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Pakistan Standard Specification for

Fiber-Reinforced Concrete



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PAKISTAN STANDARDS AND QUALITY CONTROL AUTHORITY

STANDARDS DEVELOPMENT CENTRE

(STANDARDIZATION WING),

1ST FLOOR, ST-7-A, BLOCK-3

GULISTAN-E-JAUHAR

Karachi

**PAKISTAN STANDARD SPECIFICATION
FOR
FIBER-REINFORCED CONCRETE**

0. FOREWORD:

0.1 This Standard was adopted by Pakistan Standards & Quality Control Authority after recommendations of the Technical Committee for “Plain, Reinforced & Prestressed Concrete” (BDC-9) on 17-03-2011. The same had been approved and endorsed by the Civil Engineering National Standards Committee (CENSC) on 27-03-2013.

0.2 This Standard has been prepared after taking into consideration the views and suggestions of the manufacturers, technologists, suppliers and utilizing agencies.

0.3 In preparation of this Standard the Technical Committee acknowledges with thanks the assistance drawn from the standard. (ASTM-C 1116-2008).

0.4 This Standard is subject to periodical review in order to keep pace with development in industry. Any suggestions for improvement will be recorded and placed before the committee in due course.

DRAFT PAKISTAN STANDARD SPECIFICATION

FOR

FIBER-REINFORCED CONCRETE

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 Plain Reinforced & Prestressed concrete (BDC-9)

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 Pakistan Standards/*ASTM Standards*:

- A 820/A 820M Specification for Steel Fibers for Fiber-Reinforced Concrete (PS...)
- C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field(PS...)
- C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens(PS...)
- C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete(PS...)
- C 94/C 94M Specification for Ready-Mixed Concrete(PS...)
- C 125 Terminology Relating to Concrete and Concrete Aggregates(PS...)
- C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete(PS...)
- C 143/C 143M Test Method for Slump of Hydraulic-Cement Concrete(PS...)
- C 150 Specification for Portland Cement (PS 232)
- C 172 Practice for Sampling Freshly Mixed Concrete (PS...)
- C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method(PS...)
- C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory (PS...)
- C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (PS...)
- C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete(PS...)
- C 567 Test Method for Determining Density of Structural Lightweight Concrete(PS...)
- C 666/C 666M Test Method for Resistance of Concrete to Rapid Freezing and Thawing(PS...)
- C 684 Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens(PS...)
- C 685/C 685M Specification for Concrete Made by Volumetric Batching and Continuous Mixing(PS...)
- C 887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar(PS...)
- C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone(PS...)
- C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation (PS...)
- C 1140 Practice for Preparing and Testing Specimens from Shotcrete Test Panels (PS...)

- C 1385/C 1385M** Practice for Sampling Materials for Shotcrete(PS...)
- C 1399** Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete(PS...)
- C 1436** Specification for Materials for Shotcrete(PS...)
- C 1480** Specification for Packaged, Pre-Blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Application(PS...)
- C 1550** Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel) (PS...)
- C 1602/C 1602M** Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete(PS...)
- C 1604/C 1604M** Test Method for Obtaining and Testing Drilled Cores of Shotcrete(PS...)
- C 1609/C 1609M** Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading) (PS...)
- C 1666/C 1666M** Specification for Alkali Resistant (AR) Glass Fiber for GFRC and Fiber-Reinforced Concrete and Cement(PS...)
- D 6942** Test Method for Stability of Cellulose Fibers in Alkaline Environments(PS...)
- D 7357** Specification for Cellulose Fibers for Fiber-Reinforced Concrete(PS...)
- 2.2 ACI Standards and Reports:**
- 211.1** Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete³
- 211.2** Standard Practice for Selecting Proportions for Structural Lightweight Concrete³
- 506.2** Specification for Materials, Proportioning and Application of Shotcrete³

3. Terminology

3.1 Definitions

3.1.1 For definitions of terms used in this specification, refer to Terminology **C 125**.(PS...)

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *manufacturer, n*—the producer who furnishes the fiber-reinforced concrete.

3.2.2 *purchaser, n*—the owner, or representative thereof, who buys the fiber-reinforced concrete.

4. Classification

4.1 This specification classifies fiber-reinforced concrete by the material type of the fiber incorporated.

NOTE 1—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. Improper methods of fiber addition to a concrete mix can lead to balling of some types of fiber; consult manufacturer for advice as to correct method before use. The magnitude of improvements in the

mechanical properties of the concrete or shotcrete imparted by fibers can also reflect the material characteristics, geometry, and design of the fiber type.

4.1.1 *Type I Steel Fiber-Reinforced Concrete*—Contains stainless steel, alloy steel, or carbon steel fibers conforming to Specification **A 820/A 820M**.(PS...)

4.1.2 *Type II Glass Fiber-Reinforced Concrete*—Contains alkali-resistant (AR) glass fibers conforming to Specification **C 1666/C 1666M**.(PS...)

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 and the substances present in admixtures (see **Note 2** and **4.2**).

NOTE 2—Fibers such as polyolefins (polypropylene and polyethylene), nylon, and carbon have been shown to be durable in concrete.

4.1.4 *Type IV Natural Fiber-Reinforced Concrete*—Contains natural 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 and the substances present in admixtures. When Type IV fiber-reinforced concrete contains cellulose fibers they shall conform to Specification **D 7357**.(PS...)

NOTE 3—The classification, natural fibers, refers to a population of fibers that are manufactured from natural fibrous resources and are used for the first time in concrete. Depending on the initial raw material and the manufacturing process employed to produce the fiber, the final physical and chemical fiber properties in this general classification can vary greatly. Some natural fibers are susceptible to deterioration from exposure to alkalis; Test Method **D 6942** may be used to determine the susceptibility of these fibers to deterioration as a result of exposure to alkalis in concrete. Conversely, many other natural fiber types are highly resistant to alkalis and can remain in concrete with no degradation for the complete product life cycle. (PS...)

4.2 When the purchaser chooses to permit the use of fibers other than those complying with the classifications in **4.1**, the manufacturer or supplier shall show evidence satisfactory to the purchaser that the type of fiber proposed for use shows long-term resistance to deterioration when in contact with the moisture and alkalis present in cement paste and the substances present in admixtures.

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** or Specification **C 685/C 685M**.(PS...)

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**;(PS...)

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. (PS...)

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. (PS...)

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

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 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, 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:

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. (PS...)

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).(PS...)

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.(PS...)

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, alkali-resistant (AR) glass fibers shall conform to Specification C 1666/C 1666M, and cellulose fibers shall conform to Specification D 7357.(PS...)

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 Specification C 685/C 685M.(PS...)

8.2 Fibers shall be measured by mass when fiber-reinforced concrete is produced in accordance with Specification C 94/C 94M, and by volume when the fiber-reinforced concrete is produced in accordance with Specification C 685/C 685M. When the fibers are to be measured by mass, bags, boxes, or like containers are acceptable provided that such like containers are sealed by the fiber manufacturer and have the mass contained therein clearly marked. No fraction of a container delivered unsealed, or left over from previous work, shall be used unless weighed. (PS...)

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. (PS...)

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.(PS...)

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.

9.2 Batching plant used for the preparation of continuously-mixed fiber-reinforced concrete shall comply with the applicable requirements of Specification C 685/C 685M.(PS...)

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]						
	¾ [19.5]	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*, 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.

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.(PS...)

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

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. (PS...)

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. (PS...)

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. (PS...)

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. (PS...)

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.(PS...)

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.(PS...)

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	½ 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	5s	10s
Minus Tolerance	0s	0s

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 1/4 yd or 1/4 m 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 6 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:

33[115 m]19.1.1 *Batch-Mixing*—Tests shall be made with a frequency of not less than one test for each 150 yd]. 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.

33[19 m]19.1.2 *Continuous Mixing*—Tests shall be made for each 25 yd] 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.

319.1.3 *Shotcrete*—Tests shall be made for each 50 yds[38 m] 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, fiberreinforced 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/C 666M.

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