casting of Foam Concrete Cubes & Cylinders
- Comparison of compressive strength of foam concrete
- Comparison of Foam concrete with other factors like Cost effectiveness, suitability, etc…

Foam concrete mixture with different ingredients of the materials is used in this investigation. The physical properties (Density) as well as a specific structural property (compressive strength) of foam concrete mixtures were obtained first, before the relationship between these properties were determined. Foam Concrete cubes are prepared and the tests are performed in college laboratory.

3.1 MIX CONSTITUENT PROPORTIONS AND FOAM CONCRETE PRODUCTION

Although there are no standard methods for proportioning foamed concrete, the general rules regarding w/c ratio, free water content and maintaining a unit volume apply, but it is a specified target plastic density that becomes a prime design criterion. It should be noted that it is difficult to design for a specific dry density, as foamed concrete will desorb between 50 and 200 kg/m^3 of the total mix water, depending on the concrete plastic density, early curing regime and subsequent exposure conditions. The trial and error process is often adopted to achieve foam concrete with desired properties (Nehdi2001). (flow chart:3.1 classification of production method for foam concrete)For a given mixture proportion and density, a rational proportion method based on solid volume calculation was proposed by McCormick (1967). ASTM C 796-97 provides a method of calculation of foam volume required to make cement slurry of known w/c ratio and target density. For a given 28 days compressive strength, filler-cement ratio, and fresh density, typical mixture design equations of Nambiar and Ramamurthy (2006b) determine mixture constituents (i.e., percentage foam volume, net water content, cement content, and percentage fly ash replacement). Most of the methods help in calculation of batch quantities if the mixture proportions are known. Even though the strength of foam concrete depends on its density, the strength can be increased by changing the constituent materials for a given density. In addition, for a given density, the foam volume requirement depends on the constituent material (Nambiar and Ramamurthy, 2006b). Hence, for a given strength and density requirement, the mixture design strategy should be able to determine the batch quantities. Assuming a given target plastic density (D, kg/m^3), water/cement ratio (w/c) and cement content (c, kg/m^3), the total mix water (W, kg/m^3) and fine aggregate content (f, kg/m^3) are calculated from equations (1) and (2) as follows.

Target plastic density, D = c + W + f

Where c = PC +FA fine,

f = FA coarse + sand

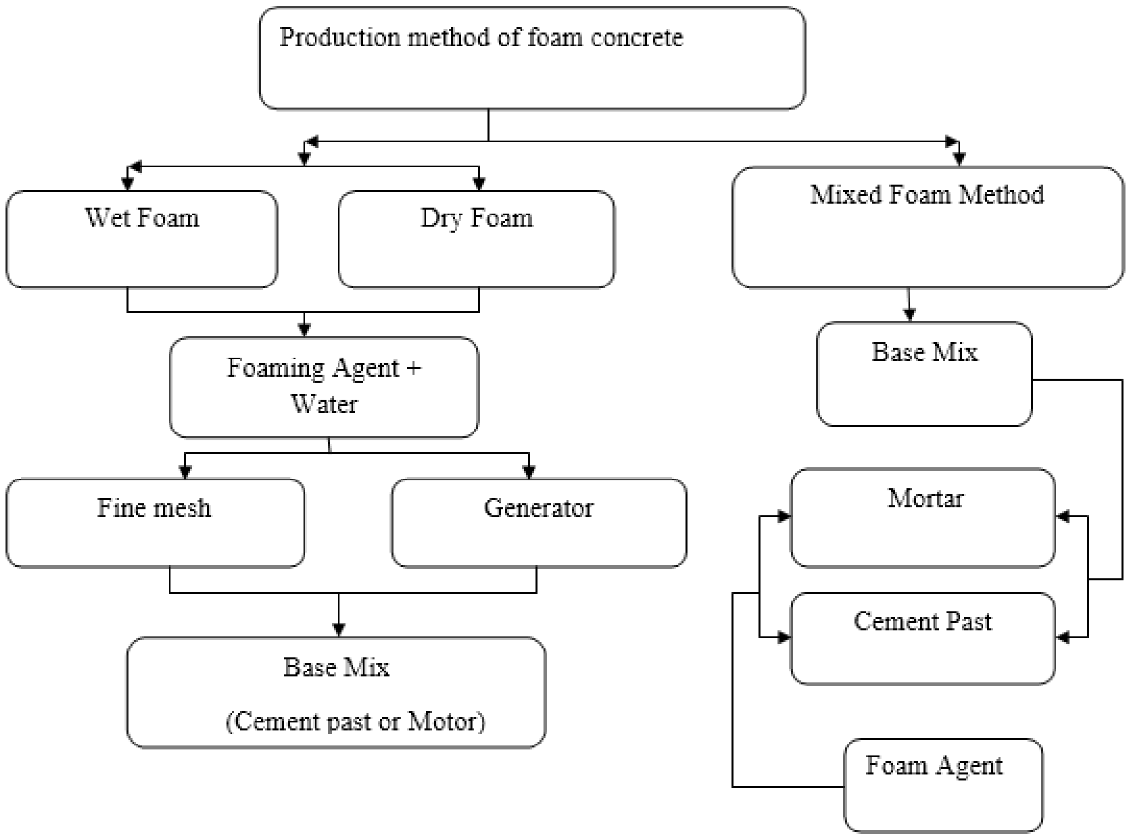
Free water content,

W = (w/c) X (PC + FA fine +FA coarse)

Foamed concrete was produced in the laboratory using a standard inclined rotating drum mixer by the addition of pre-formed foam to a mortar (i.e. mix with sand fine aggregate) or paste (i.e. mix with no sand, just FA coarse fine aggregate) 'base' mix and mixing until uniform consistency was achieved. The plastic density was measured in accordance with BS EN 12350-611 by weighing a foamed concrete sample in a pre-weighed container of a known volume. A tolerance on plastic density was set at ± 50 kg/m^3 of the target value, which is typical of industry practice for foamed concrete production. The specimens were then cast in steel moulds lined with domestic plastic 'cling' film, as foamed concrete was found to adhere strongly to the mould surface, irrespective of the type and quantity of release agent used.

After de-moulding at 24 hrs, the specimens were sealed-cured (i.e. wrapped in 'cling' film) and stored at 20ºC until testing. It is recognized that sealed-curing may result in specimens having different degrees of pore saturation. This effect was considered to be minor for the range of constituent materials studied and certainly more representative of the actual properties of the material than would be the case if standard curing was applied. Again, sealed-curing reflects typical industry practice for foamed concrete.

Flow chart:3.1 Classification process of production method for foamed concrete



3.2 EXPERIMENTAL PROCEDURE

Foamed concrete mixtures with and without sand for same target plastic density are therefore used in this investigation and the method used to determine the physical (Density) as well as a specific structural property (compressive strength) of the foamed concrete mixtures.

3.2.1COMPOSITION OF FOAM CONCRETE MIXTURE

The foamed concrete used in this research is produced under controlled conditions from cement, fly ash, sand, water and pre-formed foam. The cement used is 53 grade Ordinary Portland cement, locally available sand, fine fly ash (P60) IS certified having density 960 kg/m^3, foaming agent for produce the foam and water has been used for producing foam concrete.

Foam is a very important factor for the foam concrete. Foam was generated by using man power. for producing the foam foaming agent has been used, foaming agent is diluted with water in a ratio of 1:10 and then aerated to a density of 74 kg/m^3.

3.2.2 CURING

Lightweight Construction Methods (LCM) requires a curing means and period identical to that of conventional concrete. It is essential, as in conventional concrete, that cement-based elements have moisture for hydration at an early age. This is particularly true in the presence of direct sunlight that is known to cause rapid dehydration of concrete surfaces; curing compound can be applied as an alternative barrier. Full time continuous curing has been done in the laboratory.

3.2.3 COMPRESSIVE STRENGTH

The 150 mm test cubes were cast in steel mould and de-moulded after ± 24 hours. Then it was kept for curing in a constant temperature room up to the day of testing. The cubes were crushed on a more sensitive press (on compression testing machine) the usually used for normal concrete. Three cubes from the same mixture of foamed concrete were crushed and the average of the three results is used to define the strength of the mixture (According to IS: 516-

1959). The compressive strength was recorded to the nearest 0.1 MPa. Compressive strength of foamed concrete was recorded for 7, 14 and 28 days.

3.2.4 DENSITY

The test specimens (cubes) cast for this study have a dimension of 150mm X 150mm X 150mm. The initial density of the specimens as measured during manufacturing is casting density and it can be compared with designed density or in other words the target density. Test specimens are de-moulded within 24 hours of casting and after de-moulding, each specimen is cured in constant temperature room for 7, 14 and 28 days. The density was again measured at the time of determination of compressive strength this density is known as test density.

3.3 MATERIAL USE IN EXPERIMENT :

Assuming a target plastic density of 1900 kg/m^3

Water-cement ratio W/C is 0.35 (assuming)

Proportion =1:2.5 (Cement: FA)

Foaming agent =0.14% (cement weight)

D = c + w + f

1900= 500+170+1250

1900=1920kg/m^3

TABLE3.1:Mix design of foam concrete become

WATER	CEMENT	FA
170	500	1250
0.35	1	2.25

Table : 3.2

Trials:For Foam Concrete Mix – 1 (Containing Cement&Fine Aggregates)

Considering cement: fine aggregates in 1:2.5 proportion

Materials	Values
Cement	500kgs
Fine aggregates	1250kgs
Foam	0.90liters
w/c	0.35%

Table :3.3

Trials: For Foam Concrete Mix – 2 (Containing Cement, Blast Furnace Slag & Fine Aggregates &Fly Ash)

Considering cement: FA (blast furnace slag, fine aggregates,fly ash) in 1:2.5 proportion.

Fine aggregates = fine aggregates+ blast furnace slag+ flyash = 40%+50%+10%

Material	Values
Cement	500kgs
Fine aggregate	500kgs
Blast furnace slag	625kgs
Fly ash	125kgs
Foam	0.90liters
w/c	0.35

Table : 3.4

Trials: For Foam Concrete Mix – 3 (Containing Cement, Blast Furnace Slag & Fine Aggregates& Glass Powder)

Considering cement: FA (blast furnace slag ,fine aggregates , fly ash ,Glass powder) in 1:2.5 proportion.

Fine aggregate = fine aggregates + blast furnace slag +fly ash + Glass powder=35% +50%+5%+10%

Materials	Values
Cement	500kgs
Fine aggregates	437.5kgs
Blast furnace slag	625kgs
Fly ash	62.5kgs
Glass powder	125kgs
Foam	0.90liters
w/c	0.35

3.6 Foam concrete in comparison with other materials.

- When comparing foam concrete with other materials, one must keep in mind that:
- It is ecologically clean, "breathes", uninflammable.
- easy to produce in steady-state conditions as well as on a construction site
- is produced from components available in any region
- its prime cost is low

3.7 ADVANTAGES

- **RELIABILITY**

Foam concreteis an almost ageless and everlasting material not subject to the impact of time. It does not decompose and is as durable as rock. High compression resistance allows to use produce with lower volumetric weight while construction, which increases the temperature lag of a wall.

- **MICROCLIMATE**

Foam concrete prevents loss of heat in winter, is humidity proof, allows to avoid very high temperatures in summer and control air humidity in a room by absorbing and output of moisture, thus helping create a favourable microclimate (Microclimate in a wooden house).

- **QUICKNESS OF MOUNTING**

Small density, and, therefore, lightness of foam concrete, large sizes of blocks compared with bricks, allow to increase the speed of laying by several times. Foam concrete is easy to process and trim – to cut channels and holes for electrical wiring, sockets, and pipes. The simplicity of laying is reached through high exactness of linear dimensions, the tolerance is +/- 1 mm.

- **ACOUSTING INSULATION**

Foam concrete has a relatively high property of acoustical absorption. In buildings constructed of porous concrete the acting requirements for acoustic insulation are met.

- **ECOLOGICAL COMPATIBILITY**

During maintenance, foam concrete does not produce toxic substances and in its ecological compatibility is second only to wood. Compare: the coefficient of ecological compatibility of porous concrete is 2; of wood – 1; of brick – 10; of keramzite blocks – 20.

- **APPEARANCE**

Due to high workability, it is possible to produce various shapes of corners, arches, pyramids, which will attach beauty and architectural expressiveness to your house.

- **ECONOMY**

High geometrical exactness of dimensions of concrete produce allows to lay blocks on glue, to avoid "frost bridges" in a wall and to make inner and outer plaster thinner. Foam concrete weighs from 10% to 87% less than standard heavy concrete. Sufficient reduction of weight leads to sufficient economy on basements.

- **FIRE SAFETY**

Foam concrete produce protect from fire spread and correspond to the first degree of refractoriness, which is proved by tests.

Thus, it is can be used in fire-proof constructions. Under the impact of intensive heat, like blow lamp, on the surface of foam concrete, it does not split or blow, as it happens with heavy concrete. AS a result, armature is longer protected from heating. Tests show that foam concrete 150 mm wide can protect from fire for 4 hours. During tests carried out in Australia, an outer side of a foam concrete panel 150 mm wide was exposed to temperatures up to 1200^0C.

- **TRANSPORTATION**

Favorable combination of weight, volume and packaging makes all building constructions convenient for transportation and allow to use motor or railway transport

IV. RESULTS AND ANALYSIS

4.1 CEMENT AND FINE AGGREGATE TEST RESULTS:

Table 4.1

4.1.1 FINENESS MODULUS:

S.No	Sieve designation	Weight of retained (gms)	Cumulative weight retained (gms)	Cumulative weight retained (%)	% passing	Acceptance Limits (require as per IS 383-1979)			
						Zone-1	Zone-2	Zone-3	Zone-4
1.	10mm	0	0	0	100	100	100	100	100
2.	4.75mm	6	6	0.6	99.4	90-100	90-100	90-100	95-100
3.	2.36mm	17	23	2.3	97.7	60-95	75-100	85-100	95-100
4.	1.18mm	112	135	13.5	86.5	30-70	55-90	75-100	90-100
5.	600µ	358	493	49.3	50.7	15-34	35-59	60-79	80-100
6.	300µ	438	931	93.1	6.9	5-20	8-30	12-40	15-50
7.	150µ	64	995	99.5	0.5	0-10	0-10	0-10	0-15
8.	Pan	5	1000						

Fineness modulus=(cumulative % weight retained/100)=2.58

Table 4.2

4.1.2 BULKING OF SAND:

S.No	Height of sand taken(X)	Height of settled sand(Y)	Loss of height of sand(X-Y)	% of bulk age (X-Y/Y)*100
1.	200mm	180mm	20mm	11.11
Total				11.11

Table:4.3 cement and fine aggregates test results

Properties	Values

(A)Cement	
Grade Of Cement	53
Specific Gravity	3.15
Initial Setting Time	75 min
Final Setting Time	360 min
(B)Fine Aggregate	
Fineness Modulus	2.58
Specific Gravity	2.65

4.2 COMPRESSION TEST: (1MPa = 1N/mm^2)

Table4.4Trials: For Foam Concrete Mix – 1 (Containing Cement & Fine Aggregates)

S.No	Age Of Concrete	Cross Sectional Area(mm^2)	Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (MPa)
1.	7 days	22500	143	6.55	6.296
2.		22500	140	6.22	
3.		22500	142	6.11	
4.	14 days	22500	246	10.93	10.8
5.		22500	243	10.8	
6.		22500	240	10.66	
7.	28days	22500	340	15.11	15.230
8.		22500	345	15.33	
9.		22500	343	15.24	

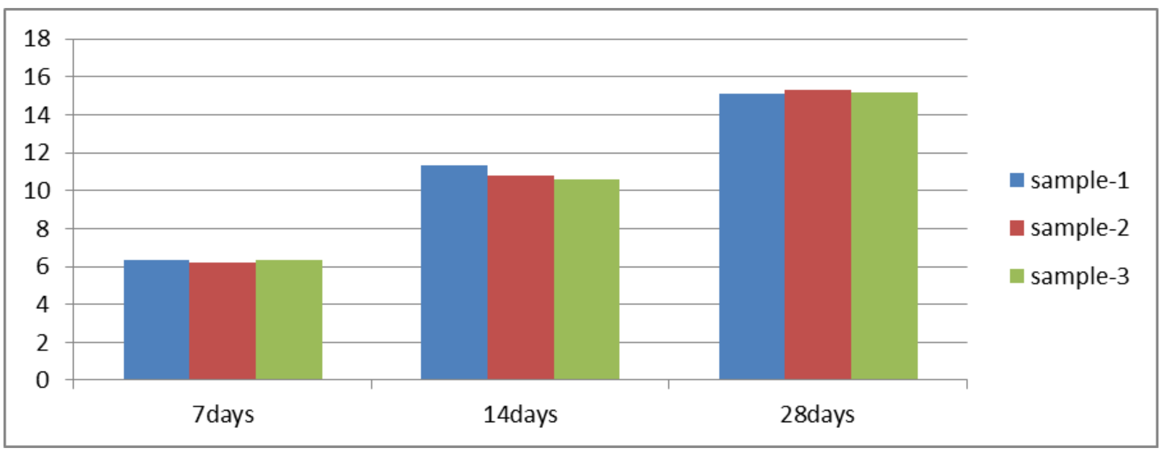


Fig:4.1 compression test trial:1

According to above graph there no variation in compressive strength. The time of curing will increases, the compressive strength also increases.

Table 4.5Trials: For Foam Concrete Mix – 2 (Containing Cement, Blast Furnace Slag & Fine Aggregates &Fly Ash)

S.No	Age Of Concrete	Cross Sectional Area(mm^2)	Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (MPa)
1.	7 days	22500	43	1.91	1.910
2.		22500	44	1.95	
3.		22500	42	1.86	
4.	14 days	22500	110	4.88	5.000
5.		22500	115	5.11	
6.		22500	113	5.02	
7.	28days	22500	200	8.9	9.0
8.		22500	205	9.11	
9.		22500	202	8.97	

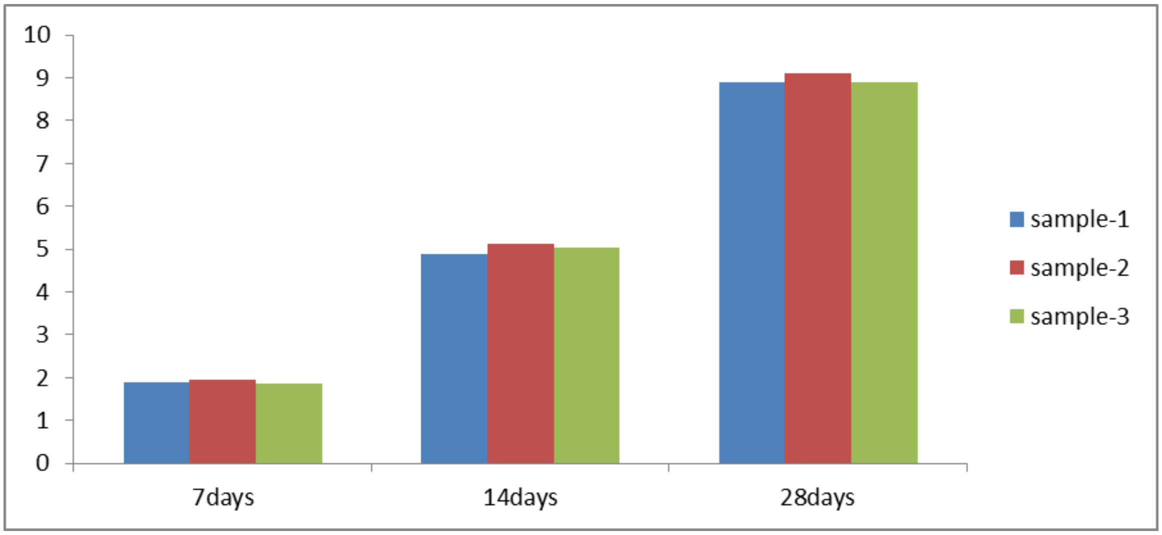


Fig :4.2 compression test trial:2

According to above graph it compared to trial-1 the compressive strength will be decreases 40%. Because of the amount of fly ash we mix in this proportion. The fly ash has low compressive strength.

4.6 Trials: For Foam Concrete Mix – 3 (Containing Cement, Blast Furnace Slag & Fine Aggregates& Glass Powder)

S.No	Age Of Concrete	Cross Sectional Area(mm^2)	Load (KN)	Compressive Strength (KN/mm^2)	Average Compressive Strength (MPa)
1.	7 days	22500	56	2.4	2.411
2.		22500	55	2.44	
3.		22500	52	2.31	
4.	14 days	22500	150	6.66	6.740
5.		22500	152	6.75	
6.		22500	153	6.8	
7.	28days	22500	255	11.33	11.332
8.		22500	254	11.28	
9.		22500	256	11.37	

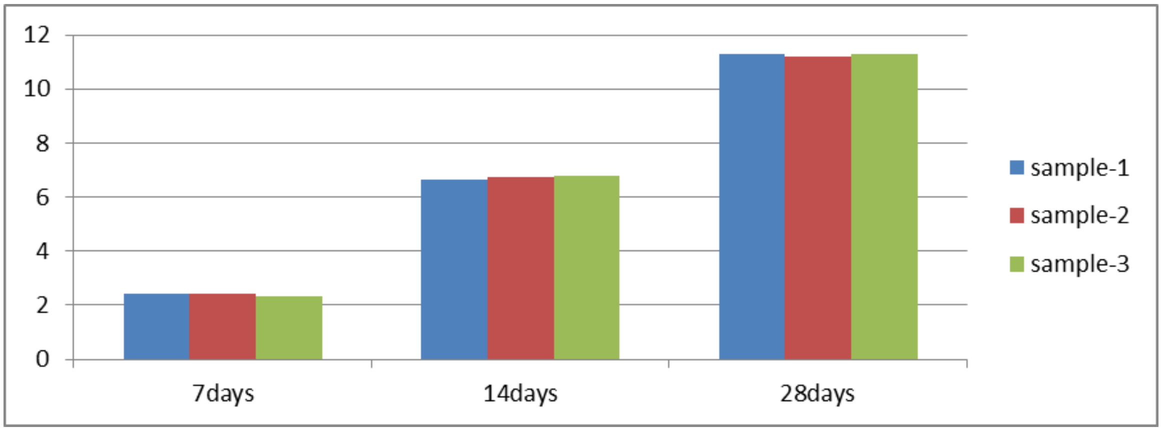


Fig:4.3 compression test trial-3

According to above graph the compressive strength will increases(25%) with compared to trial-2. Because we decrease fly ash content and added glass powder to the mix to increases compressive strength.

4.7 Compression test for bricks

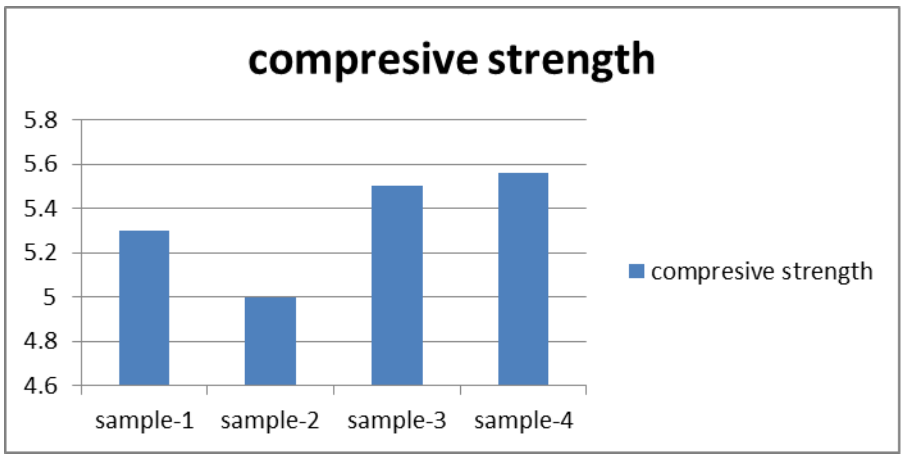


Fig:4.5Compressive Strength of Brick Specimens

The average experimental strength calculated experimentally is 5.328 MPa which goes in line with the compressive strength.

V. CONCLUSION

The density of foamed concrete is inversely proportional to the percentage of foam that is added to theslurry/mortar.

- The compressive strength and density of foam concrete increases with age.
- The compressive strength of foamed concrete increases with increase in the density.
- Fine aggregate had a beneficial effect on significantly increase in compressive strength of foamed concrete.
- De-moulding of higher density foamed concrete panels is possible after 24 hours but it requires minimum 3 daysfor lower density foamed concrete panels.
- The starting of strength gain for foamed concrete is on higher side than that of normal weight concrete andstrength gain beyond 28 days is faster than normal weight concrete.
- The addition of fly ash of equal amount of cement makes it possible to gain the target strength with age.

- This study has shown that the use of flay ash in foam concrete, can be greatly improves its properties.
- The mixed proportion for foamed concrete used in this research report cannot be used for structural purposebecause there 28 days compressive strength is less than 17 MPa.
- Improved structural efficiency in terms of strength to density ratio resulting load reduction on the structure andsubstructure.
- Strength to density ratio is much higher for foam concrete mix – 1 compared to mix – 2 & mix - 3 concrete.
- Both the foamed concrete mixed proportions can be used for making partition walls in buildings.

REFERANCE

[1] Shetty M.S. "Concrete Technology Book".

[2]. Puttappa C.G "Mechanical Properties of Foamed Concrete - ICCBT 2008 – A – (43) – pp491-500".

[3] K. Ramamurthy *, E.K. KunhanandanNambiar, G. Indu Siva Ranjani, "A classification of studies on properties of foam concrete", Cement & Concrete Composites, pp. (388–396), (2009).

[4] Kadabra, "Light weight cement", Kuranda Village Ctr, Australia (2010).

[5] Stella L. Marusin, "Ancient Cement Structures", Cement International , pp.(56– 58), (1 January 1996).

[6] "Pore cement", Conference Proceeding, International Scientific & conference, (2005).

[7] Regan PE, Arasteh AR. Lightweight aggregate foamed cement. Struct Eng;68(9):(167–73),(1990).

[8] McCormick. FC., "Rational proportioning of preformed foam cellular cement", ACI Material Journal ;64:(104–9),(1967).

[9] Herald of BSTU named after V. G. Shukhov – thematic issue "Foam cement", No.4 , (2003).

[10] Byun KJ, Song HW, Park SS., " Development of structural lightweight foamed cement using polymer foam agent". ICPIC-98; (1998).

[11] ASTM Standard test method for foaming agents for use in producing cellular ent using preformed foam , ASTM C (97-796). Philadelphia ; (1997).

[13] ACI committee 523., "Guide for cellular cements above 50 pcf, and for aggregate cements above 50 pcf with compressive strengths less than 2500 psi". ACI J;72:(50–66),(1975).

[14] Kearsley EP. Just foamed cement – an overview. In: Dhir RK, Handerson NA, editors., " Specialist techniques and materials for construction", London: Thomas Telford; (37–227),(1999).

[15]Koudriashoff IT,, "Manufacture of reinforced foam cement roof slabs" ;21(1):(37– 48),(1949).

[16] Madjoudj M, Quenendec M, Dheilly RM. "Water capillary absorption of cellular clayed concrete obtained by proteinic foaming". In: Dhir RK, Hewelett PC, Csetenyi LJ, editors. Innovations and development in concrete materials and construction. UK: Thomas Telford; (21– 513),(2002).

[17] Valore RC. "Cellular cement part 2 physical properties''. ACI J;50:(36–817),(1954).

[18] Nehdi M, Djebbar Y, Khan A., "Neural network sample for preformed foam cellular cement". ACI Mater ;98:(9– 402),(2001).

[19] Kearsley EP., " The use of foamed cement for affordable development in third world countries". In: Dhir RK, McCarthy MJ, editors. Appropriate cement technology. London: E&FN Spon; (43– 233),(1996).

[20] Visagie M, Kearsely EP., " Properties of foamed cement as influenced by airvoid parameters". Cement/ Beton ; 101:(8–14),(2002).

[21] Nambiar EKK, Ramamurthy K., "Air-void characterization of foam cement". CemConcr Res;37:(30–221),(2007).

[22] Durack JM, Weiqing, L., "The properties of foamed air cured fly ash based cement for masonry production", In: Page A, Dhanasekar M, Lawrence S, editors. In: Proceedings of 5th Australian masonry conference. Australia: Gladstone, Queensland;(38–129),(1998).

[23] Tada S, Nakano S., " Microstructural approach to properties of mist cellular cement", In: Wittmann FH, editor. Autoclaved aerated cement, moisture and properties. Amsterdam: Elsevier; (71–88),(1983).

[24] Tikalsky PJ, Pospisil J, MacDonald W., ' A method for assessment of the freezethaw resistance of preformed foam cellular concrete". CemConcr Res;34:(93– 889),(2004).

[25] Nambiar EKK, Ramamurthy K., "Fresh state characteristics of foam cement", ASCE Mater Civ Eng;20:(17–111),(2008).

[26] Tam CT, Lim TY, Lee SL., " Relationship between strength and volumetric composition of moist-cured cellular cement", Mag Concr Res;39:(12–8),(1987).

[27] Nambiar EKK, Ramamurthy K., " Samples relating mixture composition to the density and strength of foam cement using response surface methodology", CemConcr Comp;28:(60– 752),(2006).

[28]D.Hull , " An Introduction to composite Materials " , 1st edition , first published , Cambridge University Press U.k., (1980).

[29]. Alia. Akhtaruzzaman "Behavior of Foamed Slag Concrete at High Temperatures – JKAU Eng. Sci. Vol. 2, pp.119-131 (1410 A.H./1990 A.D.)".

[30]. Narayanan N., Ramamurthy K. "Structure and properties of aerated concrete - Cement & Concrete Composites 22(2000) 321±329".