



## Standard Specification for Fiber-Reinforced Concrete<sup>1</sup>

This standard is issued under the fixed designation C 1116/C 1116M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

### 1. Scope\*

1.1 This specification covers all forms of fiber-reinforced concrete that are delivered to a purchaser with the ingredients uniformly mixed, and that can be sampled and tested at the point of delivery. It does not cover the placement, consolidation, curing, or protection of the fiber-reinforced concrete after delivery to the purchaser.

1.2 Certain sections of this specification are also applicable to fiber-reinforced concrete intended for shotcreting by the dry-mix process when sampling and testing of concrete is possible only at the point of placement. In this case, the sections dealing with batching plant, mixing equipment, mixing and delivery, and measurement of workability and air content, are not applicable.

1.3 This specification does not cover thin-section glass fiber-reinforced concrete manufactured by the spray-up process that is under the jurisdiction of ASTM Subcommittee C27.40.

1.4 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.

1.5 The following precautionary statement pertains only to the test method portion, Sections 15 and 18, of this specification: *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:<sup>2</sup>

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.42 on Fiber-Reinforced Concrete.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

A 820/A 820M Specification for Steel Fibers for Fiber-Reinforced Concrete

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field

C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C 94/C 94M Specification for Ready-Mixed Concrete

C 125 Terminology Relating to Concrete and Concrete Aggregates

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

C 143/C 143M Test Method for Slump of Hydraulic-Cement Concrete

C 150 Specification for Portland Cement

C 172 Practice for Sampling Freshly Mixed Concrete

C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete

C 567 Test Method for Determining Density of Structural Lightweight Concrete

C 666/C 666M Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C 684 Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens

C 685/C 685M Specification for Concrete Made by Volumetric Batching and Continuous Mixing

C 887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar

C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

C 1140 Practice for Preparing and Testing Specimens from Shotcrete Test Panels

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

**C 1385/C 1385M** Practice for Sampling Materials for Shotcrete

**C 1399** Test Method for Obtaining Average Residual Strength of Fiber-Reinforced Concrete

**C 1436** Specification for Materials for Shotcrete

**C 1480** Specification for Packaged, Pre-Blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Application

**C 1550** Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)

**C 1602/C 1602M** Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

**C 1604/C 1604M** Test Method for Obtaining and Testing Drilled Cores of Shotcrete

**C 1609/C 1609M** Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)

## 2.2 *ACI Standards and Reports:*

211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete<sup>3</sup>

211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete<sup>3</sup>

506.2 Specification for Materials, Proportioning and Application of Shotcrete<sup>3</sup>

## 3. Terminology

3.1 Terminology used in this specification is defined in Terminology **C 125**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *manufacturer*—the contractor, subcontractor, supplier, or producer who furnishes the fiber-reinforced concrete.

3.2.2 *purchaser*—the owner or representative thereof.

## 4. Classification

4.1 This specification classifies fiber-reinforced concrete by the material type of the fiber incorporated. The performance of a fiber-reinforced concrete depends strongly upon the susceptibility of the fibers to physical damage during the mixing or shotcreting process, their chemical compatibility with the normally alkaline environment within cement paste, and their resistance to service conditions encountered within uncracked concrete or as a consequence of cracking, involving, for example, carbon dioxide, chlorides, or sulfates in solution with water and oxygen or ultraviolet light in the atmosphere. The magnitude of improvements in the mechanical properties of the concrete imparted by fibers also reflects the material characteristics of the fiber type with fibers having a high modulus of elasticity and tensile strength being more effective on an equivalent volume basis than fibers of low modulus and strength.

4.1.1 *Type I Steel Fiber-Reinforced Concrete*—Contains stainless steel, alloy steel, or carbon steel fibers.

NOTE 1—Steel fibers are not easily damaged by the mixing or shotcreting processes and uncoated steel fibers are chemically compatible with the normally alkaline environment within cement paste. Concrete may be

detrimental to some coatings, such as zinc. Carbon steel fibers will rust under conditions that cause rusting of conventional steel, for example, in the near-surface portion of concrete subject to carbonation.

4.1.2 *Type II Glass Fiber-Reinforced Concrete*—Contains alkali-resistant glass fibers.

NOTE 2—Glass fibers in concrete subjected to wetting, humid atmosphere, or contact with moist ground have the potential to react with the alkalis present in cement paste thereby weakening the fibers. They also tend to become embrittled by hydration products penetrating the fiber bundles and filling the interstitial spaces between the individual glass filaments. Both mechanisms cause reductions in strength, toughness, and impact resistance with age. The alkali-resistant (AR) types of glass fiber developed for use with cement are more resistant to alkalis than the E-glass and other types not marketed specifically for use in cement, and should be used in conjunction with established techniques for suppressing the alkali-silica reaction, for example, use of a low-alkali cement or a mineral admixture, or both. However, even the use of AR-glass fibers does not prevent deterioration in glass fiber-reinforced concrete exposed to moisture for a long period of time, but only slows the rate at which it occurs.

Glass fibers can be damaged by conventional concrete mixing processes employing coarse aggregate, but have been used in shotcrete and in other cementitious matrices such as mechanically mixed masonry mortar (see Specification **C 887**) and thin-section glass fiber-reinforced concrete prepared by the spray-up process (under the jurisdiction of ASTM Subcommittee C27.40).

4.1.3 *Type III Synthetic Fiber-Reinforced Concrete*—Contains synthetic fibers for which documentary evidence can be produced confirming their long-term resistance to deterioration when in contact with the moisture and alkalis present in cement paste or the substances present in air-entraining and chemical admixtures (see **Note 3** and 4.2).

NOTE 3—Fibers composed of some polymers may deteriorate when in contact with moisture, alkalis, or some of the ingredients of chemical admixtures. Fibers such as polyolefins (polypropylene and polyethylene), nylon, and carbon have been shown to be durable in concrete.

4.2 When the purchaser chooses to permit the use of fibers other than those complying with the classifications in 4.1, for example: natural fibers, metallic fibers other than steel, carbon fibers, and so forth, the producer shall show evidence satisfactory to the purchaser that the type of fiber proposed for use does not react adversely with the concrete matrix, including the constituents of any admixtures present, or with the surrounding environment in the cracked matrix, causing deterioration in mechanical properties with age under the exposure conditions anticipated in the application.

## 5. Basis of Purchase

5.1 The basis of purchase for fiber-reinforced concrete shall be in accordance with the *Basis of Purchase* Sections of Specification **C 94/C 94M**.

## 6. Ordering Information

6.1 In the absence of designated applicable general specifications, the purchaser shall specify the following:

6.1.1 Type of fiber-reinforced concrete required. See Section 4.

6.1.2 Type of cement at the purchaser's option, otherwise the cement shall be Type 1 meeting the requirements of Specification **C 150**;

<sup>3</sup> Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, <http://www.aci-int.org>.

6.1.3 Designated size, or sizes, of coarse aggregates;

6.1.4 Slump or time of flow required at the point of delivery, or when appropriate the point of placement, subject to the tolerances hereinafter specified;

6.1.4.1 Slump shall be specified when it is anticipated to be 2 in. [50 mm] or more, and time of flow shall be specified when slump is anticipated to be less than 2 in. [50 mm]. Slump or time of flow shall not be specified for shotcrete placed by the dry process.

NOTE 4—The time of flow of fiber-reinforced concrete through an inverted slump cone, determined in accordance with Test Method C 995, is a better indicator than slump (Test Method C 143/C 143M) of the appropriate level of workability for fiber-reinforced concrete placed by vibration because such concrete can exhibit very low slump due to the presence of fibers and still be easily consolidated. Mixtures with a time of flow of 8 to 15 s are readily consolidated by vibration. Consolidation becomes more difficult with increase in time of flow, and is extremely difficult even when using internal vibration if the time of flow exceeds 30 s. Mixtures with a time of flow less than 8 s should be evaluated in terms of slump because the time of flow is too short to determine with satisfactory precision, or may not be determinable because the fiber-reinforced concrete flows freely through the inverted cone.

6.1.5 Air content when air-entrainment is required, based on the air content of samples taken at the point of discharge, or when appropriate the point of placement, subject to the tolerances hereinafter specified;

NOTE 5—In selecting the specified air content, the purchaser should consider the exposure conditions to which the concrete will be subjected. Air contents less than shown in Table 1 may not produce adequate durability. Air contents higher than the levels shown may reduce strength without contributing further to freeze-thaw resistance.

6.1.6 When structural lightweight concrete is specified, the purchaser shall specify the density as freshly mixed density, equilibrium density, or oven-dry density.

NOTE 6—The freshly mixed density of lightweight concrete, that is the only density determinable at the time of delivery, is always higher than the equilibrium density or oven-dry density. Definitions of, and methods for determining or calculating freshly mixed, equilibrium, and oven-dry densities of lightweight concrete are covered in Test Methods C 138/C 138M and C 567.

6.1.7 If desired, any of the optional requirements of Table 2 of Specification C 1602/C 1602M.

6.1.8 One of the following Options A, B, or C, shall be used as the basis for determining the proportions of the fiber-reinforced concrete of the quality required.

#### 6.2 Option A:

6.2.1 When the purchaser assumes responsibility for mixture proportioning, the following parameters shall also be specified by the purchaser:

6.2.1.1 The cement content in pounds per cubic yard [or kilograms per cubic metre],

6.2.1.2 If supplementary cementitious are required, the type, and amounts to be used in pounds per cubic yard [or kilograms per cubic metre], or in percentages by weight of cement,

6.2.1.3 The maximum allowable amount of mixing water in gallons per cubic yard or litres per cubic metre, including surface moisture on the aggregates, but excluding water absorbed by the aggregate,

6.2.1.4 If air-entraining admixtures are required, the type, name, and dosage range to be used to achieve the specified air content, (see 6.1.4),

6.2.1.5 If chemical admixtures are required, the type, name, and dosage range to be used, and:

6.2.1.6 The type of fibers to be used and the amount in pounds per cubic yard [or kilograms per cubic metre], (see Classification Section 4).

NOTE 7—The dosage of air-entraining, water-reducing (including high-range), accelerating, and retarding admixtures needed to satisfy the material performance requirements varies. Therefore, dosage ranges should be specified to ensure that the material performance requirements can be met.

NOTE 8—The purchaser, in selecting requirements for which he assumes responsibility should give consideration to requirements for workability, placeability, durability, surface texture, and density. The purchaser is referred to ACI Practices 211.1 and 211.2 for selecting proportions that will result in concrete suitable for various types of structures and conditions of exposure, and to ACI Report 544.3R<sup>4</sup> for selecting concrete and fiber parameters suitable for fiber-reinforced concrete. For guidance on selecting proportions for fiber-reinforced shotcrete, the purchaser is referred to ACI Reports 506.1R<sup>5</sup> and 506.R<sup>6</sup> and ACI Specification 506.2.

6.2.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of concrete, furnish a statement to the purchaser giving the sources, relative densities, sieve analyses, and saturated surface-dry masses of fine and coarse aggregates, and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser.

#### 6.3 Option B:

6.3.1 When the purchaser requires the manufacturer to assume full responsibility for mixture proportioning (see Note 8), the purchaser shall also specify the following:

<sup>4</sup> ACI 544.3R-93, "Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete," American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

<sup>5</sup> ACI 506.1R-98, "Committee Report on Fiber Reinforced Shotcrete," American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

<sup>6</sup> ACI 506R-05, "Guide to Shotcrete," American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

TABLE 1 Recommended Total Air Content for Air-Entrained Concrete<sup>A,B</sup>

Exposure Condition <sup>C</sup>	Total Air Content, %					
	Nominal Maximum Sizes of Aggregate, in. [mm]					
	¾ [19.0]	1 [25.0]	1½ [37.5]	2 [50.0]	3 [75.0]	
Mild	4.5	4.0	3.5	3.0	2.5	1.5
Moderate	6.0	5.5	5.0	4.5	4.0	3.5
Severe	7.5	7.0	6.0	6.0	5.5	4.5

<sup>A</sup> For air-entrained concrete, when specified.

<sup>B</sup> Unless exposure conditions dictate otherwise, air contents recommended above may be reduced by up to 1 % for concretes with specified compressive strength,  $f_c$ , of 5000 psi [34.5 MPa] or above.

<sup>C</sup> For description of exposure conditions, refer to ACI 211.1, Table number 5.3.3 with attention to accompanying footnotes.



6.3.1.1 Requirements for flexural performance determined in accordance with one of the following: Test Method **C 1399**, **C 1550** or **C 1609/C 1609M**, using samples obtained at the point of discharge, or when appropriate at the point of placement. At the option of the purchaser, compressive strength (Test Method **C 39/C 39M**) shall be specified when the flexural requirements are considered inadequate for ensuring the quality of the matrix of the fiber-reinforced concrete. Unless accelerated curing and testing in accordance with the warm water or boiling water procedures of Test Method **C 684** is specified, tests shall be performed after standard moist curing in accordance with Practices **C 31/C 31M** at 28 days, or such other ages as are specified by the purchaser.

NOTE 9—While flexural strength at first peak is affected by the type and amount of fibers, it is more dependent on the characteristics of the mortar or concrete matrix, so it is recommended that the purchaser, when specifying flexural strength at first peak, consider factors known to influence the strength of normal concrete such as, water-cement ratio, aggregate maximum size, and the presence of chemical or supplementary cementitious materials.

6.3.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of concrete, furnish a statement to the purchaser giving the sources, relative densities, sieve analyses, and saturated surface-dry masses of fine and coarse aggregates, the dry masses of cement and supplementary cementitious materials, the type, dimensions, and weight of fibers, the quantities, types and names of chemical and air-entraining admixtures (if any), and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser. The manufacturer shall also furnish evidence satisfactory to the purchaser that the materials to be used and the proportions selected will produce fiber-reinforced concrete of the quality specified.

#### 6.4 Option C:

6.4.1 When the purchaser requires the manufacturer to assume responsibility for mixture proportioning with the minimum allowable cement content specified (see **Note 8**), the purchaser shall also specify the following:

6.4.1.1 Requirements for flexural performance determined in accordance with one of the following: Test Method **C 1399**, **C 1550**, or **C 1609/C 1609M**, using samples obtained at the point of discharge, or when appropriate the point of placement. At the option of the purchaser, compressive strength (Test Method **C 39/C 39M**) shall be specified when the flexural requirements are considered inadequate for ensuring the quality of the matrix of the fiber-reinforced concrete. Unless accelerated curing and testing in accordance with the warm water or boiling water procedures of Test Method **C 684** is specified, tests shall be performed after standard moist curing in accordance with Practices **C 31/C 31M** at 28 days, or such other ages as are specified by the purchaser (see **Note 9**).

6.4.1.2 Minimum cement content in pounds per cubic yard [or kilograms per cubic metre].

6.4.1.3 If admixtures are required, the type, name, and dosage to be used. The cement content shall not be reduced when admixtures are used.

NOTE 10—Option C can be distinctive and useful only if the designated

minimum cement content is at about the same level that would ordinarily be required for the mechanical properties, aggregate size, and workability specified. It must be an amount that will be sufficient to ensure durability under expected service conditions, as well as satisfactory surface texture and density. For additional information refer to ACI Practices **211.1** and **211.2**.

6.4.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser giving the sources, relative densities, sieve analyses and saturated surface-dry masses of fine and coarse aggregates, the dry masses of cement and supplementary cementitious materials, the type, dimensions, and weight of fibers, the quantities, types and names of chemical and air-entraining admixtures (if any), and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser. The manufacturer shall also furnish evidence satisfactory to the purchaser that the materials to be used and the proportions selected will produce fiber-reinforced concrete of the quality specified.

6.5 The proportions arrived at by Options A, B, or C for each class of fiber-reinforced concrete approved for use in a project shall be assigned a designation to facilitate identification of each mixture delivered to the project. A certified copy of the proportions of all mixtures as established in Options A, B, or C shall be kept on file by the manufacturer.

6.6 The purchaser shall ensure that the manufacturer is provided copies of all reports of tests performed on concrete samples taken to determine compliance with specification requirements. Reports shall be provided on a timely basis.

## 7. Materials and Manufacture

7.1 In the absence of designated applicable specifications covering requirements for quality of materials, the following specifications shall govern:

7.1.1 Except for fibers, materials for the manufacture of fiber-reinforced concrete shall conform to Specification **C 94/C 94M** and materials for the manufacturer of fiber-reinforced concrete intended for shotcreting shall conform to Specification **C 1436**.

7.1.2 *Fibers*—Fibers shall be capable of producing fiber-reinforced concrete meeting the requirements of this specification. Steel fibers shall conform to Specification **A 820/A 820M**.

## 8. Measuring Materials

8.1 Except as otherwise specifically permitted by the purchaser, cement, supplementary cementitious materials, fine and coarse aggregates, mixing water, and admixtures shall be measured in accordance with the applicable requirements of Specification **C 94/C 94M** or **C 685/C 685M**.

8.2 Fibers shall be measured by weight. When approved by the purchaser, fibers may be measured in bags, boxes, or like containers. Such bags, boxes, or containers shall be sealed by the fiber manufacturer and shall have the weight contained therein clearly marked. No fraction of an unsealed bag, box or like container delivered unsealed, or left over from previous work, shall be used unless weighed.

8.3 Prepackaged, dry, combined materials, including fibers, shall comply with the packaging and marking requirements of Specification **C 387** or **C 1480** and shall be accepted for use provided that after addition of water, the resulting fiber-reinforced concrete meets the performance requirements of this specification.

## 9. Batching Plant

9.1 Batching plant used for the preparation of batch-mixed fiber-reinforced concrete shall comply with the applicable requirements of Specification **C 94/C 94M**.

NOTE 11—A vibrating screen or other device for separating fibers may be required to avoid clumping of some types of fibers prior to mixing with concrete.

## 10. Mixing Equipment

10.1 Mixers or agitators for batch-mixed fiber-reinforced concrete shall comply with the applicable requirements of Specification **C 94/C 94M**.

10.2 Mixers for continuously mixed fiber-reinforced concrete shall comply with the applicable provisions of Specification **C 685/C 685M**.

## 11. Mixing and Delivery

11.1 Batch-mixed fiber-reinforced concrete, whether prepared on site or at a location remote from the site, shall be mixed and delivered to the point designated by the purchaser in accordance with the applicable requirements of Specification **C 94/C 94M** including the requirements for uniformity in the Annex.

11.2 Continuously mixed fiber-reinforced concrete, whether prepared on site or at a location remote from the site, shall be mixed and delivered to the point designated by the purchaser in accordance with the applicable requirements of Specification **C 685/C 685M** including the requirements for uniformity in the Annex.

11.3 Fiber-reinforced concrete shall be free of fiber balls when delivered.

## 12. Batch Ticket Information

12.1 The manufacturer of the fiber-reinforced concrete shall furnish to the purchaser a delivery ticket or statement of particulars on which is printed, stamped, or written, information in one of the following two alternative formats:

12.1.1 *Batch-Mixing Format*—The details identified in the applicable requirements of Specification **C 94/C 94M**, and details of the type, brand, and amount of fibers used.

12.1.2 *Continuous Mixing Format*—The details identified in the applicable requirements of Specification **C 685/C 685M**, and details of the type, brand, and amount of fibers used.

## 13. Inspection of Materials, Production, and Delivery

13.1 The manufacturer shall afford the inspector all reasonable access, without charge, for making necessary checks of the production facilities and for securing necessary samples to determine if the materials used in the fiber-reinforced concrete comply with the requirements of this specification. Inspection, sampling, and testing shall not interfere unnecessarily with the manufacturing and delivery operations.

## 14. Sampling

14.1 The contractor shall afford the inspector all reasonable access, without charge, for the procurement of samples of freshly mixed fiber-reinforced concrete at the time of placement to determine compliance with the requirements of this specification.

14.2 Samples of batch-mixed fiber-reinforced concrete shall be obtained in accordance with Practice **C 172** or **C 1385/C 1385M** as appropriate, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with Specification **C 94/C 94M**.

14.3 Samples of continuously mixed fiber-reinforced concrete shall be obtained in accordance with the applicable requirements of Specification **C 685/C 685M**, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with Specification **C 685/C 685M**.

## 15. Workability and Air Content Tests

15.1 Make tests for workability and air content at the time of placement at the option of the inspector as often as necessary for control checks and acceptance purposes, and always when specimens for tests on hardened concrete are made. When water is added in accordance with the requirements of this specification (see Tolerances in Workability Section 16), repeat all tests, and use the results of the second set of tests to establish whether or not the requirements of this specification are met.

15.2 If the measured slump, time of flow, or air content fall outside the limits permitted by this specification, make a check test immediately on another portion of the same sample. If the results again fall outside the permitted limits, the material represented by the sample fails to meet the requirements of this specification.

## 16. Tolerances in Workability

16.1 Unless other tolerances are included in the project specifications, the following shall apply to all forms of fiber-reinforced concrete except dry-mix shotcrete.

16.1.1 When the project specifications for slump are written as a “maximum” or “not to exceed” requirement:

Specified Slump		
	If 3 in. [75 mm] or less	If more than 3 in. [75 mm]
Plus Tolerance	0	0
Minus Tolerance	1½ in. [40 mm]	2½ in. [65 mm]

When the project specifications for time of flow are written as a “minimum” or “not less than” requirement:

Specified Time of Flow		
	If 15 s or less	If more than 15 s
Plus Tolerance	5 s	10 s
Minus Tolerance	0 s	0 s

These tolerances apply only if one addition of water is permitted on the job provided such addition does not increase the water-cement ratio above the maximum permitted by the project specifications.

NOTE 12—The slump of a fiber-reinforced concrete is less than the slump of an otherwise identical concrete without fibers. The magnitude of the difference depends strongly on the amount and type of fibers, so it is

recommended that trial mixtures representing the amount and type of fibers to be used in the work be prepared and tested to ensure that the specified slump requirements are met. This recommendation is also appropriate when workability is specified in terms of time of flow.

16.1.2 When the project specifications for slump are not written as a “maximum” or “not to exceed” requirement:

**Tolerances for Nominal Slumps**

For Specified Slump of	Tolerance
2 in. [50 mm] and less	$\pm \frac{1}{2}$ in. [15 mm]
2 to 4 in. [50 to 100 mm]	$\pm 1$ in. [25 mm]
more than 4 in. [100 mm]	$\pm 1\frac{1}{2}$ in. [40 mm]

When the project specifications for time of flow are not written as a “minimum” or “not less than” requirement:

For Specified Time of Flow of	Tolerance
8 to 15 s	$\pm 3$ s
more than 15 s	$\pm 5$ s

16.2 Fiber-reinforced concrete shall be available within the permissible range of slump or time of flow for a period of 30 min starting either on arrival at the job site or after the permitted slump adjustment, whichever is later. The first and last  $\frac{1}{4}$  yd<sup>3</sup> or  $\frac{1}{4}$  m<sup>3</sup> discharged are exempt from this requirement. If the user is unprepared for discharge of the material at the job site, the manufacturer shall not be responsible for failure to meet slump or time of flow requirements after 30 min have elapsed beyond either the actual arrival time at the job site or the requested delivery time, whichever is later.

## 17. Tolerance in Air Content

17.1 When air-entrainment is specified, the total air content measured using Test Method **C 173/C 173M** or Test Method **C 231** shall be within a tolerance of  $\pm 1.5$  of the specified value in percent.

## 18. Acceptance Testing of Hardened Fiber-Reinforced Concrete

18.1 Obtain material for the preparation of test specimens in accordance with the sampling section of this specification.

18.2 When post-crack flexural performance is used as the basis for acceptance of fiber-reinforced concrete, make, condition, and test sets of test specimens in accordance with Test Method **C 1399**, **C 1550** or **C 1609/C 1609M** as specified.

18.3 When flexural strength is used as the basis for acceptance, make and test sets of at least three test specimens in accordance with the requirements for sampling and conditioning given in Test Method **C 1609/C 1609M**. Test specimens representing thin sections, as defined in Test Method **C 1609/C 1609M**, or specimens representing fiber-reinforced shotcrete of any thickness, shall be tested as cast or placed without being turned on their sides before placement on the support system. Acceptance shall not be based on flexural strength alone when post-crack performance is important.

NOTE 13—Test Method **C 1609/C 1609M** provides for the determination of first peak flexural strength when required by the purchaser. For many type-amount fiber combinations, the first peak flexural strength is not significantly greater than the peak strength in flexure.

18.4 When compressive strength is used as part of the basis for acceptance of fiber-reinforced concrete, make sets of at least two test specimens in accordance with the applicable requirements of Practices **C 31/C 31M** and **C 192/C 192M**, or Test Methods **C 42/C 42M** or **C 1604/C 1604M** and condition and test in accordance with Test Methods **C 39/C 39M**, **C 42/C 42M**, or **C 1604/C 1604M**. Acceptance shall not be based on compressive strength alone.

18.5 The testing laboratory performing acceptance tests shall comply with the requirements of Practice **C 1077**.

## 19. Frequency of Tests

19.1 The frequency of tests on hardened fiber-reinforced concrete shall be in accordance with the following requirements:

19.1.1 *Batch-Mixing*—Tests shall be made with a frequency of not less than one test for each 150 yd<sup>3</sup> [115 m<sup>3</sup>]. Each test shall be made from a separate batch. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

19.1.2 *Continuous Mixing*—Tests shall be made for each 25 yd<sup>3</sup> [19 m<sup>3</sup>] or fraction thereof, or whenever significant changes have been made in the proportioning controls. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

19.1.3 *Shotcrete*—Tests shall be made for each 50 yd<sup>3</sup> [38 m<sup>3</sup>] placed using specimens sawed or cored from the structure or from corresponding test panels prepared in accordance with Practice **C 1140**. On each day fiber-reinforced shotcrete is prepared, at least one test shall be made for each class of material.

19.2 The representative of the purchaser shall ascertain and record the delivery-ticket number or equivalent information and the exact location in the work at which the material represented by each test is deposited.

## 20. Calculation of Test Results

20.1 A test result shall be based on the mean of the property values for a set of hardened concrete test specimens constituting a test unit as defined herein or in the applicable test method.

20.2 Any individual test specimen in a set constituting a test unit, as defined herein or in the applicable test method, shall be deemed defective and discarded if it shows definite evidence of improper sampling, molding, handling, curing, or testing, and the mean of the property values for the remaining test specimens shall be considered the test result. If more than one specimen in the set is deemed defective on this basis, the test result shall be rejected.

## 21. Performance Requirements

21.1 Unless specifically excluded by the purchaser when ordering material in accordance with Option B or C, fiber-reinforced concrete prepared in accordance with this specification shall meet the following requirements:

21.2 For post-crack flexural performance determined in accordance with Test Method **C 1399**, **C 1550** or **C 1609/C 1609M**, the test results shall equal or exceed the specified values at the applicable test age.

NOTE 14—A post-crack performance requirement should not be specified when fibers are used only to control plastic shrinkage cracking.

21.3 When first-peak and peak flexural strength, in accordance with Test Method **C 1609/C 1609M**, or compressive strength, in accordance with Test Method **C 39/C 39M**, are performance requirements, the test results shall equal or exceed the specified values at the applicable test age.

21.4 When the fiber-reinforced concrete is to be exposed to cycles of freezing and thawing, and the purchaser requires evidence of satisfactory durability, such evidence shall be provided by the manufacturer. A proven record of satisfactory freeze-thaw durability for concrete with or without fibers, made using the same air content, aggregates, and mixture proportions as the fiber-reinforced concrete specified for the work, shall be considered acceptable evidence when the concrete has been in place for at least two winters. In the absence of such a record, satisfactory durability shall be demonstrated for the fiber-reinforced concrete proposed for the work by the attainment of an average durability factor of at least 80 % for a set of three specimens tested according to Procedure A of Test Method **C 666**.

## 22. Failure to Meet Requirements

22.1 When fiber-reinforced concrete fails to meet the requirements of this specification, the manufacturer and the purchaser shall confer to determine whether agreement can be reached as to what adjustment, if any shall be made. If agreement on a mutually satisfactory adjustment cannot be reached by the manufacturer and the purchaser, a decision shall be made by a panel of three qualified engineers, one of whom shall be designated by the purchaser, one by the manufacturer, and the third chosen by these two members of the panel. The question of responsibility for the cost of such arbitration shall be determined by the panel. Its decision shall be binding, except as modified by a court decision.

## 23. Keywords

23.1 accuracy; average residual-strength; certification; fibers; fiber-reinforced concrete; flexural parameters; materials for; scales; testing; toughness

## SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to the specification since the last issue, C 1116–03, that impact the use of this specification.

- (1) Revised Referenced Documents section and text to update references
- (2) Revised terminology to comply with the form and style of ASTM and C09.

- (3) Revised Sections **6** and **7** to conform to Specification **C 94/C 94M**.
- (4) Changed standard to a dual designation and revised **1.4**.

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