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Standard Specification for Fiber-Reinforced Concrete and Shotcrete¹

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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 Concrete²
- C 31 Practice for Making and Curing Concrete Test Specimens in the Field³
- C 33 Specification for Concrete Aggregates³
- C 39/C 39M Test Method for Strength of Cylindrical Concrete Specimens³

- C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete³
- 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 Concrete³
- 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 Concrete³
- C 143/C 143M Test Method for Slump of Hydraulic Cement Concrete³
- C 150 Specification for Portland Cement⁴
- C 172 Practice for Sampling Freshly Mixed Concrete³
- C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method³
- C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle⁴
- C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory³
- C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method³
- C 260 Specification for Air-Entraining Admixtures for Concrete³
- C 330 Specification for Lightweight Aggregates for Structural Concrete³
- C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete³
- C 494/C 494M Specification for Chemical Admixtures for Concrete³
- C 567 Test Method for Determining Density of Structural Lightweight Concrete³
- C 595 Specification for Blended Hydraulic Cements⁴
- C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete³
- C 637 Specification for Aggregates for Radiation-Shielding Concrete³
- C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing³
- C 684 Test Method for Making, Accelerated Curing, and

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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.



- Testing of Concrete Compression Test Specimens³
C 685/C 685M Specification for Concrete Made by Volumetric Batching and Continuous Mixing³
C 887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar⁵
C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone³
C 1017/C 1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete³
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 Evaluation³
C 1141 Specification for Admixtures for Shotcrete³
C 1240 Specification for Silica Fume for Use in Hydraulic-Cement Concrete, Mortar, and Grout³
C 1399 Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete³
D 512 Test Methods for Chloride Ion in Water⁶
D 516 Test Methods for Sulfate Ion in Water⁶
2.2 *ACI Standards and Reports:*
211.1 Standard Practice for Selecting Proportions for Normal and Heavyweight Concrete⁷
211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete⁷
214 Recommended Practice for Evaluation of Strength Test Results of Concrete⁷
506.1R, State-of-the-Art Report on Fiber-Reinforced Shotcrete⁷
506.2 Specification for Materials, Proportioning and Application of Shotcrete⁷
506.R, Guide for Shotcreting⁷
544.3R Guide for Specifying, Mixing, Placing and Finishing Steel Fiber-Reinforced Concrete⁷
2.3 *AASHTO Standard:*
T26 Test Method for Solids Content of Wash Water⁸

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 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 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 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, etc., the producer shall show evidence satisfactory to the

⁵ Annual Book of ASTM Standards, Vol 04.05.

⁶ Annual Book of ASTM Standards, Vol 11.01.

⁷ Available from American Concrete Institute, PO Box 19150, Detroit, MI, 48219.

⁸ Available from American Association of State Highway and Transportation Officials, Washington DC.



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 Types of fine and coarse aggregate at the purchaser's option, otherwise the aggregates shall be normal weight meeting the requirements of Specification C 33;

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),

6.2.1.2 If mineral admixtures are required, the type, and

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)						
	3/8 (9.5)	1/2 (12.5)	3/4 (19.0)	1 (25.0)	1 1/2 (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.



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 or C 192 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 or C 192 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