Designation: C 1116 – 03

Standard Specification for Fiber-Reinforced Concrete and Shotcrete[1]

This standard is issued under the fixed designation C 1116; 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 inch-pound units are to be regarded as 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:*

A 820 Specification for Steel Fibers for Fiber-Reinforced Concrete[2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field[3]

C 33 Specification for Concrete Aggregates[3]

C 39/C 39M Test Method for Strength of Cylindrical Concrete Specimens[3]

C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[3]

C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)[3]

C 94/C 94M Specification for Ready-Mixed Concrete[3]

C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)[4]

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[3]

C 143/C 143M Test Method for Slump of Hydraulic Cement Concrete[3]

C 150 Specification for Portland Cement[4]

C 172 Practice for Sampling Freshly Mixed Concrete[3]

C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[3]

C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle[4]

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory[3]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[3]

C 260 Specification for Air-Entraining Admixtures for Concrete[3]

C 330 Specification for Lightweight Aggregates for Structural Concrete[3]

C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete[3]

C 494/C 494M Specification for Chemical Admixtures for Concrete[3]

C 567 Test Method for Determining Density of Structural Lightweight Concrete[3]

C 595 Specification for Blended Hydraulic Cements[4]

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete[3]

C 637 Specification for Aggregates for Radiation-Shielding Concrete[3]

C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing[3]

[1] 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.

Current edition approved July 10, 2003. Published September 2003. Originally approved in 1989. Last previous edition approved in 2002 as C 1116 – 02.

[2] *Annual Book of ASTM Standards*, Vol 01.04.

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

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

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

C 684 Test Method for Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens[3]
C 685/C 685M Specification for Concrete Made by Volumetric Batching and Continuous Mixing[3]
C 887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar[5]
C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone[3]
C 1017/C 1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete[3]
C 1018 Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)[3]
C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[3]
C 1141 Specification for Admixtures for Shotcrete[3]
C 1240 Specification for Silica Fume for Use in Hydraulic-Cement Concrete, Mortar, and Grout[3]
C 1399 Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete[3]
D 512 Test Methods for Chloride Ion in Water[6]
D 516 Test Methods for Sulfate Ion in Water[6]
2.2 *ACI Standards and Reports:*
211.1 Standard Practice for Selecting Proportions for Normal and Heavyweight Concrete[7]
211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete[7]
214 Recommended Practice for Evaluation of Strength Test Results of Concrete[7]
506.1R, State-of-the-Art Report on Fiber-Reinforced Shotcrete[7]
506.2 Specification for Materials, Proportioning and Application of Shotcrete[7]
506.R, Guide for Shotcreting[7]
544.3R Guide for Specifying, Mixing, Placing and Finishing Steel Fiber-Reinforced Concrete[7]
2.3 *AASHTO Standard:*
T26 Test Method for Solids Content of Wash Water[8]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *fibers*—slender and elongated filaments in the form of bundles, networks, or strands of any natural or manufactured material that can be distributed throughout freshly mixed concrete.

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

3.1.3 *purchaser*—the owner or representative thereof.

4. Classification

4.1 This specification classifies fiber-reinforced concrete or shotcrete by the material type of the fiber incorporated. The performance of a fiber-reinforced concrete or shotcrete 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 sulphates in solution with water and oxygen or ultraviolet light in the atmosphere. The magnitude of improvements in the mechanical properties of the concrete or shotcrete 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 or Shotcrete*—Contains stainless steel, alloy steel, or carbon steel fibers (see Note 1).

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. Some coatings, such as aluminum, may be detrimental to concrete. 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 or Shotcrete*—Contains alkali-resistant glass fibers (see Note 2).

NOTE 2—Glass fibers in concrete or shotcrete subjected to wetting, humid atmosphere, or contact with moist ground have the potential to react with the alkalies 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 alkalies 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 or Shotcrete*—Contains synthetic fibers for which documentary evidence can be produced confirming their long-term resistance to deterioration when in contact with the moisture and alkalies 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, alkalies, 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

[5] *Annual Book of ASTM Standards*, Vol 04.05.
[6] *Annual Book of ASTM Standards*, Vol 11.01.
[7] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.
[8] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

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 or shotcrete 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 conventionally mixed fiber-reinforced concrete shall be the cubic yard or cubic metre of freshly mixed and unhardened material as discharged from the mixer.

5.2 The volume of freshly mixed and unhardened material in a given batch shall be determined from the total weight of the batch divided by the unit weight in pounds per cubic foot or kilograms per cubic metre. The total weight of the batch shall be calculated either as the sum of the weights of all materials, including water, entering the batch, or as the net weight of the concrete in the batch as delivered. The unit weight shall be determined in accordance with Test Methods C 138/C 138M or C 567 from the average of at least three measurements, each on a different sample. Sampling shall be in accordance with Practice C 172.

NOTE 4—It should be understood that the volume of hardened concrete may be, or may appear to be, less than expected due to waste and spillage, over-excavation, spreading forms, some loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the manufacturer.

5.3 The basis of purchase for fiber-reinforced shotcrete shall normally be the cubic yard or cubic metre. For wet-mix shotcrete, the volume shall be calculated from the quantities delivered and the unit weight. For dry-mix shotcrete, the volume shall be calculated from the weights of constituent materials mixed and their respective specific gravities. At the option of the purchaser, where the surface to be shotcreted is plane and a uniform finished thickness of shotcrete is specified, the basis of purchase shall be the square yard or square metre.

6. Ordering Information

6.1 The purchaser shall specify the following:

6.1.1 Type of fiber-reinforced concrete or shotcrete 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;

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 5—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;

6.1.5.1 Air-entrainment shall not be specified for shotcrete placed by the dry process.

NOTE 6—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 resistance to freezing and thawing. 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 unit weight as wet weight, air-dry weight, or oven-dry weight.

NOTE 7—The unit weight of freshly mixed lightweight concrete, that is the only unit weight determinable at the time of delivery, is always higher than the air-dry or oven-dry weight. Definitions of, and methods for determining or calculating air-dry and oven-dry weights of lightweight concrete are covered in Test Method C 567.

6.1.7 One of the following Alternatives, 1, 2, or 3, shall be used as the basis for determining the proportions of the fiber-reinforced concrete or fiber-reinforced shotcrete of the quality required.

6.2 *Alternative Number 1*:

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),

TABLE 1 Recommended Total Air Content for Air-Entrained Concrete[A,B]

Exposure Condition[C]	Total Air Content, %						
	Nominal Maximum Sizes of Aggregate, in. (mm)						
	⅜ (9.5)	½ (12.5)	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	2.0	1.5
Moderate	6.0	5.5	5.0	4.5	4.5	4.0	3.5
Severe	7.5	7.0	6.0	6.0	5.5	5.0	4.5

[A] For air-entrained concrete, when specified.

[B] 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.

[C] For description of exposure conditions, refer to ACI 211.1, Table number 5.3.3 with attention to accompanying footnotes.

6.2.1.2 If mineral admixtures 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 8—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 9—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 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 and 506.R 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, specific gravities, sieve analyses, and saturated surface-dry weights 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 *Alternative Number 2*:

6.3.1 When the purchaser requires the manufacturer to assume full responsibility for mixture proportioning (see Note 9), the purchaser shall also specify the following:

6.3.1.1 Requirements for flexural toughness parameters, or first-crack strength, or both, determined in accordance with Test Method C 1018, or requirements for average residual-strength determined in accordance with Test Method C 1399, or, at the option of the purchaser, for flexural strength determined in accordance with Test Method C 78, 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 or C 192/C 192M at 28 days, or such other ages as are specified by the purchaser.

NOTE 10—While first-crack strength 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 first-crack strength, consider factors known to influence the strength of normal concrete such as, water-cement ratio, aggregate maximum size, and the presence of chemical or mineral admixtures.

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, specific gravities, sieve analyses, and saturated surface-dry weights of fine and coarse aggregates, the dry weights of cement and mineral admixtures, 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 or shotcrete of the quality specified.

6.4 *Alternative Number 3*:

6.4.1 When the purchaser requires the manufacturer to assume responsibility for mixture proportioning with the minimum allowable cement content specified (see Note 9), the purchaser shall also specify the following:

6.4.1.1 Requirements for flexural toughness, parameters, or first-crack strength, or both, determined in accordance with Test Method C 1018, or requirements for average residual-strength determined in accordance with Test Method C 1399 , or, at the option of the purchaser, for flexural strength determined in accordance with Test Method C 78, 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 or C 192/C 192M at 28 days, or such other ages as are specified by the purchaser (see Note 10).

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 11—Alternative Number 3 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, specific gravities, sieve analyses and saturated surface-dry weights of fine and coarse aggregates, the dry weights of cement and mineral admixtures, 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 or shotcrete of the quality specified.

6.5 The proportions arrived at by Alternatives 1, 2, or 3 for each class of fiber-reinforced concrete or shotcrete 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 Alternatives 1, 2, and 3 shall be kept on file by the manufacturer.

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 *Cement*—Cement shall conform to Specification C 150 or C 595.

7.1.2 *Aggregates*—Aggregates shall conform to Specifications C 33, C 330, or C 637 consistent with the type of concrete required.

7.1.3 *Water*:

7.1.3.1 The mixing water shall be clear and apparently clean. If it contains quantities of substances that discolor it or make it smell or taste unusual or objectionable or cause suspicion, it shall not be used unless service records of concrete made with it or other information indicates that it is not injurious to the quality of the concrete. Water of questionable quality shall be subject to the acceptance criteria of Table 2.

7.1.3.2 Wash water from mixer washout operations may be used as mixing water provided tests of wash water comply with the physical tests of Table 2. Wash water shall be tested at a weekly interval for approximately 4 weeks, and thereafter at a monthly interval provided that no single test exceeds the applicable limit. Optional chemical requirements in accordance with Table 3 may be specified by the purchaser when appropriate for the construction. The testing frequency for chemical limits shall be as given above unless otherwise specified by the purchaser.

NOTE 12—When recycled wash water is used, attention should be given to effects on the dosage rate and batching sequence of air-entraining and other chemical admixtures, and a uniform amount should be used in consecutive batches.

7.1.4 *Admixtures*—Admixtures for conventionally mixed fiber-reinforced concrete shall conform to Specifications C 260, C 618, C 494/C 494M, C 1017/C 1017M, C 1141, or C 1240, whichever is applicable.

TABLE 2 Acceptance Criteria for Questionable Water Suppliers

	Limits	Test Method
Compressive strength, min % control at 7 days	90	C 109/C 109M[A]
Time of set, deviation from control, h: min	from 1.00 early to 1.30 later	C 191[A]

[A] Comparisons shall be based on fixed proportions and the same volume of test water compared to control mix using city water or distilled water.

TABLE 3 Chemical Limitations for Wash Water Used as Mixing Water

	Limits	Test Method[A]
Chemical requirements, maximum concentration in mixing water, ppm[B]		
Chloride as Cl ppm:		D 512
Prestressed concrete or in bridge decks	500[C]	
Other reinforced concrete in most environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms	1000[C]	
Sulfate as SO_4, ppm	3000	D 516
Alkalies as (Na_2O + 0.658 K_2O), ppm	600	
Total solids, ppm	50 000	AASHTO T26

[A] Other test methods that have been demonstrated to yield comparable results may be used.

[B] Wash water reused as mixing water in concrete may exceed the listed concentrations of chloride and sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregates and other sources, does not exceed the stated limits.

[C] For conditions allowing use of $CaCl_2$ accelerator as an admixture, the chloride limitation may be waived by the purchaser.

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

8. Measuring Materials

8.1 Except as otherwise specifically permitted by the purchaser, cement, pozzolans, 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 and shall be accepted for use provided that after addition of water, the resulting fiber-reinforced concrete or shotcrete 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 13—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.

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.

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 or shotcrete 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 or shotcrete 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, 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 Section16), 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 14—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	±½ in. (15 mm)
2 to 4 in. (50 to 100 mm)	±1 in. (25 mm)
more than 4 in. (100 mm)	±1½ in. (40 mm)

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

Tolerances for Time of Flow

For Specified Time of Flow of	Tolerance
8 to 15 s	±3 s
more than 15 s	±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 ¼ yd^3 or ¼ m^3 discharged a re 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 ±1.5 of the specified value in percent.

18. Acceptance Testing of Hardened Fiber-Reinforced Concrete or Shotcrete

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

18.2 When flexural toughness parameters, or first-crack strength, or both, or average residual-strength, are used as the basis for acceptance of fiber-reinforced concrete or shotcrete, make, condition, and test sets of test specimens in accordance with Test Method C 1018 or Test Method C 1399 as appropriate.

18.3 When flexural strength is used as the basis for acceptance, make sets of at least three test specimens in accordance with the requirements for sampling and conditioning given in Test Method C 1018, and test in accordance with the applicable requirements of Test Methods C 42/C 42M or C 78. Test specimens representing thin sections, as defined in Test Method C 1018, 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 toughness is important.

NOTE 15—Test Method C 1018 provides for the determination of flexural strength when required by the purchaser. For many type-amount fiber combinations, the flexural strength is not significantly greater than the first-crack strength.

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 and condition and test in accordance with Test Methods C 39/C 39M or C 42/C 42M. 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 or shotcrete 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^3 (115 m^3). 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^3 (19 m^3) 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^3 (38 m^3) placed using specimens sawed or cored from the structure or from corresponding test panels. 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 Alternatives Number 2 or 3, fiber-reinforced concrete or shotcrete prepared in accordance with this specification shall meet the following requirements:

21.2 For flexural toughness parameters defined in accordance with Test Method C 1018, or for average residual-strength values defined in accordance with Test Method C 1399, the test results shall equal or exceed the specified values at the applicable test age.

NOTE 16—A toughness requirement should not be specified when fibers are used only to control plastic shrinkage cracking.

21.3 When first-crack strength, flexural strength, or compressive strength 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 or shotcrete 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; materials for; scales; testing; toughness

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to the standard since the last issue (C 1116 – 02) that impact the use of this standard.

(1) Revised 6.1.3 to provide for size of coarse aggregate required.