ICC EVALUATION SERVICE

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ACCEPTANCE CRITERIA FOR CONCRETE WITH SYNTHETIC FIBERS

AC32

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PREFACE

Evaluation reports issued by ICC Evaluation Service, LLC (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the *International Building Code*® reads as follows:

> The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

This acceptance criteria has been issued to provide all interested parties with guidelines for demonstrating compliance with performance features of the applicable code(s) referenced in the acceptance criteria. The criteria was developed and adopted following public hearings conducted by the ICC-ES Evaluation Committee, and is effective on the date shown above. All reports issued or reissued on or after the effective date must comply with this criteria, while reports issued prior to this date may be in compliance with this criteria or with the previous edition. If the criteria is an updated version from the previous edition, a solid vertical line (**|**) in the margin within the criteria indicates a technical change, addition, or deletion from the previous edition. A deletion indicator (→) is provided in the margin where a paragraph has been deleted if the deletion involved a technical change. This criteria may be further revised as the need dictates.

ICC-ES may consider alternate criteria, provided the report applicant submits valid data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. Notwithstanding that a product, material, or type or method of construction meets the requirements of the criteria set forth in this document, or that it can be demonstrated that valid alternate criteria are equivalent to the criteria in this document and otherwise demonstrate compliance with the performance features of the codes, ICC-ES retains the right to refuse to issue or renew an evaluation report, if the product, material, or type or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use of the product, material, or type or method of construction.

Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports.

1.0 INTRODUCTION

1.1 Purpose: The purpose of this acceptance criteria is to establish requirements for concrete with synthetic fibers to be recognized in an ICC Evaluation Service, LLC (ICC-ES), evaluation report under the 2009 and 2006 *International Building Code*® (IBC), the 2009 and 2006 *International Residential Code*® (IRC), the BOCA® *National Building Code*/1999 (BNBC), the 1999 *Standard Building Code*© (SBC) and the 1997 *Uniform Building Code*™ (UBC). The bases of recognition are IBC Section 104.11, IRC Section R104.11, BNBC Section 106.4, SBC Section 103.7 and UBC Section 104.2.8. Applicable code sections in the IBC are Sections 1909 (Structural Plain Concrete) and 1910 (Minimum Slab Provisions); in the IRC are Table R402.2 (Minimum Specified Compressive Strength of Concrete) and Section R506 [Concrete Floors (On Ground)]; in the BNBC are Sections 1901.0, 1902.0, and 1905; in the SBC are Sections 1901 and 1909; and in the UBC are Sections 1907.12, 1922 and 1922.3.

1.2 Scope: Synthetic fibers are added to concrete to reduce plastic shrinkage cracking of reinforced concrete and structural plain concrete and/or to reduce shrinkage and temperature cracking in structural plain concrete slabs on grade.

1.2.1 Consideration shall be given to the volume, size and type of fibers used. Extrapolation to other volumes, sizes and types of fibers shall be documented in accordance with this acceptance criteria, or by an engineering evaluation signed, sealed and dated by a registered design professional.

1.2.2 The fibers are regarded as an admixture and are used in addition to any structural reinforcement, shrinkage and temperature reinforcement and joints required in the applicable code.

1.2.3 The fibers may be used in concrete over steel deck construction.

1.2.4 The fibers may be used in fire-resistive construction on steel decks.

1.3 Reference Standards: Where standards are referenced in this criteria, these standards shall be applied consistently with the code upon which compliance is based. Standards editions applicable to each code are summarized in Table 1.

1.3.1 Codes:

1.3.1.1 2009 and 2006 *International Building Code*® (IBC), International Code Council.

1.3.1.2 2009 and 2006 *International Residential Code*® (IRC), International Code Council.

1.3.1.3 BOCA® *National Building Code*/1999 (BNBC).

1.3.1.4 1999 *Standard Building Code*© (SBC).

1.3.1.5 1997 *Uniform Building Code*™ (UBC).

1.3.2 ASTM International Standards:

1.3.2.1 ASTM C 31, Standard Practice for Method of Making and Curing Concrete Test Specimens in the Field.

1.3.2.2 ASTM C 39, Test Method for Compressive Strength of Cylindrical Concrete Specimens.

1.3.2.3 ASTM C 78-02, Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

1.3.2.4 ASTM C 94, Standard Specification for Ready-Mixed Concrete.

1.3.2.5 ASTM C 192, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.

1.3.2.6 ASTM C 234-91a, Test Method for Bond Strength[1].

1.3.2.7 ASTM C 403-99, Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance.

1.3.2.8 ASTM C 494-05a, Standard Specification for Chemical Admixtures for Concrete.

1.3.2.9 ASTM C 470-02a, Standard Specification for Molds for Forming Concrete Test Cylinders Vertically.

1.3.2.10 ASTM C 666-97, Test Method for Resistance of Concrete to Rapid Freezing and Thawing.

1.3.2.11 ASTM C 823-00, Standard Practice for Examination and Sampling of Hardened Concrete in Construction.

1.3.2.12 ASTM C 1018-97, Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)[1].

1.3.2.13 ASTM C 1116-06 Specification for Fiber-Reinforced Concrete and Shotcrete.

1.3.2.14 ASTM D 698-00a, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort.

1.3.2.15 ASTM D 1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.

1.3.2.16 ASTM D 2256-02, Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method.

1.3.2.17 ASTM E 119, Standard Test Methods for Fire Test of Building Construction and Materials.

1.3.3 American Concrete Institute (ACI) Committee Reports:

1.3.3.1 ACI 305R-99, Specification on Hot Weather Concreting.

1.3.3.2 ACI 318 (-08 for the IBC and IRC, -95 for the BNBC, SBC and UBC), Building Code Requirements for Structural Concrete.

1.3.3.3 ACI 544.2R-89(1999), Measurement of Properties of Fiber-reinforced Concrete.

1.3.3.4 ACI 544.1R-96(2002), State-of-the-Art Report on Fiber Reinforced Concrete.

1.4 Definitions:

1.4.1 Admixture: Admixture is material other than water, aggregate, or hydraulic cement used as an ingredient of concrete and added to concrete before or during its mixing to modify its properties.

1.4.2 Plastic Shrinkage Cracking: Plastic shrinkage cracking is cracking that occurs in the surface of fresh concrete soon after it is placed and while it is still plastic.

[1]Discontinued by ASTM International. Available from Global Engineering Documents [telephone (800) 854-7179; web site http://www.global.jhs.com.]

1.4.3 Reinforced Concrete: Reinforced concrete is defined in Section 1902 of the IBC and Section 2.2 of ACI 318.

1.4.4 Structural Plain Concrete: Structural plain concrete is defined in Section 1902 of the IBC and Section 2.2 of ACI 318.

1.4.5 Shrinkage and Temperature Cracking: Shrinkage and temperature cracking is cracking failure in tension due to a decrease in length or volume caused by a reduction in moisture content.

1.4.6 Synthetic Fibers: Synthetic fibers are fibers manufactured from polymer-based materials such as polypropylene, nylon and polyethylene telephthalate (PET).

2.0 BASIC INFORMATION

2.1 General: The following information shall be submitted:

2.1.1 Product Description: Complete information concerning material specifications, fiber type, size and fiber tensile strength.

2.1.2 Installation Instructions: Printed instructions for mixing and dosage rates, as provided with the packaging of the product.

2.1.3 Packaging and Identification: A description of the method of packaging the product and identifying it in the field. Identification provisions shall include the evaluation report number.

2.2 Testing Laboratories: Testing laboratories shall comply with the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

2.3 Test Reports: Test reports shall comply with AC85.

2.3.1 Test reports shall include the following:

2.3.1.1 Description of type of synthetic fiber.

2.3.1.2 Description of test procedure.

2.3.1.3 Statement on passing or failing, where applicable.

2.4 Product Sampling: Products shall be sampled in accordance with Section 3.0 of AC85.

3.0 TEST AND PERFORMANCE REQUIREMENTS

3.1 General: Consideration shall be given to the volume, size and type of fibers used. Extrapolation to other volumes, sizes and types of synthetic fibers shall be justified. Recognition in evaluation reports of synthetic fibers in concrete are divided into the categories described in Sections 3.1.1 through 3.1.4, below:

3.1.1 Synthetic fibers used in controlling plastic shrinkage cracking of reinforced concrete and structural plain concrete. The fibers are regarded as an admixture and are used in addition to any structural reinforcement, and to any shrinkage and temperature reinforcement required in Section 1907.12 of the IBC, or joints required in Section 1909.3 of the IBC.

3.1.2 Synthetic fibers used to help reduce shrinkage and temperature cracking in structural plain concrete slabs on grade. The fibers are used in addition to joints required in Section 1909.3 of the IBC.

3.1.3 Fibers used in concrete over steel deck construction. See Section 4.8.

3.1.4 Fibers in fire-resistive concrete over steel deck construction. See Section 4.9.

3.2 Test Requirements:

3.2.1 For recognition under Section 3.1.1, results of tests conducted in accordance with Sections 4.1 through 4.5, inclusive, are required.

3.2.2 For recognition under Section 3.1.2, results of tests conducted in accordance with Sections 4.1 through 4.7, inclusive, are required.

3.2.3 For recognition under Section 3.1.3, results of tests conducted in accordance with Sections 4.1 through 4.8, inclusive, are required. For noncomposite concrete placement over steel deck, compliance with Section 4.8 may be omitted.

3.2.4 For recognition of fibers under Section 3.1.4, results of tests conducted in accordance with Sections 4.1 through 4.9, inclusive, are required. For noncomposite concrete placement over steel deck, compliance with Section 4.8 may be omitted.

4.0 TEST METHODS

All tests shall be conducted using appropriate sections of the reference mix outlined in Sections 11 through 15 of ASTM C 494.

4.1 Concrete Flexural Strength: Purpose of the test is to evaluate whether the addition of fibers to a concrete mix adversely affects the flexural strength of the concrete.

4.1.1 Comparative tests shall be conducted in accordance with ASTM C 78.

4.1.2 Sampling and conditioning shall comply with Section 7.2 of ASTM C 1018.

4.1.3 Tests shall be conducted on three specimens with synthetic fibers in the concrete mix, and three specimens without fibers (control).

4.1.4 Conditions of Acceptance: The average flexural strength of the three specimens with fibers shall be equal to the average flexural strength of the control specimens, at 28 days. Slight deviations, due to variations in testing, may be considered.

4.2 Concrete Compressive Strength: The purpose of the test is to evaluate whether the addition of fibers to a concrete mix adversely affects the compressive strength.

4.2.1 Comparative tests shall be conducted in accordance with ASTM C 39.

4.2.2 Tests shall be conducted on three concrete specimens with synthetic fibers, and three specimens without fibers (control).

4.2.3 Conditions of Acceptance:

4.2.3.1 The average compressive strength of the three specimens with the fibers shall be equal to the average compressive strength of the control specimens at 28 days. Slight deviations, due to variations in testing, may be considered.

4.2.3.2 The average compressive strength of the three specimens with synthetic fibers shall not be less than the specified compressive strength for the mix design.

4.3 Freeze-thaw Durability: The purpose of the test is to evaluate whether the addition of fibers to a concrete mix adversely affects the freeze-thaw durability of the concrete.

4.3.1 Comparative tests shall be conducted in accordance with Procedure A of ASTM C 666.

4.3.2 Tests shall be conducted on three concrete specimens with synthetic fibers, and three specimens without fibers (control). Air content of each mixture shall be as specified in Section 12.2.2 of ASTM C 494.

4.3.3 Condition of Acceptance: The average durability factor of the three specimens containing the fibers shall be at least equal to the average durability factor of the control specimens. The number of cycles shall be 300 or until the average relative MOE of the fiber specimens or the control specimens reaches 60 percent of the respective initial modulus, whichever occurs first.

4.3.4 In lieu of providing test information in accordance with ASTM C 666, a proven record of freeze-thaw performance in accordance with Section 21.4 of ASTM C 1116 may be provided. The field test report shall be prepared by a recognized independent agency, and include the size, quantity, trade name and type of fiber along with the concrete mix design. Test reports from at least three separate locations are required.

4.4 Effect on Reinforcement Bond Strength: (May be omitted if use of fibers is limited to plain concrete slabs on grade.) The purpose of the test is to determine whether the addition of fibers to a concrete mix adversely affects the bond strength between the reinforcement and concrete.

4.4.1 Comparative tests shall be conducted in accordance with ASTM C 234. Steel reinforcement shall be evaluated horizontally in accordance with Section 4.3 of ASTM C 234. Concrete shall be cured a minimum of 26 days.

4.4.2 Tests shall be conducted on three concrete specimens with synthetic fibers, and three specimens without fibers (control).

4.4.3 Conditions of Acceptance: The average bond strength for the steel reinforcement embedded in the concrete with the fibers shall be equal to or exceed the average bond strength for the steel reinforcement embedded in the control specimen. Slight deviations, due to variations in testing, may be considered.

4.5 Plastic Shrinkage Cracking: The purpose of the test is to show that fibers decrease the plastic shrinkage cracking of concrete. Testing shall be conducted in accordance with Annex A.

Conditions of Acceptance: Noted in Annex A.

4.6 Compatibility with Concrete: The purpose of the test is to evaluate the long-term resistance of the fiber to deterioration when in contact with moisture and alkalis present in cement paste or the substances present in air-entraining and chemical admixtures.

4.6.1 Procedure:

4.6.1.1 The test begins with two cylinders filled with concrete having the correct proportion of fibers. Cylinders shall be placed in a moist environment at 73°F ± 3°F (23.7°C ± 1.7°C) for two years. A moist environment exists when test specimens have free water on the entire surface area at all times.

4.6.1.2 At the end of two years, the cylinders shall be broken and the fibers examined under 1500× magnification to see if there is any deterioration.

4.6.1.3 Conditions of Acceptance: There shall be no deterioration of fibers.

4.6.2 Alternative Test (Optional): On an interim basis, tests conducted in accordance with one of the procedures outlined in Annex B or Annex C are acceptable.

Results of tests conducted in accordance with Sections 4.6.1 and 4.6.2, above, shall be submitted within two years of the date of application for an evaluation report.

4.7 Post-crack Integrity:

4.7.1 General: One of the following tests shall be used to evaluate the integrity of concrete with synthetic fibers, after cracking:

4.7.1.1 Post-peak Flexural Strength: This test evaluates the ability of fibers to hold concrete together after cracking. Tests shall be conducted in accordance with the procedure outlined in Annex D.

Conditions of Acceptance: The average post-peak flexural strength of the test specimens shall be at least 50 psi (345 kPa) or 20 percent of the peak stress, whichever is less.

4.7.1.2 Impact Resistance: This test compares the impact resistance of concrete with and without synthetic fibers. The test shall be conducted in accordance with the procedure outlined in Annex E.

Conditions of Acceptance: The number of blows to ultimate failure for fiber concrete specimens shall exceed the blows to plain concrete specimens by 100 percent at 7 days and 50 percent at 28 days.

4.8 Concrete over Steel Deck Composite Construction Test:

4.8.1 General: The purpose of the test is to evaluate whether the addition of fibers to a concrete mix placed over steel deck adversely affects the shear bond between the concrete and steel deck construction.

Results of full-scale superimposed load tests (see Figure 1) providing comparative load capacity and deflection information, shall be submitted. A minimum of two decks for each reinforcement method shall be tested. Consideration shall be given to the volume, type and size of fibers used. Extrapolation to other volumes, types and sizes shall be justified.

4.8.2 Procedure (see Figure 1):

4.8.2.1 A No. 20 gage [0.0359 inch (0.91 mm)] steel deck (ASTM A 653 Structural Steel Grade 33), 3 inches (76 mm) deep with 12-inch (304.8 mm) rib spacing, designed for composite use, shall be used.

4.8.2.2 Two and one-half inches (63.5 mm) of concrete fill having a specified compressive strength of 3,000 psi (20.7 MPa), shall be used. Specimens shall include:

1. One set of specimens containing concrete fill with 6 x 6—W1.4 x W1.4 (WWF), 1 inch (25.4 mm) below the top of the slab.

2. One set of specimens containing concrete fill with fibers.

4.8.2.3 The composite deck shall be loaded at the quarter points in approximately eight equal increments until failure. Increments can be determined from the theoretical load capacity of the composite construction.

4.8.2.4 Ultimate flexural load capacity shall be determined for each set. At least three dial gauges equally spaced at midspan shall be used for deflection readings. Deflection readings shall be reported.

4.8.2.5 Conditions of Acceptance:

1. Average ultimate flexural capacity of the decks with fibers shall equal or exceed the average ultimate flexural capacity of the decks with WWF.

2. The average mean shear transfer coefficient (VT) for the decks with the fibers shall equal or exceed the average mean transfer coefficient for the deck with the WWF.

4.9 Fire-resistance Test: The purpose of the test is to evaluate whether the addition of fibers in a concrete mix will adversely affect the fire resistance of steel deck assemblies.

Consideration shall be given to the volume, type and size of fiber used. Extrapolation to other volumes, types and sizes, shall be justified.

Tests shall be conducted in accordance with ASTM E 119 (UBC Standard 7-1).

5.0 QUALITY CONTROL

5.1 A quality control manual complying with the ICC-ES Acceptance Criteria for Quality Control Manuals (AC10) shall be submitted.

5.2 Third-party follow-up inspections are not required under this acceptance criteria.

6.0 EVALUATION REPORT RECOGNITION

The evaluation report shall include the following information:

6.1 If the report applicant purchases the fibers from a fiber manufacturer, evidence is needed of an agreement between the fiber manufacturer and the applicant indicating that the manufacturer will inform the applicant of any changes to the fiber. The applicant shall then notify ICC-ES.

6.2 The evaluation report shall include the condition that use of the fibers is approved by the project engineer or architect.

6.3 For structural plain concrete, the evaluation report shall indicate that control joints, as required by Section 1909.3 of the IBC, are to be provided.

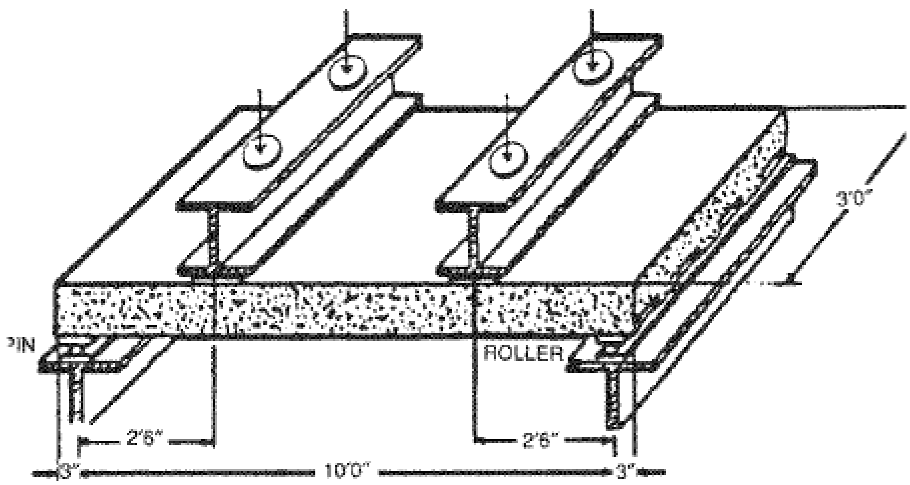
6.4 For reinforced concrete, the evaluation report shall indicate that structural reinforcement and shrinkage and temperature reinforcement in accordance with Section 1907.12 of the IBC are to be provided.

6.5 A batch ticket, signed by a ready-mix representative, shall be available to the code official upon request. The delivery ticket shall include, in addition to the items noted in ASTM C 94, the type and amount of fibers added to the concrete mix.

6.6 If recognition for other types of concrete, such as lightweight, is desired, results of tests conducted in accordance with this criteria shall be submitted for each type.■

TABLE 1—APPLICABLE EDITIONS OF ASTM STANDARDS

ASTM	DATE OF STANDARD				
	IBC	IRC	BNBC	SBC	UBC
C 31	-06	NA	-98	-91	-91
C 39	-05	NA	-96	-93a	-93a
C 94	-07	-07	-98b	-94	-94
C 192	-06	NA	NA	-90a	-90a
D 1557	-02e01	NA	NA	-91	NA
E 119	-07	-07	-98	-95a	-83



For **SI:** 1 inch = 25.4 mm.

FIGURE 1—TEST ASSEMBLY FOR SECTION 4.8 WITH 10-FOOT SPAN

ANNEX A
TEST METHOD FOR EVALUATING PLASTIC SHRINKAGE CRACKING OF RESTRAINED CONCRETE WITH SYNTHETIC FIBERS

A1.0 INTRODUCTION

This test method compares the surface cracking of a concrete panel containing synthetic fibers with the surface cracking of a control concrete panel without fibers. Both concretes are subjected to prescribed conditions of moisture loss severe enough to produce cracking. Both concretes shall also be subjected to anticipated job conditions of temperature and humidity to obtain the difference between the cracking potentials of plain concrete and concrete with synthetic fibers in the field.

Shrinkage cracking is quantified by computing the area of surface cracks in each panel specimen to obtain a value in square inches, which represents the assumed total area of crack opening on the surface of the concrete panels.

The effect of fibers on the development of shrinkage cracking is determined by expressing the cracking value for the concrete with synthetic fibers as a percentage of the value for the control concrete (without fibers) when subjected to the identical and simultaneous drying conditions.

Values of shrinkage cracking stated in square inches (mm^2) are regarded as the standard. This method attempts to control or duplicate atmospheric variables to quantify the performance of the fiber variable in a given concrete mixture. Since many other variables, such as cement fineness, aggregate gradation and surface finishes, also influence cracking potential and cannot be precisely duplicated, this method may not be suitable for interlaboratory evaluations.

A2.0 SUMMARY OF METHOD

Following casting and screeding, the surfaces of concrete test panels with and without fibers are subjected to airflow produced by a fan or fans. The use of a fan box is a method for producing a uniform airflow over the panel surface (see Figure A1). A clear cover over the specimen in conjunction with the fan box will aid in obtaining uniform airflow and allow for specimen observation.

The test is conducted using a method shown in Figure A1, by exposing the panels to an evaporation rate of 0.2 pound of water per square foot of surface per hour (0.975 $kg/m^2/h$) or more. (See ACI 305.)

Referring to the evaporation graph in ACI 305R, evaporative variables are set in the laboratory for the comparison test to obtain a minimum of the critical rate, i.e., 0.2 pound of water per square foot of surface per hour (0.975 $kg/m^2/h$). The evaporation rate is monitored by a one-square-foot (0.0929 m^2) pan of water that is weighed initially and thereafter periodically until the termination of the test, to determine the evaporation rate (Annex Note 1).

Annex Note 1: A principal determinant in this method is evaporative water loss that is controlled by the atmospheric environment of the test specimens. Since the concrete specimens will not always provide the same rate of free water evaporation as is available from the pan of water, the rate of evaporation from the pan of water is the standard for this test.

The drying conditions are intended to induce shrinkage in cracking which will occur due to internal or external restraints on volume reduction. End of test shall be determined when final set of the concrete is reached. Final set will be determined according to ASTM C 403.

The specimens shall be uncovered and exposed to the same conditions. The total area of crack opening at the end of the test is computed for each test panel. The shrinkage of the concrete is expressed as the total area of crack opening for the panel in square inches.

During the setting stage, from initial through final set, "plastic" shrinkage cracks occur. Because it is difficult to measure cracks in the plastic state, all cracks are measured after the termination of the test period.

The test specimens and monitoring pan are inserted into an environmental chamber designed for this purpose. (See Figures A1 and A2.) The atmospheric variables set to achieve the minimum prescribed evaporation rate are not critical in the comparison test, because the average evaporative rate is the determining factor of the test.

Before casting of the concrete panels, it is expeditious to check the atmospheric variables in the laboratory test facility to determine that the necessary conditions can be achieved.

Cracking values are determined by counting the number of cracks in each panel and recording the approximate length and width of each crack. The accumulated crack area is computed based on these measurements, to determine the cracking value for each test panel. The ratio of the cracking values for fiber-reinforced versus control panels is the fiber effectiveness ratio expressed as a percentage. Refer to Section A6.0 for quantification of cracking.

A3.0 APPARATUS

Molds: As shown in Figure A2, a mold with a depth of 4 inches (102 mm), a minimum surface area of 1.75 square feet (0.16 m^2), and rectangular dimensions of 14 inches by 22 inches (356 mm by 559 mm), with internal restraint and stress risers. The mold shall be fabricated from metal, plastic or plyform (Annex Note 2). Fabricate the internal restraints and stress riser for a separate sheet metal piece. This sheet metal piece shall seat snugly at the bottom of the mold. (See Figure A2.)

Annex Note 2: The use of plyform, with very little absorption, is an appropriate choice for constructing lightweight, stiff molds.

Restraint: Two 1.25-inch (31.7 mm) risers, placed 4 inches (102 mm) inward from each end of the mold, provide restraint to the concrete. The center 2.5-inch (63.5 mm) stress riser serves as an initiation point for plastic shrinkage cracking.

The sheet metal stress riser insert is lightly oiled to provide appropriate debonding of the concrete from the bottom of the sheet. The insert is considered to be properly oiled when the entire surface is coated and all excess oil has been removed. The sides of the mold are oiled in the same manner as the insert.

Fan(s): Adjustable-speed fan(s) capable of achieving a minimum 10 mph (16.1 km/h) airflow over the entire test specimen surface area.

Sensors: Sensors shall provide means of recording ambient air and concrete temperatures to the nearest 1°F (0.5°C), and relative humidity to the nearest 1 percent, near the test specimen surface during testing. An anemometer capable of measuring air velocity to the nearest 1 mph (1.61 km/h) shall be used.

Vibrating Platform: Any device that can fully consolidate the test panels within 12 seconds and that meets minimum frequency requirements for an external vibrator, is suitable.

Monitoring Pan: A pan suitable for holding water in the air stream between the concrete test panels. The sides of the pan shall be vertical and shall expose precisely 1 square foot (0.0929 m^2) of water ±1 percent to the atmosphere. This size of pan will expedite the calculation of evaporation rate. The exposed lip of the pan shall not extend more than $^1/_8$ inch (3.2 mm) above the water level at the start of the test. A 12-inch-by-12-inch-by-1-inch (305 mm by 305 mm by 25 mm) or 8-inch-by-18-inch-by-1-inch (203 mm by 457 mm by 25 mm) configuration is appropriate.

Scale: A balance or scale for weighing the monitoring pan shall have a capacity of at least 5 pounds (2.2 kg) and shall be accurate to within 0.1 percent of its capacity.

Optional: A scale for weighing the test panels shall have a capacity of at least 200 pounds (90.7 kg) and shall be accurate to within 1 percent of the test load.

A4.0 SAMPLING, TEST SPECIMENS AND TEST UNITS

General Requirements: The preferred specimen depth for concrete is 4 inches (102 mm). Maximum coarse aggregate size when using stress risers is $^3/_4$ inch (19 mm).

Test Specimens: The specimens are cast in the laboratory in accordance with the applicable provisions of ASTM C 192.

Test Units: A test unit is at least six test specimens. Three are control specimens without fibers. The other specimens are identical except they contain specified amounts and types of fiber. Control concrete specimens may be compared to more than one series of fiber-reinforced concrete specimens.

A5.0 PROCEDURE

The molds are filled with concrete and subjected to a source of external vibration until the concrete is consolidated and approximately level with the top of the mold. Each specimen is then screeded three times with an angle iron screed. The total vibration time is limited to 12 seconds, to avoid material segregation.

Optional: The molds are weighed prior to filling the concrete. Following removal of any waste concrete adhering to the outside of the mold, each specimen while in the mold is weighed prior to testing, to allow evaporation in the form of water loss during testing to be determined at the end of the test by subsequent weighing.

After vibration and screeding, the surface of the concrete shall be floated with a magnesium float to embed the aggregate and compact the surface. The number of passes shall be determined for each mixture and material source used during testing. Float specimens of the same mixture and material using equal number of passes.

The fiber-reinforced and control specimens are placed in the selected exposure area downstream from the fan(s). (See arrangement in Figure A1.)

The fan(s), preset to achieve a minimum airflow velocity of 10 mph (16.1 km/h), are turned on, and the time of day is recorded. Simultaneously, the specimens are exposed to identical drying conditions. The evaluation of cracking commences at this time.

Air and concrete temperatures, relative humidity and airflow velocity, at a location 4 inches (102 mm) above the specimen, shall be recorded at the start and at 30-minute intervals. The time at which cracking is first observed shall be recorded for each specimen.

Observations are continued at 30-minute intervals until final set, or for a minimum of three hours. Measurement of cracking commences only at the completion of the drying period.

The evaporation rate is determined by initially weighing the full monitoring pan at the start of the test and at 30-minute intervals thereafter. The weight loss in pounds is recorded to the nearest 0.01 pound (4.53 g) at each weighing in the air stream to prevent an interruption in evaporation losses.

Annex Note 3: Adjustments shall be made if necessary to maintain the standard evaporation rate at the prescribed level. It is suggested that the monitoring pan be placed on a scale in the air stream for continuous monitoring without periodic removal during testing.

After final set, or a minimum of three hours under the test conditions, atmospheric variables are recorded, and the fans are stopped and the total water loss from the monitoring pan is determined. The test is not valid if the total standard evaporation rate was less than 0.2 pound of water per square foot of surface per hour (0.975 kg/m^2/h).

Optional: If mass loss of test panels is desired, test panels are weighed at this time.

A6.0 QUANTIFICATION OF CRACKING

Cracks are quantified by computing the crack opening area at the surface of the panels. The unit of measurement is square inches (mm^2).

Measurement of cracks commences after the end of drying. Each crack shall be identified and measured in a progressive order from one side of the panel to the other. As each crack is measured, it shall be identified with a bright, felt-tipped pen to prevent duplication. The approximate length of a crack is determined by laying a string along its length and subsequently recording the straight-line distance of string from end to end. It is important to use the same care and measuring methodology on each specimen. Average crack width shall be computed by recording and averaging widths measured along the crack at a minimum of 1-inch (25.4 mm) intervals (Annex Note 4). When all measurements have been taken and all cracks have been marked, this step is complete.

Annex Note 4: A crack comparator or crack microscope, available from many sources, is required to determine the width of the cracks.

It is very important to use the same care and measuring methodology on each specimen. The cracking values of each panel shall be computed by multiplying crack lengths by their associated average widths and accumulating these products to determine the specimen's total cracking value.

A7.0 CONDITIONS OF ACCEPTANCE

The results shall be evaluated on the basis of averaging the test results. Any peculiar individual test results shall be noted.

The minimum accepted for the final results shall be that synthetic fibers decrease the plastic shrinkage cracking of concrete by 40 percent.

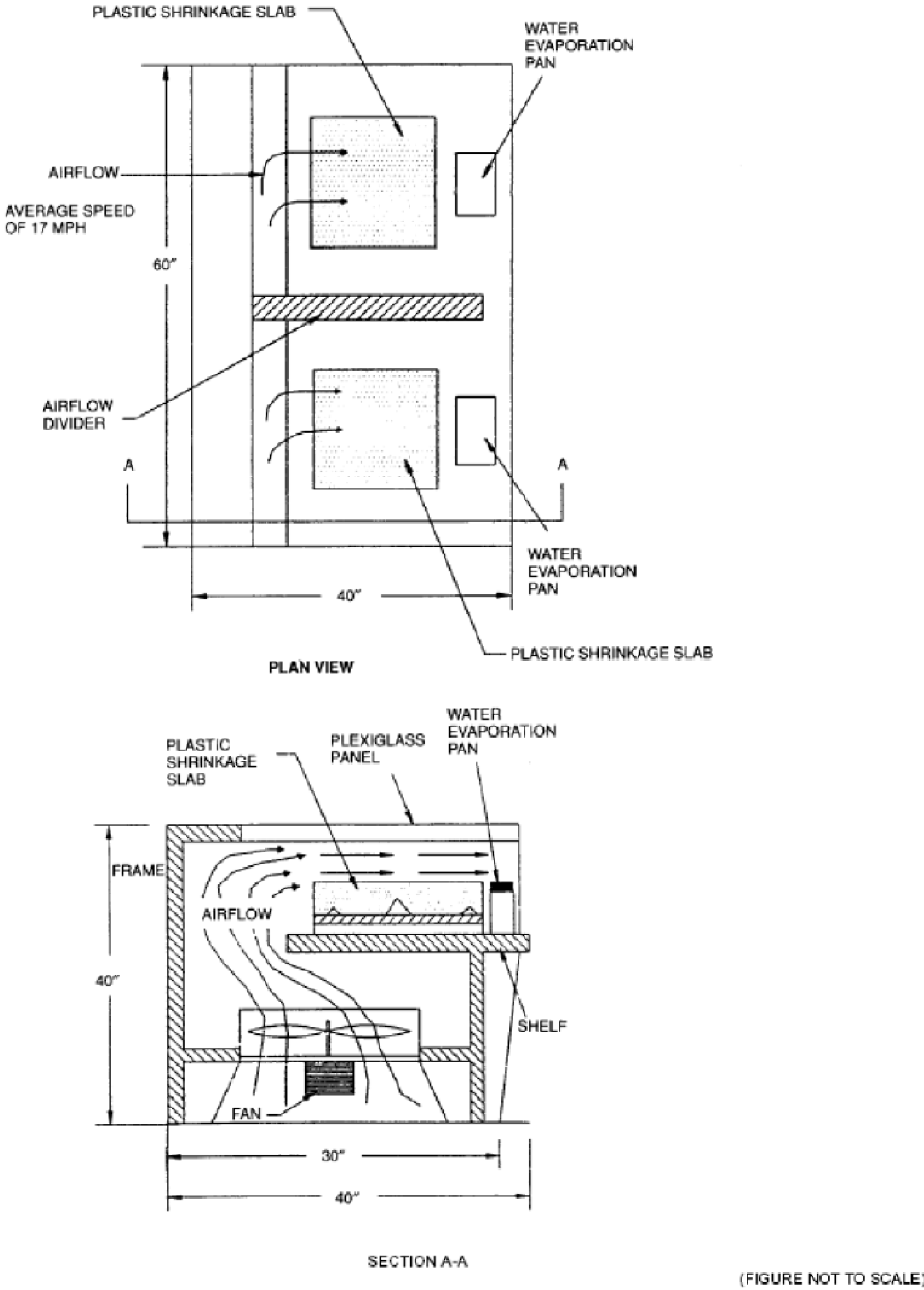
A8.0 REPORT

The report shall include the following:

- Concrete strength, unit weight, and the amount of air entrainment (if applicable).
- The amount in lb./yd^3 (kg/m^3) of water; aggregates with aggregate gradation and fibers; admixture in fluid oz./yd^3 (mL/m^3); water-cement ratio and slump for each concrete mixture evaluated.
- The fiber volume percentage and type of fiber in each concrete mixture evaluated.
- Depth and dimensions of specimens.
- Cracking value of each specimen determined in square inches (mm^2).
- The total measured rate of moisture loss in pounds per square foot (kg/m^2).
- Cracking ratio relative to control without fibers:

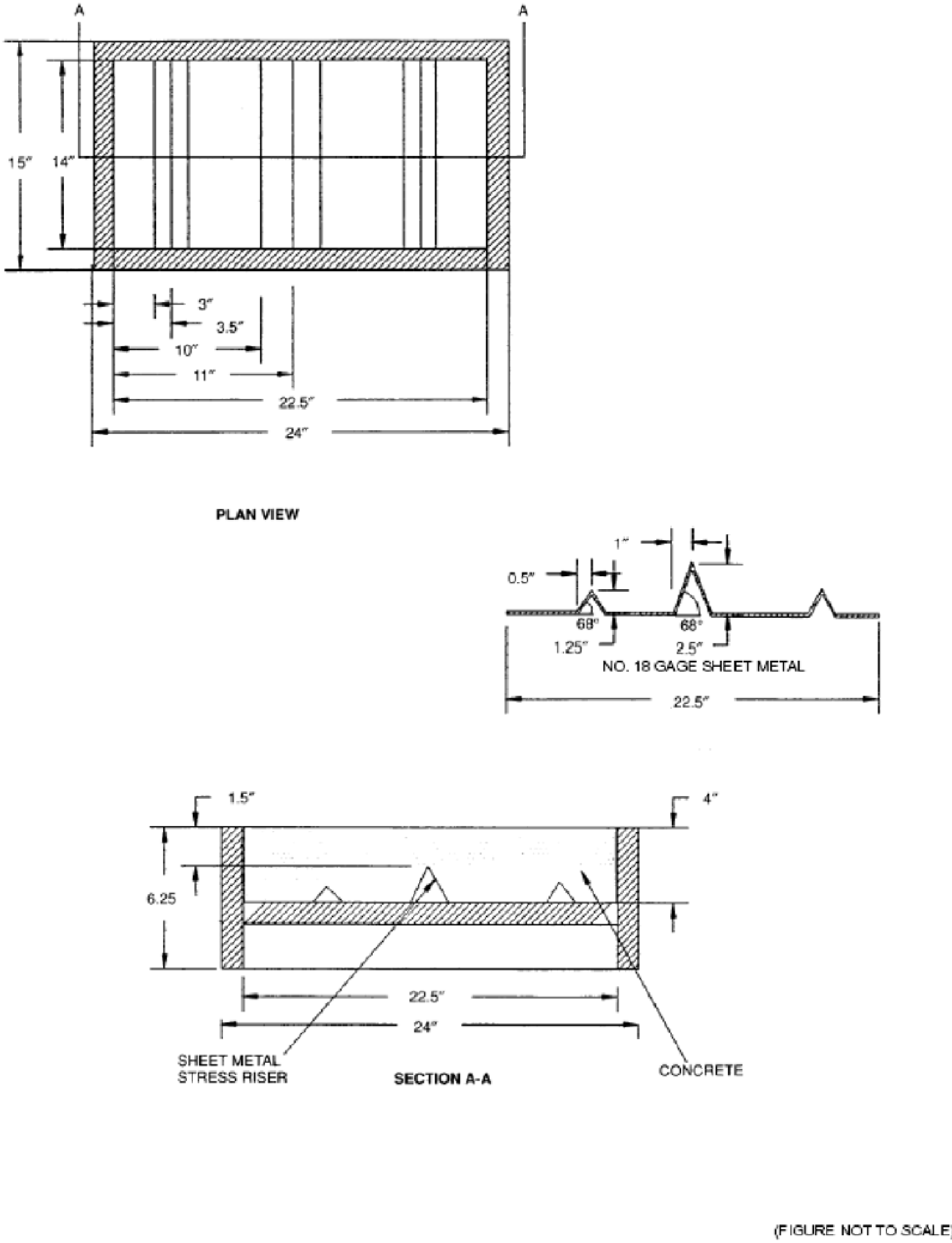
  Cracking value (FRC)/Cracking value (control) X 100%

- Mass loss of specimens (optional)
- Calculated moisture loss of each panel in pounds of water per square foot (kg/m^2) of surface (optional).



For **SI:** 1 inch = 25.4 mm.

FIGURE A1—SCHEMATIC OF FAN BOX USED WITH PLASTIC SHRINKAGE SLAB TO TEST FIBERS



For **SI:** 1 inch = 25.4 mm.

FIGURE A2—SCHEMATIC OF PLASTIC SHRINKAGE MOLD USED FOR FIBER TESTS

ANNEX B
TEST METHOD FOR DETERMINING ALKALINE RESISTANCE OF FIBERS

B1.0 INTRODUCTION

This test method covers the laboratory procedure for determining the alkaline resistance over time of fibers used for reinforcing concrete.

B2.0 MATERIALS

Materials shall include:

- Continuous filament.
- Three solutions of calcium hydroxide at pH's 11 to 13.

B3.0 METHOD

B3.1 Prepare 24 skeins of fiber, each several feet long.

B3.2 Prepare three solutions of calcium hydroxide ranging in pH from 11 to 13.

B3.3 Submerge six skeins of fiber in each solution. Make sure all solutions are well covered and monitored to control pH. The solutions shall be maintained at room temperature [70°F ± 2°F (21°C ± 1°C)].

B3.4 Remove one skein from each solution following 3, 7, 11, 20, 28 and 35 days. Wash, dry and condition each skein for 24 hours at 70°F ± 2°F (21°C ± 1°C) and 65 ± 2 percent relative humidity.

B3.5 Tensile test each skein according to ASTM D 2256. One control skein with each pH series shall be tested. A total of 10 specimens from each skein shall be tested. Record the breaking strength for each specimen and calculate the average breaking strength for each skein. Calculate the breaking strength retained as follows:

Skein Breaking Strength (Avg.)/ Control Breaking Strength (Avg.) X 100% =

% Breaking Strength Retained

B3.6 Examine each skein under the microscope and note surface defects.

B4.0 CONDITIONS OF ACCEPTANCE

The breaking strength retained shall be at least 90 percent of the control skein.

ANNEX C
TEST METHOD FOR DETERMINING LONG-TERM DURABILITY OF FIBERS USED IN FIBER-REINFORCED CONCRETE

C1.0 INTRODUCTION

This test method evaluates the long-term durability of fibers in concrete in accordance with an accelerated aging procedure. The accelerated test method was adopted from "Toughness of Glass Reinforced Concrete Panels Subjected to Accelerated Aging," by S. P. Shah, J. I. Daniel, and D. Ludirdja, which appeared on pages 82-99 of the September-October, 1987, PCI Journal.

C2.0 MATERIALS

Materials shall include:

- Cut fiber.
- Concrete mix: 3,000 psi (20.7 MPa).

C3.0 PROCEDURE

C3.1 The accelerated aging test for durability is adopted from the test used for glass-fiber-reinforced concrete. In this test, the fiber-reinforced specimens are stored in lime-saturated water at 50°C (122°F) for various time intervals. This elevated temperature was found to accelerate the fiber degradation process. The presence and effectiveness of the fibers could be evaluated using either tension or flexure testing. For the purpose of this evaluation, flexure testing is used. The flexural test is conducted prior to accelerated aging and following 4, 8, 16, 32 and 52 weeks of accelerated aging.

C3.2 The fibers are added to the concrete at a rate of 8 pounds per cubic yard (4.7 kg/m^3) of concrete (approximately 0.5 percent by volume). The primary contribution of fibers in concrete is ductility. This high volume loading allows for well-defined load deflection curves under flexural loading, and thus consistently measurable toughness index values. Minute changes in fiber effectiveness will be easily seen and measured because of the high fiber volume.

C3.3 Prepare the primary test specimens, 4-inch-by-4-inch-by-14-inch (102 mm by 102 mm by 356 mm) beams.

Three test specimens, plus several extras, shall be made for each time interval. Moist cure for 28 days. After curing, place the specimens in a lime-saturated water bath maintained at 122°F (50°C) [Compressive cylinders, measuring 6 inches (152 mm) in diameter by 12 inches (305 mm) in height, shall also be cast and cured. Test at 28 days to obtain the compressive strength for quality control purposes.]

C3.4 Remove appropriate specimens just prior to testing. Conduct flexural testing according to ASTM C 1018. Calculate the toughness index values (I_5, I_{10}, I_{30}, I_{10}/I_5 I_{30}/I_{10}) using the load deflection curves.

C4.0 CONDITIONS OF ACCEPTANCE

The I_{30}/I_{10} ratio for fiber-reinforced specimens following accelerated aging shall be at least 85 percent of the unaged specimen value.

ANNEX D
TEST METHOD FOR DETERMINING POST-PEAK FLEXURAL STRENGTH OF SYNTHETIC FIBER-REINFORCED CONCRETE

D1.0 INTRODUCTION

This test method evaluates the flexural post-peak strength of synthetic fiber-reinforced concrete in terms of the stress sustained by fibers consequent to concrete matrix cracking. Flexural post-peak strength of synthetic fiber-reinforced concrete is indicative of crack widening or post-cracking resistance provided by fibers.

D2.0 DESCRIPTION OF TERMS SPECIFIC TO THIS STANDARD

D2.1 Flexural Stress: Maximum stress in a cross section under the effect of bending moment and based on elastic section analysis.

D2.2 Peak Deflection: Loading point deflection attained by a specimen tested under one-third point bending at the maximum (peak) load.

D3.0 SUMMARY OF METHOD

Beams (molded or sawn) of synthetic fiber-reinforced concrete are tested in flexure using the third-point loading arrangements as described in ASTM C 78. Loads and deflections at loading points (one-third points) are monitored either continuously using an X-Y plotter or incrementally via displacement transducers or dial gauges at sufficient frequency. The data collected is used to draw the flexural stress vs. load point deflection of beam specimens. Post-peak range starts approximately at the point where the flexural load (or stress) levels off consequent to the maximum (peak) load or peak stress. The flexural stress sustained by the material in the post-peak range is termed the post-peak flexural strength.

D4.0 SIGNIFICANCE AND USE

The post-peak flexural strength of synthetic fiber-reinforced concrete can be used to describe material crack widening and/or cracking resistance in the range beyond the ultimate flexural stress. Furthermore, it can be used to characterize or specify synthetic fiber reinforced concrete.

D5.0 APPARATUS

D5.1 Testing Machine: Testing machine is according to ASTM C 78 and, additionally, shall be operated at a constant deflection rate.

D5.2 Deflection Measurements: Dial gages or displacement transducers shall be used for deflection measurement.

D5.3 X-Y Plotter: X-Y plotter can be used to draw load deflection curve for this test method.

D6.0 SAMPLING, TEST SPECIMENS, AND TEST UNITS

D6.1 Length of test specimens shall be at least 2 inches (51 mm).

D6.2 This test method is used for synthetic fiber-reinforced concrete specimens, assuming that proper concrete practice is followed and uniform fiber distribution, without balling or tangling, is achieved.

D7.0 PROCEDURE

D7.1 At least three specimens for each concrete mixture are needed to obtain the post-peak flexural strength.

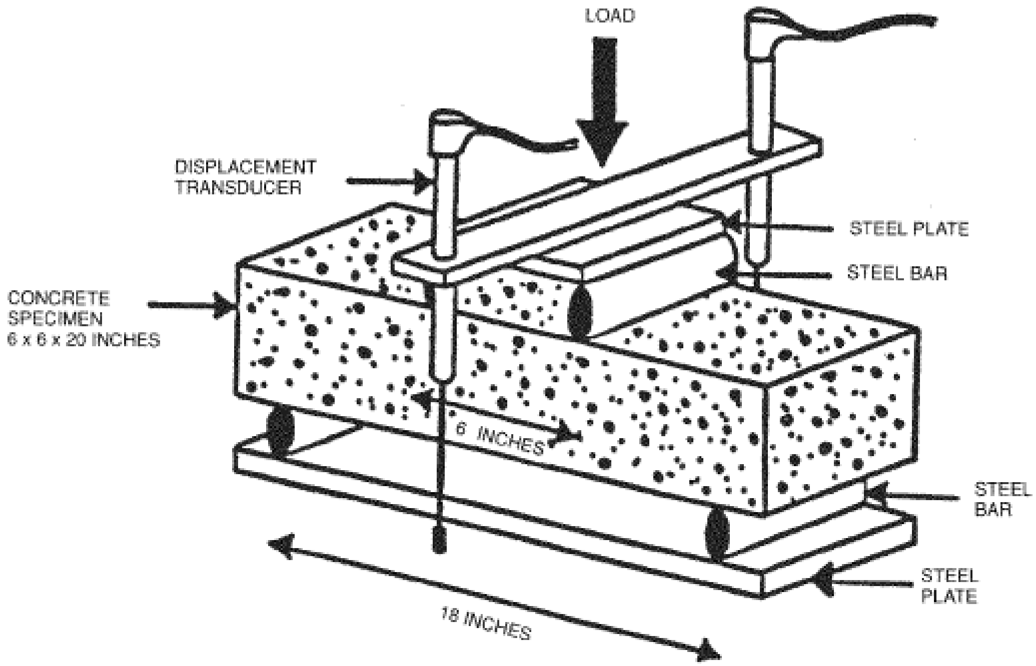
D7.2 A typical experimental setup is shown in Figure D1. For each specimen, the stress-deflection curve is constructed.

D7.3 The average post-peak stress for each specimen is determined.

D7.4 The range over which post-peak strength is averaged starts from Point A (the point at which flexural resistance starts to increase after it has decreased from the peak value) and proceeds to a specified deflection value. Point A is defined as the point at which the deflection equals 1.50 times the deflection at peak load. The point at which the deflection equals five times the peak deflection, marks the conclusion of the post-peak range for the purpose of the test method described herein.

D7.5 The average post-peak flexural resistance of three specimens is considered representative for a synthetic fiber concrete mixture. No specimen can deviate from the average by more than 10 percent for validation of this test procedure.

D7.6 Figure D2 can facilitate comprehension of the concept of post-peak flexural resistance of synthetic fiber reinforced concrete.



For **SI:** 1 inch = 25.4 mm.

FIGURE D1—TYPICAL EXPERIMENTAL SET-UP FOR MEASUREMENT OF POST-PEAK FLEXURAL STRENGTH

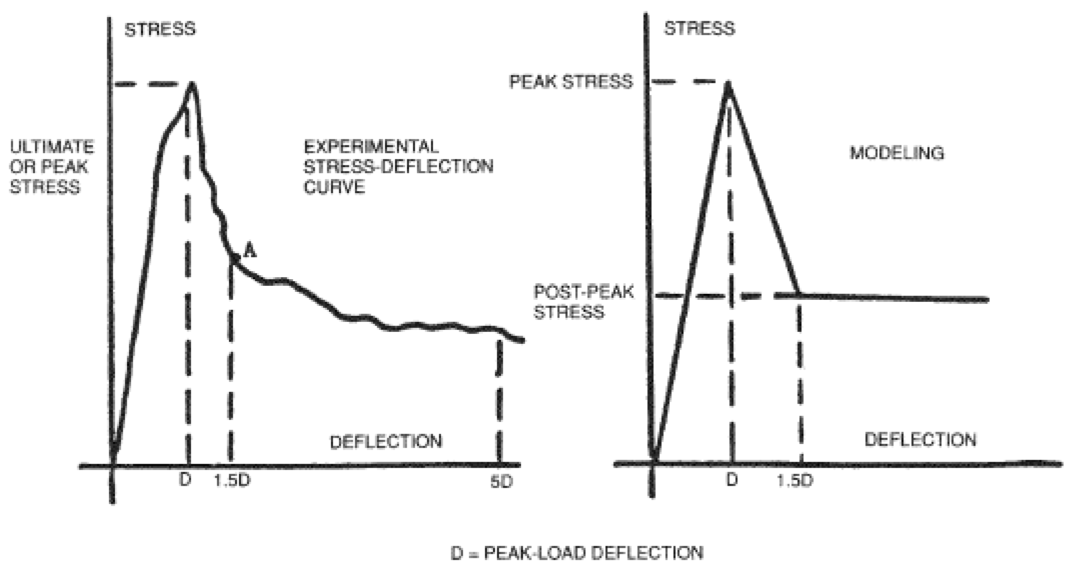


FIGURE D2—POST-PEAK FLEXURAL RESISTANCE OF SYNTHETIC FIBER-REINFORCED CONCRETE

ANNEX E
TEST METHOD FOR EVALUATING IMPACT RESISTANCE OF CONCRETE WITH SYNTHETIC FIBERS

E1.0 SCOPE

The test method compares the impact resistance of concrete with and without synthetic fibers. Impact resistance is characterized by the measure of:

1. The energy consumed to fracture a specimen.
2. The number of blows in a “repeated impact” test to achieve a prescribed level of distress.
3. The extent of damage.

E2.0 APPARATUS

The equipment for the drop weight impact test consists of:

E2.1 A standard, manually or mechanically operated 10-pound (4.54 kg) compaction hammer with an 18-inch (457 mm) drop as specified in ASTM D 698 or ASTM D 1557.

E2.2 A $2^1/_2$-inch-diameter (63.5 mm) hardened steel ball.

E2.3 A flat base plate with four lugs welded to it. (Refer to Figures E1 and E2.)

E2.4 Molds to cast 6-inch-diameter (152 mm) by $2^1/_2$-inch (63.5 mm) $\pm^1/_8$-inch (±3 mm) concrete specimens. This is accomplished with molds complying with ASTM C 31 or C 470.

E3.0 TEST PROCEDURE

The $2^1/_2$-inch-thick-by-6-inch-diameter (63.5 mm by 152 mm) concrete samples are prepared using external vibration.

The method, frequency, amplitude and time of vibration shall be recorded. Test specimens of $2^1/_2$-inch (63.5mm) thickness shall be cast in a single layer to avoid fiber orientation and fiber-free planes. The molds are filled partially to the $2^1/_2$-inch (63.5 mm) depth and float-finished.

The specimens are tested at 7 and 28 days of age. Specimen thickness shall be recorded to the nearest $^1/_{16}$ inch (1.6 mm). The reported thickness is determined by averaging the measured thickness at the center and each edge of the specimen along any diameter across the top surface. The samples shall be coated on the bottom with a thin layer of petroleum jelly or a heavy grease, and placed on the base plate within the positioning lugs with the finished face up. The base plate shall be bolted to a rigid base such as a concrete floor or cast concrete block. The hardened steel ball is placed on top of the specimen within the bracket. Foamed elastomer pieces shall be placed between the specimen and positioning lugs to restrict movement of the specimen during testing to first visible crack.

The drop hammer shall be placed with its base upon the steel ball and held there with enough down pressure to keep it from bouncing off the ball during the test. The hammer shall be repeatedly dropped 18 inches (457 mm), and the number of blows required to cause the first visible crack on the top and to cause ultimate failure are both recorded. The foam elastomer is removed after the first visible crack is observed. Ultimate failure occurs when the test specimen comes in contact with three of the four lugs welded to the base plate. Illustrative details are in Figures E1 and E2.

E4.0 SAMPLING, TEST SPECIMENS AND TEST UNITS

E4.1 Sampling: Five specimens are molded for each test age and test condition. Specimens involving a given variable can be made on any given day. When it is possible to make at least one specimen for each variable on a given day, the mixing of the entire series of specimens shall be completed in as few days as possible, and one of the mixtures shall be repeated each day as a standard comparison.

E4.2 Test Specimens: The test specimens are cast in accordance with ASTM C 192, the Standard Method for Making and Curing Concrete Test Specimens in the Laboratory.

E4.3 Test Units: A test unit is at least five test specimens of each variation. One unit is the control concrete without fibers. The other units are the same concrete mixture with specified amounts and types of fiber.

E5.0 CONDITIONS OF ACCEPTANCE

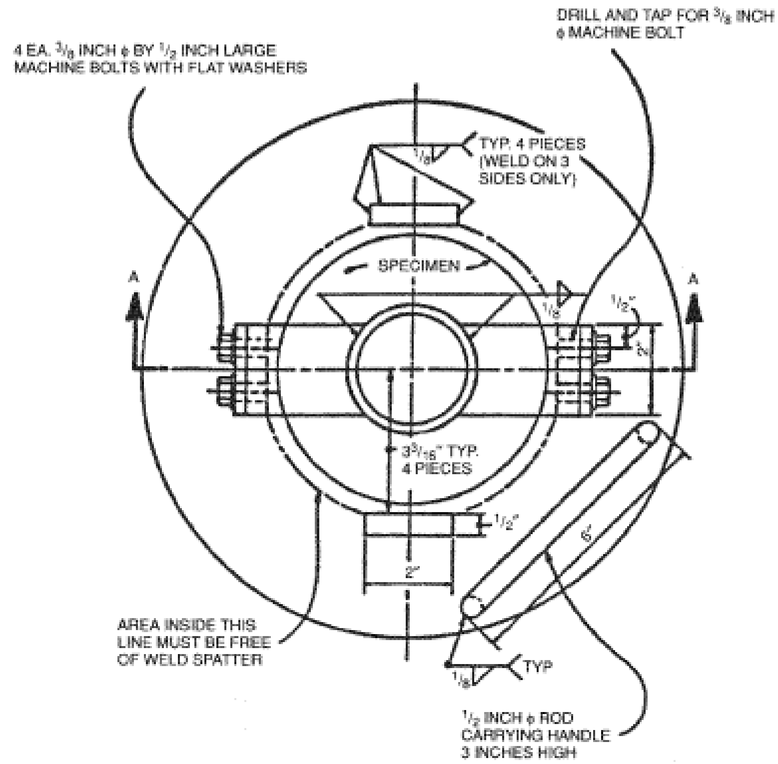
The results shall be evaluated on the basis of averaging the test results. Any individual peculiarities among test results shall be noted. The minimum acceptance for the final results shall be that the synthetic fibers increased the impact of concrete by 100 percent at 7 days and 50 percent at 28 days.

E6.0 REPORT

In addition to the requirements of AC85, the report shall include the following:

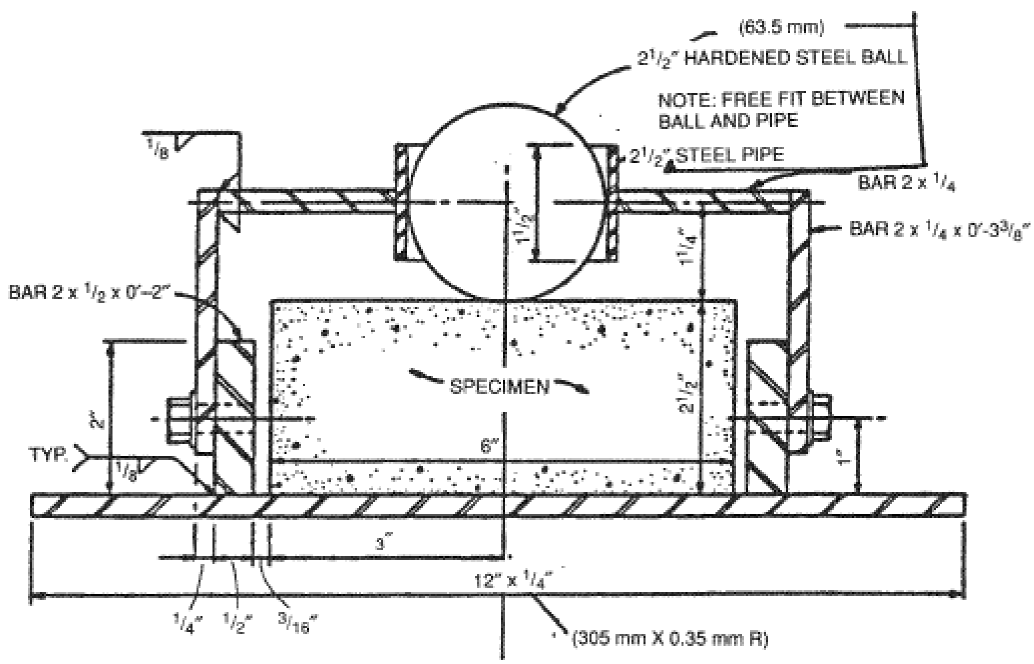
ACCEPTANCE CRITERIA FOR CONCRETE WITH SYNTHETIC FIBERS (AC32)

- The concrete design mix for all variations.
- Fiber dosage for each set of specimens, by weight.
- Fiber length for each of set specimens.
- Thickness and dimension of specimen.
- Height of hammer drop.
- Number of blows to first visible crack.
- Number of blows to ultimate failure.



For **SI:** 1 inch = 25.4 mm.

FIGURE E1—PLAN VIEW OF TEST DEVICE



For **SI:** 1 inch = 25.4 mm.

FIGURE E2—SECTIONAL VIEW A-A OF TEST DEVICE