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Guide Test Methods for Fiber-Reinforced Polymer (FRP) Composites for Reinforcing or Strengthening Concrete and Masonry Structures

Reported by ACI Committee 440

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Due to differences in the physical and mechanical behavior of fiber-reinforced polymer (FRP) materials compared to steel, unique test methods for FRP bars and laminates are required. This guide provides model test methods for the short- and long-term mechanical, thermo-mechanical, and durability testing of FRP bars and laminates. It is anticipated that these model test methods may be considered, modified, and adopted, either in whole or in part, by a U.S. national standards-writing agency such as ASTM International or AASHTO. The publication of these test methods by ACI Committee 440 is an effort to aid in this adoption. The recommended test methods are based on the knowledge gained worldwide from review of research results and literature.

Keywords: anchorage; bond; coupler; creep; fatigue; fiber-reinforced polymer composites; modulus of elasticity; shear; splice; stirrup; strength; tendon.

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PART 1—GENERAL

1.1—Introduction

Conventional concrete and masonry structures are reinforced with nonprestressed steel, prestressed steel, or both. Recently, composite materials made of fibers embedded in a polymeric resin, also known as fiber-reinforced polymer (FRP) composites, have become an alternative to steel reinforcement. Because FRP materials are nonmetallic and noncorrosive, the problems of steel corrosion are avoided with FRP reinforcement. Additionally, FRP materials exhibit several properties, such as high tensile strength, that make them suitable for use as structural reinforcement. FRP materials are supplied as bars for reinforced and prestressing applications and in flat sheets or laminates for use as repair materials.

The mechanical behavior of FRP differs from the behavior of steel reinforcement. FRP materials, which are anisotropic due to the fiber orientation in the bars and laminates, are characterized by high tensile strength only in the direction of the reinforcing fibers. This anisotropic behavior affects the shear strength and dowel action of FRP bars and the bond performance of FRP bars to concrete.

FRP composites are available with a wide range of mechanical properties, including tensile strengths, bond strengths, and elastic moduli. Generally, FRP composites are not covered by national material standards. Instead, manufacturers of FRP composites provide test data and recommend design values based on these test data. Therefore, it is difficult to compare test results between product manufacturers. In addition, research has considered the durability of FRP reinforcement in environments containing moisture, high and low temperatures, and alkaline environments. Test methods that allow for the comparison of mechanical property retention in a wide range of standard environments are needed so that durable FRP-reinforced structures can be ensured.

1.2—Scope

This guide provides model test methods for determining the short- and long-term mechanical properties of FRP reinforcing bars, grids, tendons, and laminates—both prestressed and nonprestressed—for concrete and masonry structures. As noted in the individual methods, most of the methods for bars are also suitable for sections cut from grids. Where necessary, the tests consider the bars and laminates tested embedded in or bonded to concrete or masonry. For the most part, however, these tests are considered to be material tests and not component or structural tests.

These model test methods are intended for consideration, modification, and adoption, either in whole or in part, by a U.S. national standards-writing agency such as ASTM International or AASHTO. The publication of these test methods by ACI Committee 440 is an effort to aid in this adoption.

The guide contains only test methods and not material standards. The individual test methods contained in this guide do not specify minimum material properties that must be met for the materials to be considered acceptable for use. Guidance on deciding whether a material is acceptable based on test results is made in the material specifications and design provisions that complement these test methods (ACI 440.1R; ACI 440.2R; ACI 440.6).

The test methods presented in this guide are the recommendations of ACI Committee 440, and have not been adopted by ACI as standards. As such, they are, for the most part, written in nonmandatory language, using "should" and "may" rather than "shall" and "must." In keeping with the usual test method format, however, some language is imperative ("Fill a cylinder with water..." rather than "A cylinder should be filled with water..."). Although typically considered to be mandatory language, the use of imperative language in these test methods is for readability, and remains as committee recommendations only.

1.3—Existing ASTM test methods

The recommended test methods provided herein are based on the knowledge obtained worldwide from review of research results and literature. Relevant ASTM standards are referenced in the individual methods; others are listed in Table 1.3. In many cases, existing ASTM test methods are appropriate to determine material properties for FRP bars and laminates. Where such methods are completely acceptable for FRP reinforcement, no new method has been proposed. The new methods that are provided have been developed for one or more of the following reasons:

a) To provide a test method where no current method exists

b) To provide more detailed requirements that are specific to FRP reinforcing bars or laminates, such as details on how to grip the reinforcement in the test fixture

c) To adapt a test method originally developed for steel reinforcing bars to work with FRP bars

d) To provide calculated test results compatible with other ACI documents.

Table 1.3 lists specific ASTM test methods and complementary ACI 440.3R methods for various material properties. Where both ASTM and ACI 440.3R test methods exist, the differences between the methods are summarized. Hundreds of ASTM test methods are applicable to FRP composites and organic polymers. The table only describes key material properties and selected ASTM tests that can be used to determine these properties. For some properties, ASTM provides more than one test procedure. The table does not attempt to discuss the differences between various ASTM test methods.

1.4—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," http://terminology.concrete.org. The definitions provided herein complement that resource.

alkaline—having a pH greater than 7 (OH^- concentration greater than 1×10^{-7} M).

anchorage—device at the ends of an FRP tendon that grips the tendon, allowing a minimum of slip and transferring prestressing load from the tendon to the abutment.

anchorage reinforcement—latticed or spiral reinforcing steel or FRP bars provided as confining reinforcement for the anchorage and arranged in front of it.

anchoring section—FRP bar section embedded in the anchorage and anchorage reinforcement, including the surrounding concrete or masonry.

aramid fiber—highly oriented organic fiber derived from polyamide incorporating into an aromatic ring structure.

average load (stress)— mean value of the maximum and minimum repeated loads (stresses).

bend capacity—ultimate tensile stress carried by the FRP stirrup, provided that failure occurs in the bend.

bend radius—inside radius of the bend.

bending angle—angle formed by the straight sections of a specimen on either side of the deflector.

bending diameter ratio—ratio of the external diameter of the deflector surface in contact with the FRP bar to the diameter of the FRP bar.

bending tensile capacity—tensile capacity at failure of a specimen within the deflected section.

bonded length—length of the test bar that is in contact with concrete.

carbon fiber—fiber produced by heating organic precursor materials containing a substantial amount of carbon, such as rayon, polyacrylonitrile (PAN), or pitch, in an inert environment.

characteristic length—for bars or tendons that have a repeating surface deformation pattern, the characteristic length is the distance, in inches (mm), of this pattern; for a spiral pattern, the characteristic length is the pitch.

coefficient of thermal expansion (CTE)—measure of the relative change in linear dimension in a material based on a unit increase in temperature of that material. Note: Due to the anisotropy of FRP composites, the CTE in the longitudinal direction of the bar is likely to be different from that measured in the transverse direction.

creep rupture—material failure due to deformation (accumulated strain) caused by creep.

creep rupture load capacity—load at which failure occurs after a specified period of time from initiation of a sustained load.

cure—to irreversibly change the properties of a thermosetting resin by chemical reaction such as condensation, ring closure, or addition. Note: Cure can be accomplished by adding curing (cross-linking) agents with or without heat and pressure.

deflected section—section of an FRP bar that is bent and maintained at the required bending angle and bending diameter ratio.

deflector—device used to maintain the position, alter the bending angle, or alleviate the stress concentrations in an FRP bar; such a device may sometimes be installed in the deflected section.

equivalent bar diameter—equivalent bar diameter is determined based on the cross-sectional area of the FRP bar (ASTM D7205/D7205M).

equivalent circumference—circumference of an assumed circle with the equivalent area determined according to ASTM D7205/D7205M.

fatigue life—number of cycles of deformation or load required to bring about failure of a material, test specimen, or structural member.

fatigue strength—maximum load (stress) range at which the specimen does not fail at a prescribed number of cycles.

fiber-volume fraction—ratio of the volume of fibers to the volume of the composite.

frequency—number of loading (stressing) cycles per second.

Table 1.3—Test methods for FRP composites used in concrete and masonry structures

Property	ASTM test method(s)	ACI 440 test method	Summary of differences
Cross-sectional area	D7205/D7205M	—	ASTM D7205/D7205M replaces ACI 440.3R-04 Method B.1.
Longitudinal tensile strength and modulus	D7205/D7205M	—	ASTM D7205/D7205M replaces ACI 440.3R-04 Method B.2.
Bond properties	A944	B.3	ASTM Pullout Test C234 (ASTM C234) has been withdrawn and, as written, did not provide adequate specimen size to prevent splitting of concrete cylinder when using FRP bars. The only remaining ASTM test method for bond of steel bars to concrete is beam-end test method (A944), which has not been modified for use with FRP bars. Ongoing work by ACI Committee 440 is expected to produce beam bond test methods.
Shear strength	D7617/D7617M	—	ASTM D7617/D7617M replaces ACI 440.3R-04 Method B.4.
Bent bar capacity	—	B.5	No existing ASTM test method available.
Durability properties	—	B.6	No existing ASTM test method available.
Fatigue properties	D3479	B.7	The ACI method provides specific information on anchoring bars in the test fixtures and on attaching elongation measuring devices to the bars. The ACI method also requires specific calculations that are not provided in the ASTM method.
Creep properties	D7337/D7337M	—	ASTM D7337/D7337M replaces ACI 440.3R-04 Method B.8.
Relaxation properties	D2990 E328	B.9	The ACI method provides specific information on anchoring bars in the test fixtures and on attaching elongation measuring devices to the bars. The ACI method also requires specific calculations that are not provided in the ASTM method.
Anchorage properties	—	B.10	No existing ASTM test method available.
Tensile properties of deflected bars	—	B.11	No existing ASTM test method available.
Effect of corner radius on strength	—	B.12	No existing ASTM test method available.
Flexural properties	D790 D4476	—	No ACI method developed.
Coefficient of thermal expansion (CTE)	E831 D696	—	No ACI method developed.
Glass transition temperature	E1356 E1640 D648 E2092	—	No ACI method developed.
Volume fraction	D3171 D2584	—	No ACI method developed.
Direct tension pulloff	D7522/D7522M	—	ASTM D7522/D7522M replaces ACI 440.3R-04 Method L.1.
Tensile strength and modulus	D7565/D7565M	—	ASTM D7565/D7565M replaces ACI 440.3R-04 Method L.2.
Lap shear strength	D7616/D7616M	—	ASTM D7616/D7616M replaces ACI 440.3R-04 Method L3.
Bond strength	D4551 C882	—	No ACI method developed.

FRP bar—composite material formed into a long, slender, structural shape suitable for the internal reinforcement of concrete and consisting of primarily longitudinal unidirectional fibers bound and shaped by a rigid polymer resin material. The bar may have a cross section of variable shape, commonly circular or rectangular, and may have a deformed or roughened surface to enhance bonding with concrete.

FRP laminates—two or more layers of fiber reinforcements, such as, glass, carbon, and aramid arranged in one or more orientations—for example, 0, 90, +45, –45 degrees—and held together by a polymer matrix. Laminates come in the physical form of dry, prepreg, and precured materials.

FRP tendon—FRP element, such as a bar or strand, or a bundle of such elements primarily used in tension to impart compressive stress to concrete or masonry.

gauge length—distance between two gauge points on the test section, over which the percentage of elongation is determined.

glass fiber—fiber drawn from an inorganic fusion of silica (SiO_2) and other compounds that has cooled without crystallization.

grid—two-dimensional (planar) or three-dimensional (spatial) rigid array of interconnected FRP bars that form a contiguous lattice that can be used to reinforce concrete. Note: The lattice can be manufactured with integrally connected bars or made of mechanically connected individual bars.

impregnate—in the case of FRP composites, to saturate the fibers with resin.

load (stress) amplitude—one-half of the load (stress) range.

load (stress) range—difference between the maximum and minimum repeated loads (stress).

load (stress) ratio—minimum load (stress) divided by maximum load (stress).

maximum repeated load (stress)—maximum load (stress) during repeated loading (stressing).

minimum repeated load (stress)—minimum load (stress) during repeated loading (stressing).

number of cycles—number of times the repeated load (stress) is applied to the test specimen.

pitch—black residue from the distillation of petroleum, used as a precursor for the production of carbon fibers; the other precursor for polymer fibers is polyacrylonitrile.

polyacrylonitrile (PAN)—polymeric precursor for the production of carbon fibers; the other precursor for carbon fibers is pitch.

precured FRP—fully cured FRP that is usually made in a factory and brought to the site as a rigid solid; if used as a repair material for concrete, a precured FRP should be bonded to the surface of the concrete with an adhesive.

precursor—rayon, polyacrylonitrile, or pitch fibers from which carbon fibers are derived.

prepreg FRP—reinforcement fabrics for FRP laminates that have been preimpregnated with a resin; usually this resin is cured to an intermediate stage (B-staged) and the resulting prepreg is stored at cold temperatures; the cure restarts once the prepreg is brought to room temperature.

relaxation—reduction of stress (or load) in a material under a constant state of strain (or deformation).

relaxation rate—absolute value of the slope of the relaxation curve at a given time. In particular, the relaxation value after 1 million hours is referred to as the million-hour relaxation rate.

repeated load (stress)—load (stress) alternating cyclically between fixed maximum and minimum values.

***S-N* curve**—graphical plot of the repeated load (stress) along a vertical axis versus the number of cycles to fatigue failure on the horizontal axis.

stress—load divided by the cross-sectional area of a lot of specimens. Refer to ASTM D7205/D7205M for the calculation of cross-sectional area.

tail length—length provided beyond the bend portion.

tensile capacity—maximum tensile load carried by test specimen before failure.

tensile strength—ultimate tensile strength of FRP bars in the direction parallel to the fibers.

test section—portion of a specimen between the anchoring sections of the test specimen.

thermoset—resin that is formed by cross-linking polymer chains. Note: A thermoset cannot be melted and reshaped because the polymer chains form a three-dimensional network.

ultimate strain—change in length per unit length corresponding to the tensile capacity.

1.5—Notation

A = cross-sectional area of FRP bar (according to ASTM D7205/D7205M), mm^2
a_1 = empirical constant
b_1 = empirical constant
C_b = equivalent circumference of FRP bar, mm
D = external diameter at deflector surface position, mm
d_b = equivalent diameter of reinforcing bar, mm
E_L = axial (longitudinal) modulus of elasticity of FRP bar, MPa
F = tensile load, N
F_{u1} = tensile capacity before immersion, N
F_{u2} = tensile capacity after immersion, N
F_{ub} = ultimate load capacity according to bend test of FRP bars, N
f_u = ultimate tensile strength parallel to the fibers (according to ASTM D7205/D7205M), MPa
f_{ub} = bend capacity of the FRP stirrup, MPa
ℓ = bonded or overlap length, mm
L_c = length from the top of the embedded bar to the point of attachment of the measuring device, mm
L_t = tail length of bend bar, mm
P = tensile failure load of specimen, N
R_{et} = tensile capacity retention rate, percent
r_t = radius of bend in FRP reinforcement, mm
S = reduced tensile strength of specimen corresponding to a specific corner radius, MPa
S_c = elastic elongation, mm
T = time, h
W_0 = initial mass of the specimen before immersion, g
W_1 = mass of the specimen after immersion for a period (Time 1), g
Y_r = relaxation rate, percent
α = bending angle, degrees
χ = strength reduction factor due to bend effect
$\Delta\varepsilon$ = strain increment
ΔP = tensile load increment, N
τ = bond or shear stress, MPa

PART 2—TEST METHODS FOR FRP BARS

B.1—Test method for cross-sectional properties of FRP bars

This test method has been replaced by ASTM D7205/D7205M, Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars.

B.2—Test method for longitudinal tensile properties of FRP bars

This test method has been replaced by ASTM D7205/D7205M, Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars.

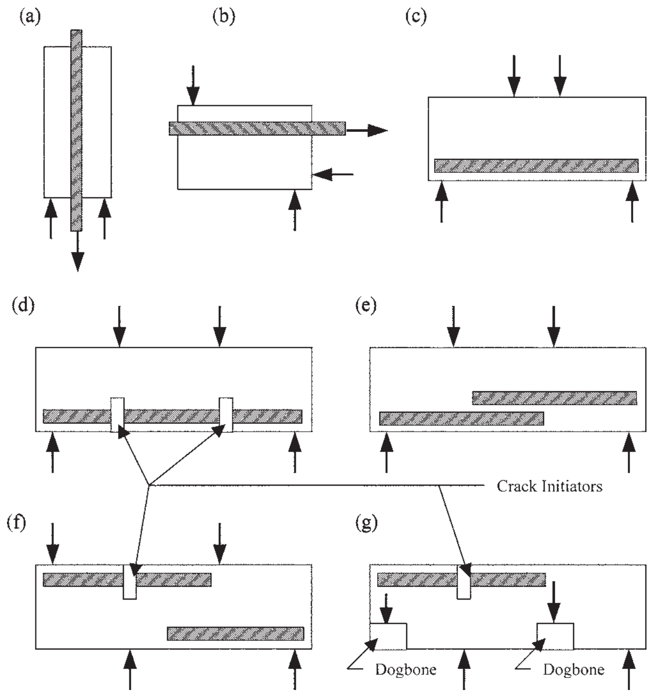


Fig. B.3.1a—Types of test methods for different bond values of FRP reinforcement in concrete: (a) pullout specimen; (b) beam-end specimen; (c) simple beam specimen; (d) hinged beam-end specimen; (e) splice specimen; (f) cantilever beam specimen (without dogbones); and (g) cantilever beam specimen (with dogbones).

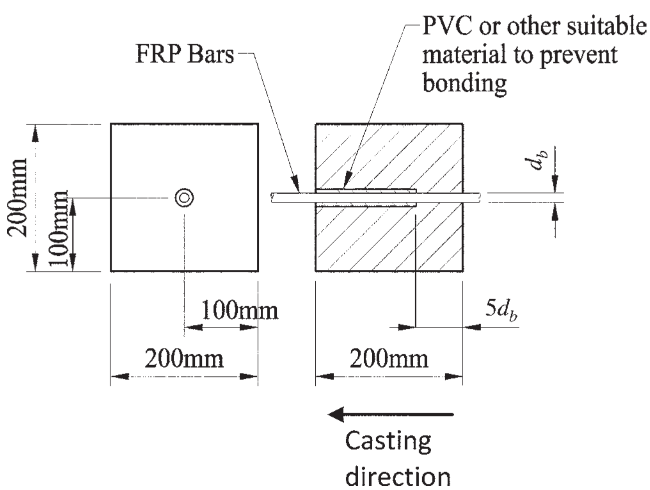


Fig. B.3.1b—Vertical bond test specimen.

B.3—Test method for bond strength of FRP bars by pullout testing

The following references are provided for historical and informational purposes only—Al-Zahrani et al. (1996); Benmokrane et al. (2002); Chaallal and Benmokrane (1993); and Freimanis et al. (1998).

B.3.1 *Scope*—This test method specifies the test requirements for determining the bond strength of FRP bars used as reinforcing bars or prestressing tendons in concrete by pullout testing. Various types of test methods are available for the determination of different bond values of FRP reinforcement in concrete structures, as shown schematically in Fig. B.3.1a. This test method describes the pullout test specimen to determine the bond strength.

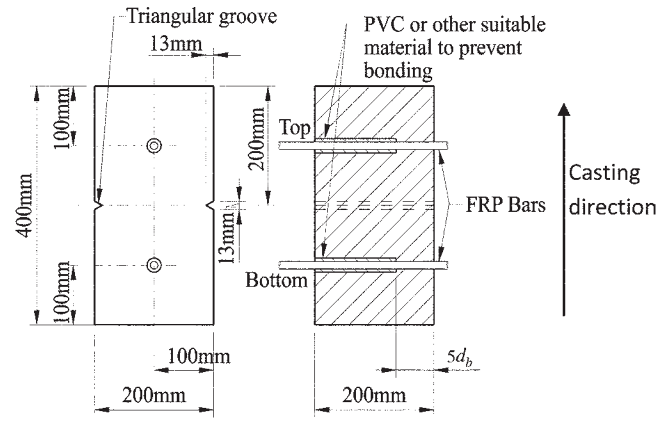


Fig. B.3.1c—Horizontal bond test.

Two methods for casting test specimens are provided. The first method aligns the bar with the concrete casting direction, similar to that of a longitudinal bar in a reinforced concrete column (Fig. B.3.1b). The second method aligns the bars transverse to the concrete casting direction, similar to that of the longitudinal bar in a reinforced concrete beam or slab (Fig. B.3.1c).

B.3.2 *Referenced documents*

ASTM A944-10—Standard Test Method for Comparing Bond Strength of Steel Reinforcing Bars to Concrete Using Beam End Specimens

ASTM C39/C39M-12—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C143/C143M-10—Standard Test Method for Slump of Hydraulic Cement Concrete

ASTM C192/C192M-07—Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

ASTM C293/C293M-10—Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center Point Loading)

ASTM C511-09—Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

ASTM C617/C617M-11 Standard Practice for Capping Cylindrical Concrete Specimens

ASTM D618-08—Standard Practice for Conditioning Plastics for Testing

ASTM D7205/D7205M-06(2001)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

B.3.3 *Significance and use*

B.3.3.1 This test method for measuring bond strength by pullout testing is intended for use in laboratory tests in which the principal variable is the size or type of FRP bars. The test method should not be used to establish design bond values and development lengths for FRP bars embedded in concrete.

B.3.3.2 This test method is intended to determine the bond behavior for material specifications, research and development, and quality assurance. The bond behavior will be specimen-configuration-dependent, which may affect both analysis and design. The primary test result is the bond strength of the specimen to normalweight concrete, which is an important factor to consider in the use of FRP bars as reinforcing bars or tendons.

B.3.3.3 This test method may also be used to determine the conformance of a product or a treatment to a requirement relating to its effect on the bond developed between FRP bar and concrete. The result obtained from this test method should be used only for comparative purposes to compare parameters or variables of bond strength. The method may be used to establish long-term environmental effects on bond to concrete, including environmental reduction factors for FRP bars embedded in concrete.

B.3.4 *Test equipment and requirements*

B.3.4.1 Use a testing machine with a loading capacity in excess of the tensile capacity of the test specimen and calibrated according to ASTM E4. A testing machine with either loading-rate or displacement-rate control is preferred. The load should be applied to the reinforcing bar at a rate no greater than 20 kN/minute or at the no-load speed of the testing machine head of not greater than 1.3 mm/minute, depending on the type of testing machine used and the means provided for ascertaining or controlling testing speed.

B.3.4.2 The loading plate (Fig. B.3.4.2) should be a machined steel plate at least 200 mm square and 20 mm thick, and have a hole drilled through its center of sufficient diameter to accommodate the FRP bar.

B.3.4.3 The loading end of the FRP bar should be fitted with an anchor capable of transmitting loads until the bar is pulled out of the concrete by a bond failure. The load transmission device should only transmit axial loads to the FRP bars, without applying either torsion or bending.

B.3.4.4 The displacement measuring devices fitted to both the free end and loaded end of the FRP bars should be displacement measuring devices (LVDTs) or similar apparatuses, reading accurately to 0.01 mm. Three LVDTs at 120-degree intervals at the loaded end and either one concentric gauge or two gauges at 180-degree intervals at the free end of the bar are recommended (Fig. B.3.4.4).

B.3.4.5 Two types of molds for bond test specimens are required:

1. For 200 mm concrete cubes, each containing a vertically embedded bar
2. For 200 x 200 x 400 mm prisms, each containing two horizontally embedded bars

Preferably, the molds should be made of metal no less than 6 mm thick. The molds should be watertight and constructed for easy removal without disturbing the embedded bars.

B.3.5 *Specimen preparation*

B.3.5.1 FRP bar specimens should be representative of the lot or batch being tested. Each specimen should be cut into 1200 mm long sections and assembled with an anchor (ASTM D7205/D7205M) at one end. The test specimens should contain either one FRP bar embedded parallel to the direction of casting of the concrete (Fig. B.3.1b), or two FRP bars embedded perpendicular to the direction of casting of the concrete (Fig. B.3.1c). Five specimens of each type should constitute a set of test specimens. If a specimen has failed or slipped at the anchoring section, or split the concrete cover, an additional test should be performed on a separate specimen taken from the same lot as the failed specimen.

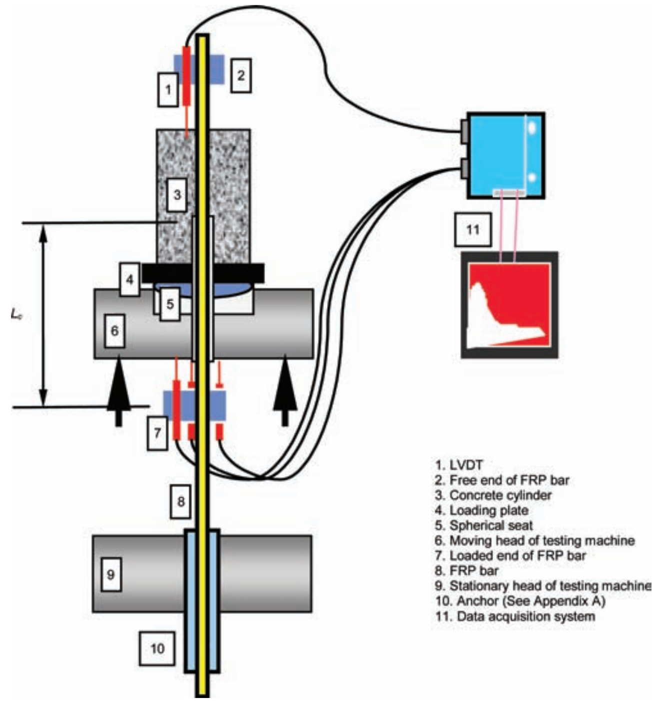


Fig. B.3.4.2—Schematic details of pullout bond test setup.

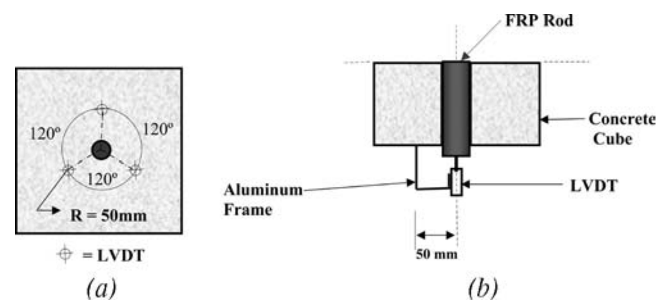


Fig. B.3.4.4—Positions of LVDTs at surface of concrete cube: (a) plan view of three LVDTs at loaded end; and (b) one LVDT at free end.

B.3.5.1.1 *Specimens for parallel embedded bar (Fig. B.3.1b)*—These specimens should consist of concrete cubes, 200 mm on each edge, with a single FRP bar embedded vertically along the central axis in each specimen. The bar should project upward from the top face a sufficient length to extend through the bearing blocks and the support of the testing machine, and provide an adequate length to be gripped for application of load. If splitting failure of concrete occurs consistently, a 300 mm cube is needed and new tests should be performed.

B.3.5.1.2 *Specimens for perpendicular embedded bar (*Fig. B.3.1c*)*—These specimens should consist of concrete prisms 200 x 200 x 400 mm, with the longer axis in the vertical direction. Two bars should be embedded in each specimen, perpendicular to the longer axis and parallel to and equidistant from the sides of the prism. In the vertical direction, one bar should be located with its axis 100 mm from the bottom of the prism and the other with its axis 300 mm from the bottom. The bar should project from the concrete face a sufficient length to extend through the bearing blocks and the support of the testing machine, and provide an adequate length to be gripped for application of load. A triangular groove should be formed on each of the two opposite sides of the prism parallel to the bars and at the midheight of the prism. These grooves should be at least 13 mm deep, measured perpendicular to the surface of the concrete. The grooves should facilitate breaking of the prism into two test specimens at the weakened plane before performing the bond tests.

The bonded length of the FRP bar should be five times the diameter of the FRP bar. If the bonded length, as defined previously, does not represent the bonding characteristics of the FRP bar, the bonded length may be extended as appropriate. Outside of the bonded section, the embedded bar should be sheathed with polyvinyl chloride (PVC) or other suitable material to prevent bonding. At the free end, bars should protrude from the concrete slightly so that the end of the LVDT(s) will bear on the bar (Fig. B.3.4.4).

B.3.5.2 Place the bars into the molds as follows:

a) The opening in the form through which the FRP bar is inserted should be sealed using oil, putty, or similar materials to prevent egress of water and other substances

b) The orientation of the specimen should not be changed until the form is removed

B.3.5.3 Before casting the test specimens, coat the inside surface of the molds with a thin film of mineral oil, petroleum jelly, or stearic acid paste. The following procedures are recommended for placement of concrete in the molds unless another well-established method is used.

a) For 200 x 200 x 400 mm prisms, place the concrete in four layers of approximately equal thickness and rod each layer 25 times with a 16 mm diameter tamping rod

b) For 200 mm cubes, place the concrete in four layers of approximately equal thickness and rod each layer 25 times with a 16 mm diameter tamping bar

c) After the top layer has been consolidated, strike off the surface with a trowel and protect against moisture evaporation by one of the acceptable methods described in 7.1 of ASTM C192/C192M. Care should be taken that evaporation does not take place in the area adjacent to the protruding FRP bar for vertically cast specimens

B.3.5.4 The concrete should be a standard mixture, with coarse aggregates having a maximum dimension of 20 to 25 mm. It should be batched and mixed in accordance with the applicable portions of ASTM C192/C192M. The concrete should have slump of 100 ± 20 mm in accordance with ASTM C143/C143M, and the compressive strength at 28 days should be 30 ± 3 MPa in accordance with ASTM C39/C39M. A minimum of five standard 150 x 300 mm or 100 x 200 mm control cylinders should be made for determining compressive strength from each batch of concrete.

B.3.5.5 Molds should not be removed from the specimens earlier than 20 hours after casting. Extreme care should be taken to prevent striking or otherwise disturbing the FRP bars. Immediately after removing the molds, specimens should be cured in accordance with ASTM C192/C192M until the time of testing. Specimens should be tested at an age of 28 days.

B.3.5.6 When the specimens are between 7 and 14 days old, the 200 x 200 x 400 mm prisms should be broken in half in flexure to form two 200 mm cubes. Specimens should be broken as simple beams with center-point loading in accordance with ASTM C293/C293M. The two triangular grooves in the upper and lower faces of the prisms should be located at midspan. The load should be applied to a 19 mm diameter bar laid in the upper groove until fracture occurs. Care should be taken not to strike or otherwise disturb the FRP bars during the operation.

B.3.5.7 The surface of the 200 mm cube containing the vertically embedded bar should be capped so as to use it as the bearing surface in the pullout test. The applicable portions of ASTM C617, relative to capping materials and procedures, should be followed.

B.3.6 *Conditioning*—Unless a different testing environment is specified, the pullout tests should be conducted at the standard laboratory atmosphere 23 ± 3°C and 50 ± 10 percent relative humidity.

Preconditioning of FRP bar specimens before casting in concrete, such as post-production machining, abrading, or other such processing, is permitted but should be reported.

B.3.7 *Test method*

B.3.7.1 The specimen should be mounted in the testing machine in one of the following two test setups.

B.3.7.1.1 The capped or bearing surface of the cube from which the long end of the bar projects should be in contact with the bearing block (or plaster pad) assembly. The spherically seated bearing block should rest on a support that transfers the reaction from this block to the load cell of the testing machine. The projecting FRP bar should extend through the bearing block assembly and the support, and the anchor should be gripped for tension by the jaws of the testing machine (Fig. B.5.7.1). The free end of the bar may also be potted in an anchor as described in ASTM D7205/D7205M.

B.3.7.1.2 The concrete cube should be fixed on the stationary head of the testing machine. LVDTs at the loaded end and free end are attached to measure the slip of the FRP bar, as shown in Fig. B.3.4.4. The anchor is then threaded into or gripped by the connection on the moving head of the testing machine.

B.3.7.2 Assemble the testing apparatus on the specimen. Carefully measure and record, to the nearest 0.5 mm, the distance between the top surface of the bonded length and the point of attachment of the measuring device on the FRP bar. The elongation of the FRP bar over this distance may be calculated and subtracted from the measured slip plus elongation to obtain the loaded-end slip. Moreover, free-end slip shall be measured to the nearest 0.5 mm.

B.3.7.3 Apply load to the FRP bar at a load rate no greater than 20 kN/minute, or at a testing machine head speed not greater than 1.3 mm/minute.

B.3.7.4 Read and record the applied load and the LVDT readings at a sufficient number of intervals throughout the test to provide at least 15 readings by the time a slip of 0.25 mm has occurred at the loaded end of the FRP bar. The slippage of the free end should be recorded in increments of 0.01 mm, together with the corresponding applied load.

B.3.7.5 Continue the loading and readings at appropriate intervals until rupture of the FRP bar occurs or slippage of at least 2.5 mm occurs at the loaded end of the embedded length.

B.3.7.6 For cases where a specimen is judged to have undergone a tensile failure at an anchoring section, to have slipped out of an anchoring section before the FRP bar has slipped from the concrete, or where the load is significantly reduced due to splitting or cracking of the concrete, the data should be disregarded and additional tests should be performed until the number of valid tests is not less than five.

B.3.8 *Calculations*

B.3.8.1 The average bond stress should be calculated according to Eq. (B.3.8.1) and reported with a precision to three significant digits, and the data for the pullout or bond stress versus slippage at both free-end and loaded-end displacement for each specimen should be plotted.

$$\tau = \frac{F}{C_b \ell} \tag{B.3.8.1}$$

where C_b is π times the effective bar diameter from ASTM D7205/D7205M.

B.3.8.2 Average bond stresses causing slippage at the free end and the loaded end of 0.05 mm, 0.10 mm, and 0.25 mm, and the maximum bond stress (the bond strength) at failure, should be calculated.

B.3.8.3 At each load level, the slip at the loaded end should be calculated as the average of the readings of the LVDTs, minus the elongation S_c of the FRP bar in the length L_c between the top surface of bonded length and the point of attachment of the measuring devices on the FRP bar, the latter being calculated using Eq. (B.3.8.3)

$$S_c = \frac{FL_c}{E_L A} \tag{B.3.8.3}$$

B.3.9 *Test report*—The test report should include the following items.

B.3.9.1 *Properties of concrete*—The following concrete properties should be included in the test report.

a) The mixture proportions of cement, fine aggregate, coarse aggregate, admixture (if used), and the *w*/*c*

b) Slump of freshly mixed concrete as determined in accordance with ASTM C143/C143M

c) Twenty-eight-day strength of control cylinders as determined in accordance with ASTM C39/C39M

d) Any deviation from the stipulated standards in such aspects as mixing, curing, dates of demolding, and testing of control cylinders

B.3.9.2 *Properties of FRP bar*—The following FRP bar properties should be included in the test report.

a) The trade name, shape, and date of manufacture (if available), and lot number of product tested

b) Type of fiber and fiber binding material (as reported by the manufacturer), fiber volume fraction, surface treatment, and preconditioning of FRP bar

c) Designation, equivalent diameter, and cross-sectional area, as determined according to ASTM D7205/D7205M

d) Modulus of elasticity and ultimate tensile strength, as determined in accordance with ASTM D7205/D7205M

e) A close-up photograph of the bars showing surface deformations and characteristics

B.3.9.3 *Additional items*—The following additional items should be included in the test report.

a) Numbers or identification marks on test specimens

b) Date of test, test temperature, and loading rate

c) Dimensions of test specimens and bonded length of FRP bar

d) A brief description of the gripping device

e) Average bond stress causing slippage at the free end of 0.05, 0.10, and 0.25 mm for each specimen

f) Average bond stress causing slippage at the loaded end of 0.05, 0.10, and 0.25 mm for each test specimen

g) Maximum bond stress, failure mode, and averages for each test specimen

h) Bond stress-slippage displacement (free-end and loaded-end) plots for each test specimen

B.4—Test method for transverse shear strength of FRP bars

This test method has been replaced by ASTM D7617/D7617M, Standard Test Method for Transverse Shear Strength of Fiber Reinforced Polymer Matrix Composite Bars.

B.5—Test method for strength of FRP bent bars and stirrups in bend locations

The following reference is provided for historical and informational purposes only—Morphy et al. (1997).

B.5.1 *Scope*—This test method specifies test requirements for the strength of FRP bent bars used as an anchorage for stirrups in concrete structures.

B.5.2 *Referenced documents*

ASTM International

ASTM C39/C39M-12—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C143/C143M-10—Standard Test Method for Slump of Hydraulic Cement Concrete

ASTM C192/C192M-07—Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

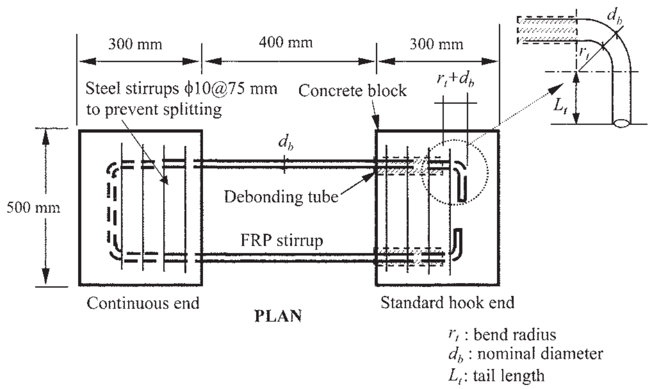


Fig. B.5.5.1—Configuration of specimen.

ASTM D7205/D7205M-06(2001)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

B.5.3 *Significance and use*

B.5.3.1 This test method is intended for use in laboratory tests to determine the strength of the bent portion provided as an anchorage in which the principal variable is the size, bend radius, or type of FRP stirrup.

B.5.3.2 Bending of FRP stirrups to develop anchorage leads to a significant reduction in the strength of the stirrups. The bend radius and tail length beyond the bend are important factors affecting the bend capacity.

B.5.3.3 This test method measures the ultimate load capacity of a single FRP stirrup subjected to tensile forces in the direction of the straight portion.

B.5.3.4 This test method is intended to determine the bend capacity and strength reduction for material specifications, research and development, quality assurance, and structural design and analysis. The behavior of bent bars and stirrups should be measured according to the method given herein, in keeping with the intended purposes.

B.5.4 *Test equipment and requirements*—The hydraulic cylinder and load cell should be calibrated according to ASTM E4, have a loading capacity in excess of the capacity of the specimen, and be capable of applying load at the required loading rate. The load cell should also be capable of giving readings accurate to within 1 percent throughout the test.

B.5.5 *Specimen preparation*

B.5.5.1 The configuration of a typical specimen is shown in Fig. B.5.5.1. The dimensions of each concrete block used to anchor the FRP stirrup may be varied according to the dimensions of the stirrup used. The free length of the stirrup between the two blocks, however, should not be less than 200 mm, with 400 mm suggested. The concrete block should be reinforced using steel stirrups, as shown in Fig. B.5.5.1, to prevent splitting of the concrete block before rupture of the FRP stirrup in the bend. The tail length L_t of the FRP stirrup tested to evaluate the bend capacity should not exceed 150 mm. The debonding tube is used to eliminate the straight-bar development of the hooked bar. The debonding tube should slip over the reinforcing bar, and the ends of the debonding tube should be filled with caulk to prevent the tubes from filling with concrete during casting.

B.5.5.2 The concrete should be a standard mixture, with coarse aggregates having a maximum dimension of 20 to 25 mm. It should be batched and mixed in accordance with the applicable portions of ASTM C192/C192M. The concrete should have slump of 100 ± 20 mm in accordance with ASTM C143/C143M, and the compressive strength at 28 days should be 30 ± 3 MPa in accordance with ASTM C39/C39M. A minimum of five standard 150 x 300 mm or 100 x 200 mm control cylinders should be made for determining compressive strength from each batch of concrete.

B.5.5.3 The number of valid test results for each test condition should not be less than five. If a specimen fails by splitting of the concrete block, the test result should be disregarded and an additional test should be performed on a separate specimen taken from the same lot as the failed specimen.

B.5.5.4 If test specimens fail due to pullout of the bent bar from the concrete, this is an indication that the bend radius and tail length are inadequate for the bar being tested. It is necessary to adjust these parameters (perhaps the size of the test blocks as well) and retest.

B.5.6 *Conditioning*—Unless a different testing environment is specified as part of the experiment, the tests should be conducted at the standard laboratory atmosphere: 23 ± 3°C and 50 ± 10 percent relative humidity.

Preconditioning of FRP bars before casting in concrete is permissible but must be reported.

B.5.7 *Test method*

B.5.7.1 The test setup, shown in Fig. B.5.7.1, consists of a hydraulic jack to apply the relative displacement between the two concrete blocks and a load cell to measure the applied load. Place the steel plates and plaster bags in front of the load cell and the hydraulic jack to distribute the applied load to the surface of the concrete. A spherical washer can also be used at the end of the ram. The block containing the test section of the bar should be placed on top of steel rollers to minimize the friction forces between the block and testing bed.

B.5.7.2 Tensile strength of straight FRP bars with the same diameter as the FRP stirrups should be evaluated according to ASTM D7205/D7205M.

B.5.7.3 The test specimens should not be subjected to any shock, vibration, or torsion during the test. Increase the force in the jack in a smooth, continuous manner until the specimen fails. Do not pause the application of load during the test. The loading rate should be selected so that the specimen fails between 1 and 10 minutes from the start of the test.

B.5.7.4 Record the failure load and failure mode for the specimen.

B.5.8 *Calculations*

B.5.8.1 The bend capacity of the FRP stirrup should only be assessed on the basis of the specimen undergoing failure in the bend. In cases where block splitting has clearly taken place, the data should be disregarded, and additional tests should be performed until the number of the test specimens failing in the bend is not less than five.

B.5.8.2 The bend capacity of the FRP stirrup should be calculated according to Eq. (B.5.8.2), and rounded to three significant digits

$$f_{ub} = \frac{F_{ub}}{2A} \tag{B.5.8.2}$$

B.5.8.3 The strength-reduction factor is calculated according to Eq. (B.5.8.3)

$$\chi = \frac{f_{ub}}{f_u} \tag{B.5.8.3}$$

B.5.9 Test *report*—The test report should include the following items.

B.5.9.1 *Properties of concrete*—The following concrete properties should be included in the test report:

a) The mixture proportions of cement, fine aggregate, coarse aggregate, admixture (if any used), and *w*/*c*

b) Slump of freshly mixed concrete as determined in accordance with ASTM C143/C143M

c) Twenty-eight-day strength of control cylinders as determined in accordance with ASTM C39/C39M

d) Any deviation from the stipulated standards in such aspects as mixing, curing, dates of demolding, and testing of control cylinders

B.5.9.2 *Additional items*—The following additional items should be included in the test report.

a) Trade name, shape, and date of manufacture (if available), and lot number of FRP bar tested for stirrups

b) Type of fiber and matrix used in the FRP stirrup, and fiber volume fraction

c) Process used to fabricate the stirrups, as reported by the manufacturer

d) Numbers or identification marks on test stirrups

e) Designation, diameter, and cross-sectional area

f) Dimensions of concrete block, configuration (diameter and space) of steel stirrup confinement, debonded length, bend radius, and tail length of the bent bar.

g) Preconditioning of FRP bars before casting

h) Date of test and test temperature

i) Type and capacity of load cell

j) Bend capacity and strength reduction factor for each test stirrup

k) Average bend capacity and strength reduction factor for all specimens that failed in the bend as intended

B.6—Accelerated test method for alkali resistance of FRP bars

The following references are provided for historical and informational purposes only—Benmokrane et al. (2001, 2002); Gangarao and Vijay (1997); Gentry (2001); Mehus (1995); Nkurunziza et al. (2002); and Porter et al. (1995, 1996).

B.6.1 *Scope*—This test method specifies the test requirements for evaluating alkali resistance of FRP bars used as reinforcing bars in concrete and masonry by immersion in aqueous alkaline solution. Alkali resistance is measured by subjecting the FRP bars to an alkali environment, with or without stress, and then testing them in tension according to ASTM D7205/D7205M.

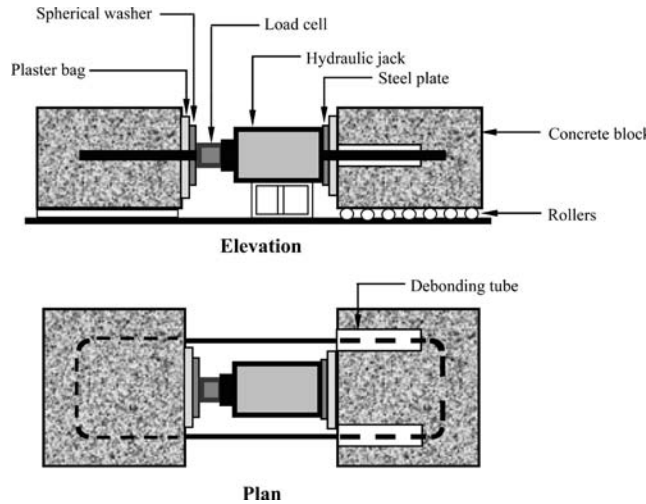


Fig. B.5.7.1—Test setup.

This test method presents three procedures conducted at a temperature of 60°C, each defining different loading conditions.

a) *Procedure A*—A system in which FRP specimens are immersed in the alkaline solution with no tensile load applied. The test control parameters are the pH value and temperature of the alkaline solution and immersion time.

b) *Procedure B*—A system in which FRP specimens are immersed in the alkaline solution under sustained tensile load. The test parameters are the sustained load level, the pH value, and temperature of the alkaline solution and immersion time.

c) *Procedure C*—A system in which FRP specimens, surrounded by moist concrete, are subjected to a sustained tensile load. The test parameters are the sustained load level, the pH value, and temperature of concrete and embedded time.

B.6.2 *Referenced documents*

ASTM International

ASTM C192/C192M-07—Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

ASTM C511-09—Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concrete

ASTM D618-08—Standard Practice for Conditioning Plastics for Testing

ASTM D5229/D5229M-92(2010)—Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

ASTM D7205/D7205M-06(2011)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

B.6.3 *Significance and use*

B.6.3.1 This test method for investigating the alkali resistance of FRP bars is intended for use in laboratory tests

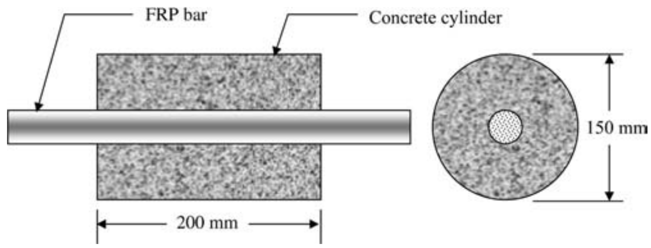


Fig. B.6.6.3—Dimensions of concrete cylinder.

in which the principal variables are the temperature and concentration of alkaline solution, the type of FRP bars, and the sustained load level.

B.6.3.2 This test method measures the mass change and tensile capacity after immersion of FRP bars in alkaline solution without stressing (Procedure A), and the tensile capacity after immersion of FRP bars in an alkaline solution and embedment of FRP bars in moist concrete under sustained load condition (Procedures B and C).

B.6.3.3 This test method is intended to determine the alkaline-resistant data for material specifications, research and development, quality assurance, and structural design and analysis. The alkaline resistance should be measured according to the method given herein. The primary test result is the mass change and tensile capacity retention of the test specimen, which are important factors to consider in the use of FRP bars.

B.6.3.4 The level of sustained loading for Procedures B and C is not specified as part of the test method. Typically, the stress in the sustained load tests should be equal to the stress caused by the dead loads, and any part of the live loads that is sustained. If service load conditions are not known, the sustained tensile stress in glass FRP bars should be set to induce a tensile strain equal to 2000 microstrain. Higher levels of sustained stress can be used as an accelerating condition. The level of sustained stress should be reported.

B.6.4 *Test equipment and requirements*—An analytical balance capable of the appropriate accuracy in accordance with Procedure A of ASTM D618 should be used. The testing machine and devices should conform to ASTM E4.

B.6.5 *Specimen preparation*

B.6.5.1 FRP bar specimens should be representative of the lot or batch being tested. In general, test specimens should not be subjected to any processing beyond manufacturing. For grid-type FRP bars, linear test specimens may be prepared by cutting away extraneous material in such a way as not to affect the performance of the tested part.

B.6.5.2 During the sampling and preparation of test specimens, all deformation, heating, outdoor exposure to ultraviolet light, and other conditions possibly causing changes to material properties of the specimen should be avoided.

B.6.5.3 The length of the specimen should be the sum of the length of the test section and the lengths of the anchoring sections. The length of the test section should not be less than 40 times the diameter of the FRP bar. For FRP bar in twisted strand form, the length of the test section should also be greater than two times the strand pitch.

B.6.5.4 The number of test specimens for pre- and post-immersion testing should not be less than five. Each specimen should be clearly labeled with identifying markings.

B.6.5.5 Coat the ends of bars and the ends and transverse elements of grids with epoxy resin to prevent the infiltration of solution via these cuts. Allow resin to cure completely before immersion.

B.6.5.6 The alkaline solution in Procedures A and B should be a composition representative of the pore water inside portland-cement concrete. The suggested composition of alkaline solution consists of 118.5 g of $Ca(OH)_2$, 0.9 g of NaOH, and 4.2 g of KOH in 1 L of deionized water. The solution should have a pH value of 12.6 to 13—a representative pH value of mature concrete pore solution. The alkaline solution should be covered before and during testing to prevent interaction with atmospheric CO_2 and to prevent evaporation.

B.6.6 *Conditioning*

B.6.6.1 Samples for Procedure A should be immersed in the alkaline solution at 60 ± 3°C for exposure times of 1, 2, 3, 4, and 6 months, unless longer exposure periods are specified. After the allotted times, the samples should be removed from the alkaline solution, thoroughly washed in deionized water, towel dried, weighed, and tested in tension to failure.

B.6.6.2 Samples for Procedure B should be installed in anchoring devices at both ends in accordance with ASTM D7205/D7205M. The test section of the specimen should be immersed in the alkaline solution inside an environmental cabinet or container holding the alkaline solutions and having a constant temperature of 60 ± 3°C. The specimen should be held in a loading fixture to subject to a constant tensile sustained load for exposure times of 1, 2, 3, 4, and 6 months, unless longer exposure periods are specified.

B.6.6.3 Samples for Procedure C should be prepared by embedding the test section of the specimens in moist concrete. Typical dimensions of the concrete cylinder are shown in Fig. B.6.6.3. The 150 mm dimension of the specimens may be increased if larger-diameter bars are used. The concrete should be a standard mixture, specified in Test Method B.3. The concrete mixture should be batched and mixed in accordance with the applicable portions of ASTM C192/C192M, and the curing procedure should conform to ASTM C511. After 28 days of curing in water, the samples should have installed anchors at both their ends in accordance with ASTM D7205/D7205M, and then positioned in the conditioning fixture for subjecting to a sustained tensile load for exposure times of 1, 2, 3, 4, and 6 months, unless longer exposure periods are specified. The concrete cylinder should be kept moist and inside an environmental cabinet having a constant temperature of 60 ± 3°C during the testing. The FRP specimens should be tested with the concrete cylinder still attached.

B.6.7 *Test method*

B.6.7.1 The pH value of the alkaline solution should be measured at the beginning of the test and after the alkali-resistance test. During immersion of the test specimens, the pH value of the alkaline solution should be monitored at least every 5 days and adjusted, if necessary, to keep the same constituents and pH value as the beginning of the test.

B.6.7.2 The external appearance of the specimen should be examined before and after the alkali resistance test for comparison of color, surface condition, and change of shape. If necessary, the specimen may be sectioned and polished, and the condition of the cross section examined under a microscope.

B.6.7.3 *Mass change testing of specimens for Procedure A*—Before immersion, the specimen should be dried until its mass is unchanged, according to Procedure D of ASTM D5229/D5229M, which is the initial mass W_0. After immersion for the prescribed period of time, the specimen should be removed from the alkaline solution, quickly washed with deionized water, dried with tissue paper, and then immediately weighed, which is the mass at Time 1, denoted as W_1. Then the specimen should have anchors installed at both ends for tensile capacity retention testing.

B.6.7.4 *Tensile capacity retention testing of specimens for Procedures A, B, and C*—Specimens should be tested in tension to failure within 24 hours after removal from the conditioning environment at the prescribed exposure length of time. The tensile test method should follow ASTM D7205/D7205M.

B.6.8 *Calculations*

B.6.8.1 The mass change of FRP bars should be calculated according to Eq. (B.6.8.1a) and (B.6.8.1b).

$$\text{mass gain (\%)} = \frac{W_1 - W_0}{W_0} \times 100 \qquad \text{(B.6.8.1a)}$$

$$\text{mass loss (\%)} = \frac{W_0 - W_1}{W_0} \times 100 \qquad \text{(B.6.8.1b)}$$

B.6.8.2 The material properties of FRP bars should be assessed only for those test specimens undergoing failure in the test section. In cases when tensile failure or slippage has occurred at an anchoring section, the data should be disregarded and additional tests performed from the same conditioning lot as the failed specimen. The tensile capacity retention should be calculated according to Eq. (B.6.8.2), with a precision to two significant digits.

$$R_{et} = \frac{F_{u2}}{F_{u1}} \times 100 \qquad \text{(B.6.8.2)}$$

B.6.9 *Test report*—The test report should include the following items.

B.6.9.1 *Common items*—The test report should include the following common items:

a) The trade name, shape, and date of manufacture (if available), and lot number of product tested

b) Type of fiber and fiber binding material, as reported by the manufacturer, and fiber volume fraction

c) Numbers or identification marks on test specimens

d) Designation, diameter, and cross-sectional area

e) Date of start and end of immersion

B.6.9.2 *Items related to alkaline solution immersion*—The test report should include the following items related to alkaline solution immersion:

a) Composition of alkaline solution, pH, temperature, immersion period, and time

b) Sustained load level, time, and procedure of solution monitoring and adjusting

c) Record of observation of external appearance and mass change

d) Specimen mass at each time interval

e) Plots of percent mass change versus time, calculated by Eq. (B.6.8.1a) or (B.6.8.1b)

B.6.9.3 *Items related to tensile testing*—The test report should include the following items related to tensile testing:

a) Test temperature and loading

b) Tensile capacities for immersed and nonimmersed test specimens at the 1-, 2-, 3-, 4-, and 6-month intervals, with averages and standard deviations of tensile capacities and tensile strength

c) Modulus of elasticity and the average for all immersed and nonimmersed test specimens, respectively

d) Ultimate strain for all immersed and nonimmersed test specimens and average ultimate strain

e) Tensile capacity retention

f) Stress-strain curves for all immersed and nonimmersed test specimens

g) Plot of tensile capacity retention versus time of exposure

B.7—Test method for tensile fatigue of FRP bars

The following references are provided for historical and informational purposes only—Adimi et al. (1998); Odagiri et al. (1997); and Rahman and Kingsley (1996).

B.7.1 *Scope*—This test method specifies the test requirements for tensile fatigue under a constant tensile load range for FRP bars used as reinforcing bars or prestressing tendons in concrete and masonry.

The specimens should be linear or grid FRP formed from continuous fibers in such a manner as to act mechanically as a monolithic body.

Various types of fatigue testing, such as tension-tension; tension-compression; compression-compression; and various combinations of tension, compression, and shear are possible. The tension-tension test method given herein is considered to be the most basic for evaluating material characteristics. The test control parameter is the load, and the loading machine is controlled so that the specimen is subjected to repetitive constant load range. In this procedure, the test control parameter may be described using either stress or applied load as a constant amplitude fatigue variable.

B.7.2 *Referenced documents*

ASTM International

ASTM D618-08—Standard Practice for Conditioning Plastics for Testing

ASTM D3039/D3039M-08—Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

ASTM D3479/D3479M-96(2007)—Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials

ASTM D7205/D7205M-06(2011)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

ASTM E739-10—Standard Practice for Statistical Analysis of Linear or Linearized Stress Life (S-N) and Strain-Life (ε-N) Fatigue Data

B.7.3 *Significance and use*

B.7.3.1 This test method is intended for use in laboratory tests in which the principal variable is the maximum value of the repeated load.

B.7.3.2 This test method is intended to develop the tensile fatigue data for material specifications, research and development, quality assurance, and structural design and analysis. The primary test result is the fatigue life of the specimen under a specific loading and environmental condition. Guidance in statistical analysis of fatigue life data, such as determination of linear or linearized stress life (*S-N*), can be found in ASTM E739.

B.7.3.3 Fatigue properties of reinforced or prestressed concrete and masonry structures are important factors to consider in design. For FRP bars used as reinforcing bars or tendons, the fatigue behavior should be measured according to the method given herein, in keeping with the intended purposes. Factors that can affect the fatigue lifetime of an FRP bar include the maximum load, the load ratio (minimum load divided by maximum load), the wave shape (sinusoidal, triangular, square, and so on), the rate of loading (Hz), the environment (such as moisture and temperature), and the method of material conditioning and specimen preparation. These factors should be reported.

B.7.3.4 This test method determines the number of repeated loading cycles required to fail an FRP bar. Such data can be used to create *S-N* curves for a particular set of testing conditions where the principal variable is the maximum value of the repeated load. Because FRP bars often have slight variations in cross-sectional area from one axial position to another, the area of a particular lot of bars is used to compute the stress in those specimens.

B.7.3.5 This test method can be used in the study of fatigue damage in an FRP bar, such as the occurrence of microscopic cracks, fiber fractures, or delaminations. The specimen's residual strength, stiffness, or both, may change due to these damage mechanisms. The loss in strength associated with fatigue damage may be determined by discontinuing cyclic loading to obtain the quasi-static tensile strength using ASTM D7205/D7205M. The loss in stiffness may be quantified by discontinuing cyclic loading at selected cycle intervals to obtain the quasi-static axial tensile stress-strain using modulus determination described in ASTM D7205/D7205M.

B.7.4 *Test equipment and requirements*

B.7.4.1 The testing machine should generally conform to ASTM E4 and be capable of maintaining constant load amplitude, maximum and minimum repeated load, and frequency. The testing machine should be fitted with a counter capable of recording the number of cycles to failure of the specimen. The load indicator should be capable of measuring loads with an accuracy of not less than 1 percent of the load range.

B.7.4.2 Anchorages should be in accordance with ASTM D7205/D7205M. Ideally, the same type of anchorage should be used for all specimens in a given series of tests.

B.7.4.3 If strain measurements are required as the result of the fatigue tests, an extensometer capable of maintaining an accuracy of ±1 percent of the indicated value should be used. The extensometer should allow a gauge length that includes an integer number of characteristic lengths of the specimen. The integer should be at least two, but possibly greater than two to obtain a gauge length of at least 50 mm.

B.7.5 *Specimen preparation*

B.7.5.1 Specimens should be representative of the lot or batch being tested. During the sampling and preparation of test specimens, all deformation, heating, outdoor exposure to ultraviolet light, and other conditions possibly causing changes to the material properties of the specimen should be avoided.

B.7.5.2 The specimen should be prepared and handled in accordance with ASTM D7205/D7205M.

B.7.5.3 There should be a minimum of five test specimens for each load (stress) level. At least five loading levels should be used to construct a plot of stress versus load cycles to failure. If a specimen fails at or slips out of an anchoring section, an additional test should be performed on a separate specimen taken from the same lot as the failed specimen.

B.7.5.4 The total length of the specimen should be 40 bar diameters plus the total gripped length of bar. The bar diameter is found by referring to ASTM D7205/D7205M.

B.7.6 *Conditioning*

B.7.6.1 *Standard conditioning procedure*—Condition specimens in accordance with Procedure A of ASTM D618. Store and test at the standard laboratory atmosphere—23 ± 3°C and 50 ± 10 percent relative humidity—unless a different environment, such as temperature or alkaline solution, is specified as part of the experiment.

B.7.6.2 *Alternate preconditioning procedure*—If another preconditioning procedure is used, the sequence of that preconditioning during specimen preparation can be important. Report if the specimen was preconditioned before or after anchors were applied.

B.7.7 *Test method*

B.7.7.1 The mounting of test specimens should be in accordance with ASTM D7205/D7205M.

B.7.7.2 For purposes of determining an *S-N* curve, the maximum and minimum loads may be set by one of the following methods:

a) Fix the average load and vary the load amplitude

b) Fix the minimum load and vary the maximum load

c) Fix the load ratio and vary the maximum and minimum load according to this fixed ratio

The method adopted should be determined according to the purpose of the test. In any case, a minimum of five load (stress) levels should be chosen such that the range of the number of cycles to failure is between 1000 and 2×10^6. Typical *S-N* curves for FRP materials are generated using Method C and use a fixed load (stress) ratio *R* of 0.1.

B.7.7.3 The following procedure may be used where the maximum stress level for the initial test is difficult to determine:

a) Select an appropriate maximum stress in the range of 20 to 60 percent of the quasi-static tensile strength, and commence fatigue testing with this value as the repeated maximum load.

b) If the specimen does not fail after 10^4 cycles at this repeated maximum stress, add 5 percent of the quasi-static tensile strength and perform the test uninterrupted using the same specimen.

c) If failure does not occur after 10^4 cycles following Step b, a further 5 percent should be added to the repeated maximum load.

d) Repeat Step c until the specimen fails.

e) The initial maximum stress applied to an untested specimen can be set at the previously found maximum load minus 5 percent of the quasi-static tensile strength.

For tendons for prestressing applications, the stress levels of interest can be in the range of 50 to 75 percent of the quasi-static tensile strength. For bars for reinforced concrete, however, the stress levels of interest may be 15 to 30 percent of the quasi-static tensile strength.

B.7.7.4 The loading frequency should be within the range of 1 to 10 Hz, preferably 4 Hz. The temperature of the bar can increase due to internal damping. Such temperature changes can affect the fatigue performance of the bar. Thus, if temperature changes are likely to occur or if any doubts about temperature exist, temperature should be monitored with a suitable device or indicator, such as a contact thermocouple or infrared thermocouple. The temperature should be monitored for newly developed FRP materials and in any case where the loading frequency exceeds 4 Hz. If measured, temperature changes should be reported. The waveform of the load signal (sinusoidal, triangular, and square) should be held constant in any series of fatigue tests that are to be compared to each other in an *S-N* curve, unless the purpose of the tests is specifically to evaluate the effects of waveform.

B.7.7.5 Static load should be applied up to the average load, after which repeated loading should begin at the prescribed frequency. The prescribed load should be introduced as rapidly as possible without dynamic effects. The maximum and minimum repeated loads should not change for the duration of the test. Counting the number of cycles should normally commence when the load on the specimen has reached the prescribed maximum load.

B.7.7.6 Complete separation (breaking) of the specimen should be deemed to constitute failure. The number of cycles to failure should be recorded. If the specimen does not fail after 2×10^6 cycles, the test may be discontinued. A specimen that does not fail should not be reused.

B.7.7.7 Tests for each specimen should normally be conducted without interruption from the start of the test to the end of the test. When a test is interrupted, the number of cycles up to the time of interruption and the period of the interruption should be recorded.

B.7.8 *Calculations*

B.7.8.1 Five valid test specimens are required at each load level. A valid specimen is one that does not fail in the anchor, fails in the gauge length at a cycle count of between 1000 and 2×10^6 cycles, or does not fail after 2×10^6 cycles.

B.7.8.2 If an *S-N* curve is desired, the curve should be plotted in accordance with ASTM E739, with maximum repeated stress, stress range, or stress amplitude represented on a linear scale on the vertical axis, and the number of cycles to failure represented on a logarithmic scale on the horizontal axis. Where measurement points coincide, the number of coinciding points should be noted. Right-facing arrows should be added to indicate points from test results for test specimens that do not fail.

B.7.8.3 If a fatigue strength is desired, the fatigue strength at 2×10^6 cycles should be derived by interpolation on an *S-N* curve obtained by one of the three load selection methods (A, B, C). The fatigue strength should be reported with a precision of three significant digits.

B.7.9 *Test report*—The test report should include the following items:

a) The trade name, shape, and date of manufacture (if available), and lot number of product tested

b) Type of fiber and fiber binding material as reported by the manufacturer, and fiber volume content

c) Numbers or identification marks on test specimens

d) Designation, diameter, and cross-sectional area for the lot from which the specimens are taken

e) Length of specimens (total and between anchors)

f) Description of preconditioning applied to specimens, including the sequence of preconditioning during specimen preparation

g) Date of test, test temperature and humidity (from start to end of test), and type of testing machine

h) Description of anchorage

i) Description of extensometer(s) and extensometer gauge length

j) Method of selecting maximum and minimum loads for a series of tests to construct an *S-N* curve (Method A, B, or C)

k) Maximum load (stress), minimum load (stress), load (stress) range, number of cycles to failure, loading waveform, and frequency for each test specimen

l) Record of observed failure mode for each test specimen

m) *S-N* curve, if obtained in a series of tests

n) Fatigue strength at 2×10^6 cycles, if obtained from an *S-N* curve

B.8—Test method for creep rupture of FRP bars

This test method has been replaced by ASTM D7337/D7337M.

B.9—Test method for long-term relaxation of FRP bars

The following reference is provided for historical and informational purposes only—Odagiri et al. (1997).

B.9.1 *Scope*—This test method specifies the test requirements for evaluating the long-term relaxation behavior of FRP bars used as prestressing tendons in concrete and masonry under a given constant temperature and strain.

B.9.2 *Referenced documents*

ASTM International

ASTM D618-08—Standard Practice for Conditioning Plastics for Testing

ASTM D7205/D7205M-06(2011)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

B.9.3 *Significance and use*

B.9.3.1 This test method for investigating long-term relaxation of FRP bars is intended for use in laboratory tests in which the principal variables are the size or type of FRP bars, magnitude of applied stress, and duration of load application.

B.9.3.2 This test method measures the load-induced, time-dependent tensile strain at selected ages for FRP bars under an arbitrary set of controlled environmental conditions and a corresponding load ratio.

B.9.3.3 This test method is intended to determine the relaxation data for material specifications, research and development, quality assurance, and structural design and analysis. The primary test result is the relaxation rate of the specimen under a specific loading and environmental condition.

B.9.3.4 Relaxation properties of prestressed concrete and masonry structures are important to consider in design. For FRP bars used as prestressing tendons, the relaxation behavior should be measured according to the method given herein, in keeping with the intended purposes.

B.9.4 *Test equipment and requirements*

B.9.4.1 Use a testing machine with a loading capacity in excess of the relaxation load of the test specimen and calibrated according to ASTM E4. The testing machine should be capable of loading at a rate of 200 ± 50 MPa per minute and sustaining load while maintaining a constant strain. It should also control strain fluctuations to no greater than $\pm 25 \times 10^{-6}$ in the specimen throughout the test period once the strain in the specimen has been fixed. If the FRP bar slips from an anchoring section, the slippage distance should be compensated so as not to affect the test results. The accuracy of the initial load applied to the specimen should be as follows:

a) Testing machines with loading capacity equal to or less than 1 kN: ±1.0 percent of set load

b) Testing machines with loading capacity of more than 1 kN: ±2.0 percent of set load

The accuracy of readings or automatic recording of loads should be within 0.1 percent of the initial load.

B.9.4.2 The anchorage should be in accordance with ASTM D7205/D7205M.

B.9.4.3 If an extensometer or strain gauge is to be fitted to the test specimen, the extensometer or strain gauge should be in accordance with ASTM D7205/D7205M.

B.9.5 *Specimen preparation*

B.9.5.1—Specimens should be representative of the lot or batch being tested. During the sampling and preparation of test specimens, all deformation, heating, outdoor exposure to ultraviolet light, and other conditions possibly causing changes to the material properties of the specimen should be avoided.

B.9.5.2 Test specimens should be prepared and handled in accordance with ASTM D7205/D7205M.

B.9.5.3 The number of valid test results for each test condition should not be less than five. If a specimen fails at or slips entirely out of an anchoring section, the test result should be disregarded and an additional test should be performed on a separate specimen taken from the same lot as the failed specimen.

B.9.6 *Standard conditioning procedure*—Condition specimens in accordance with Procedure A of ASTM D618. Store and test at the standard laboratory atmosphere—23 ± 3°C and 50 ± 10 percent relative humidity—unless a different environment is specified as part of the experiment.

B.9.7 *Test method*

B.9.7.1 Mounting of the specimen and gauge length should be in accordance with ASTM D7205/D7205M.

B.9.7.2 If a strain gauge is to be attached to the test specimen, the specimen should be preloaded by applying a load of 10 to 40 percent of the prescribed initial load, after which the strain gauge should be attached and correctly calibrated.

B.9.7.3 The initial load should be either 70 percent of the guaranteed tensile capacity or 80 percent of the million-hour creep rupture capacity, whichever is smaller. In some cases, these conditions may result in a load that causes creep rupture but not failure due to relaxation. In such cases, it should be confirmed under actual loading conditions that the load does not result in creep rupture of the FRP specimens by increasing the initial load as necessary.

B.9.7.4 The initial load should be applied without subjecting the specimen to shock or vibration. The specified rate of loading should be 200 ± 50 MPa per minute. The strain on the specimen should be kept constant after the initial load has been applied and maintained for 120 ± 2 seconds. This time should be deemed to be the test start time.

B.9.7.5 Load reduction should generally be measured over a period of at least 1000 hours. Preferably, load reduction should be recorded automatically by a recorder attached to the testing machine. If no recorder is attached to the testing machine, stress relaxation should be measured and recorded at the following times: 1, 3, 6, 9, 15, 30, and 45 minutes; and 1, 1.5, 2, 4, 10, 24, 48, 72, 96, and 120 hours. Subsequent measurements should be taken at least once every 120 hours.

B.9.8 *Calculations*

B.9.8.1 The relaxation value should be calculated by dividing the load measured in the relaxation test by the initial load.

B.9.8.2 The relaxation curve should be plotted on a semi-logarithmic graph where the relaxation value, in percent, is represented on an arithmetic scale along the vertical axis, and test time, in hours, is represented on a logarithmic scale along the horizontal axis. An approximation line should be derived from the graph data by means of the least-squares method according to Eq. (B.9.8.2)

$$Y_r = a_1 - b_1 \log T \tag{B.9.8.2}$$

B.9.8.3 The relaxation rate after 1 million hours should be determined from the approximation line; this value represents the million-hour relaxation rate. Where the service life of the structure in which the FRP bars are to be used is determined in advance, the relaxation rate for the number of years of service life, or service life relaxation rate, should also be determined.

B.9.9 *Test report*—The test report should include the following items:

a) The trade name, shape, and date of manufacture (if available), and lot number of product tested

b) Type of fiber and fiber binding material, as reported by the manufacturer, and fiber volume fraction

c) Numbers or identification marks on test specimens

d) Designation, diameter, and cross-sectional area

e) Date of test and test environmental conditions (humidity and temperature and their fluctuations)

f) Type and manufacturer of testing machine

g) Initial load and loading rate

h) Guaranteed tensile capacity and ratio of initial load to guaranteed tensile capacity

i) Relaxation curve for each test specimen

j) Average relaxation rates at 10, 120, and 1000 hours

k) Formula for determining the approximation line

l) Million-hour relaxation rate

m) Relaxation rate corresponding to design service life, or service life relaxation rate, where applicable

B.10—Test method for performance of anchorages of FRP bars

The following references are provided for historical and informational purposes only—Chaallal and Benmokrane (1993) and Nanni et al. (1996).

B.10.1 *Scope*—This test method specifies the test requirements for the performance of the anchorage of FRP bars used as pretensioned prestressing tendons in concrete and masonry. In this application, the anchorage is used only for a short period to transfer tension into the tendons. The long-term anchorage is via bond of the tendon to concrete.

The anchorage performance over extended periods of use, for instance, fatigue performance, is not covered in this test.

B.10.2 *Referenced documents*

ASTM International

ASTM D7205/D7205M-06(2011)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

B.10.3 *Significance and use*—This test method for investigating the performance of anchorage is intended for use in laboratory tests in which the principal variable is the size or type of FRP tendons used in pretensioned prestressing of tendons. This test method should not be used to develop tendon design values.

B.10.4 *Test equipment and requirements*—Use a testing machine or hydraulic jack and load cell with a loading capacity in excess of the tensile capacity of the test specimen and calibrated according to ASTM E4. A testing machine with either loading-rate or displacement-rate control is preferred. Tendons may be tested vertically or horizontally using a hydraulic jack.

FRP tendon should be loaded at a rate of 100 to 500 MPa/minute, and the test should finish in 1 to 10 minutes.

B.10.5 *Specimen preparation*—A specimen should be prepared by attaching the prestressing anchorage to be assessed to one end of the FRP tendon. The other end of the tendon should be anchored according to ASTM D7205/D7205M.

The length of the specimen should be the sum of the length of the tendon and the lengths of the anchoring sections at each end. The length of the tendon should not be less than 100 mm, nor should it be less than 40 times the diameter of the FRP tendon. For FRP tendons in twisted strand form, the length should also be greater than two times the strand pitch.

The number of test specimens should be no less than five.

B.10.6 *Test conditions*—Unless a different testing environment is specified as part of the experiment, the pullout anchorage tests should be conducted at the standard laboratory atmosphere of 23 ± 3°C and 50 ± 10 percent relative humidity.

Preconditioning of FRP tendons is permissible. Preconditioning may include abrasion of the surface of the tendon, environmental conditioning of the tendon, and post-curing of the tendon.

B.10.7 *Test method*—Test specimens should be mounted and supported by a tensile testing machine. The area and geometry of the surface supporting the anchorage and the manner of application of force should approximate the actual conditions within the prestressed concrete structure as closely as possible. The anchorage end of the tendon should be supported on a platen in a manner similar to that for the tensile specimen shown in Fig. A1.3 in ASTM D7205/D7205M.

Loading should be continued up to tensile failure, as determined by either failure of the FRP tendon or excessive deformation of the anchoring device.

B.10.8 *Calculations*—The tensile capacity for each specimen and average tensile capacity should be calculated. The modes of failure should also be recorded, noting any deformation or damage of the anchorage.

B.10.9 Test *report*—The test report should include the following items.

a) The trade name, shape, and date of manufacture (if available), and lot number of product tested

b) Type of testing machine

c) Type of fiber and fiber binding material, as reported by the manufacturer, and fiber volume fraction

d) Numbers or identification marks on test specimens

e) Designation, diameter, and cross-sectional area

f) Preconditioning of tendons, if any

g) Date of test, test temperature, and loading rate

h) Dimensions of test specimens and description of anchorage

i) Tensile failure capacity for each test specimen, average tensile capacity, location of failure, and failure modes

j) Records of any deformation or damage to anchorage

B.11—Test method for tensile properties of deflected FRP bars

B.11.1 *Scope*—This test method specifies the test requirements for tensile properties of deflected FRP bars used as prestressing tendons in concrete.

B.11.2 *Referenced documents*

ASTM International

ASTM D618-08—Standard Practice for Conditioning Plastics for Testing

ASTM D7205/D7205M-06(2011)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

B.11.3 *Significance and use*

B.11.3.1 This test method for obtaining the tensile properties of deflected FRP bars is intended for use in laboratory tests in which the principal variable is the size or type of FRP bars.

B.11.3.2 When FRP bars manufactured as straight bars are tensioned after being bent, the bending stress or added lateral pressure may cause strength reduction. This test method is developed for FRP bars bent as external prestressing or arranged in a curved layout as internal prestressing.

B.11.3.3 This test method is intended to determine the flexural tensile data of bent FRP bars for material specifications, research and development, quality assurance, and structural design and analysis. The primary test result is the bent tensile capacity of the specimen under a specific loading and environmental condition.

B.11.3.4 Flexural tensile properties of prestressed concrete and masonry structures are important factors to consider in design. For FRP bars used as tendons, the flexural tensile behavior should be measured according to the method given herein.

B.11.4 *Test equipment and requirements*

B.11.4.1 Use a testing machine with a loading capacity in excess of the tensile capacity of the test specimen and calibrated according to ASTM E4. A testing machine with either loading- or displacement-rate control is preferred. The test fixture should include a loading device, load indicator, anchorage holder, and deflector.

B.11.4.2 The loading device should have a loading capacity in excess of the tensile capacity of the test specimen and should be capable of applying load at the required loading rate.

B.11.4.3 The load indicator should be capable of displaying loads with an accuracy of not less than 1 percent of the failure load.

B.11.4.4 The anchorage holder should be suitable for the geometry of the test specimen and should be capable of accurately transmitting loads from the testing machine to the test specimen. The anchorage should be constructed so as to transmit only axial loads to the test specimen, without transmitting either torsion or flexural force.

B.11.4.5 The deflector should be capable of maintaining the required bending angle and bending diameter during the test until failure of the test specimen. The deflector surface in contact with the specimen should be suitable for contact with the bar's outer surface. For a round bar, a smooth rigid deflector surface may be used. For bars that are stranded or spiraled, it may be appropriate to use a deflector machined to match the surface of the bar.

B.11.5 *Specimen preparation*

B.11.5.1 Specimens should be representative of the lot or batch being tested. During the sampling and preparation of test specimens, all deformation, heating, outdoor exposure to ultraviolet light, or other conditions possibly causing changes to the material properties of the specimen should be avoided.

B.11.5.2 Test specimens should be prepared and handled in accordance with ASTM D7205/D7205M.

B.11.5.3 The length of the specimen should be the sum of the length of the test section and the lengths of the anchoring sections. The length of the test section should be such that the distance from an anchorage to the deflected section should not be less than 100 mm or less than 40 times the diameter of the FRP bar. For FRP bars in strand form, the distance from an anchorage to the deflected section should not be less than two times the strand pitch.

B.11.5.4 The number of test specimens for each test condition (combination of bending diameter and bending angle) should not be less than five. If a specimen fails at an anchoring section, or slips out of an anchoring section, an additional test should be performed on a separate specimen taken from the same lot as the failed specimen.

B.11.6 *Standard conditioning procedure*—Condition specimens in accordance with Procedure A of ASTM D618. Store and test at the standard laboratory atmosphere of 23 ± 3°C and 50 ± 10 percent relative humidity, unless a different environment (such as temperature or alkaline solution) is specified as part of the experiment.

B.11.7 *Test method*

B.11.7.1 The bending diameter and bending angle should be set appropriately for the test (Fig. B.11.7.1). This combination forms a single test condition. Each specimen should have only one deflected section.

B.11.7.2 Care should be taken when mounting the specimen in the testing machine to maintain the required bending angle and bending diameter at the deflected section during the test.

B.11.7.3 The specified rate of loading should be between 100 and 500 MPa/minute and the test should finish in 1 to 10 minutes. The deflected bar should exit the deflector on a tangent and not bend over the corner of the deflector.

B.11.7.4 Loading should be continued until failure of the test specimen. Failure load and failure location should be measured and recorded.

B.11.8 *Calculations*

B.11.8.1 The material properties of FRP bars should only be assessed on the basis of the specimen undergoing failure in the test section. In cases where tensile failure or slippage has occurred at an anchoring section, the data should be disregarded and additional tests should be performed until the number of test specimens failing in the test section is no less than five.

B.11.8.2 The maximum, minimum, average, and standard deviation of the bending tensile capacity for each set of test conditions should be calculated in accordance with ASTM D7205/D7205M.

B.11.8.3 The location and mode of failure should be observed and recorded for each test specimen.

B.11.9 *Test report*—The test report should include the following items:

a) The trade name, shape, and date of manufacture (if available), and lot number of product tested

b) Type of fiber and fiber binding material, as reported by the manufacturer, and fiber volume fraction

c) Numbers or identification marks on test specimens

d) Designation, diameter, and cross-sectional area

e) Condition of surface of FRP bar (material, thickness, configuration of any coating, and so on)

f) Date of test, test temperature, loading rate, and type and manufacturer of test machine

g) Type of anchor device

h) Bending angle, external diameter of deflector surface in contact with FRP bar, bending diameter ratio, and material and surface configuration

i) Bending tensile capacity for each test specimen

j) Location and mode of failure for each test specimen

k) Numbers of test specimens for each set of conditions, and maximum, minimum, average, and standard deviation of the bending tensile capacity

B.12—Test method for determining effect of corner radius on tensile strength of FRP bars

B.12.1 *Scope*—This method determines the effect of corner radius on the tensile properties of FRP bars used as reinforcing bars or prestressing tendons in concrete where bars are subject to tensile stresses. Tension tests are conducted using a three-component test fixture.

B.12.2 *Referenced documents*

ASTM International

ASTM D883-11—Standard Terminology Relating to Plastics

ASTM D3039/D3039M-08—Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

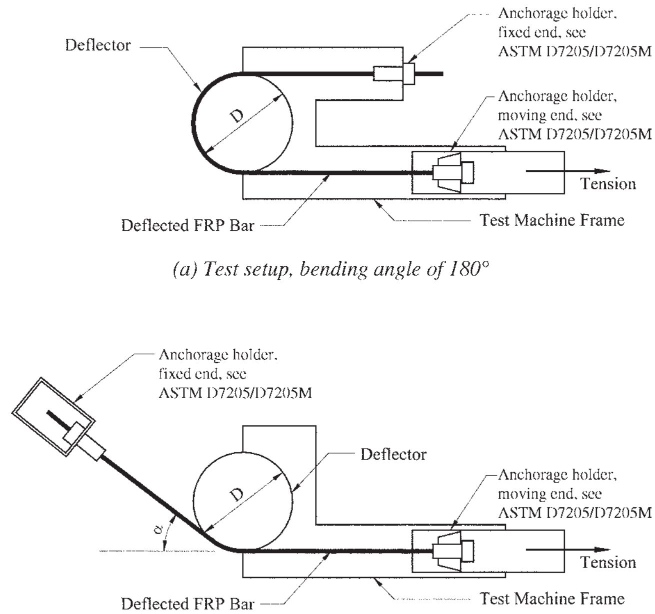
ASTM D7205/D7205M-06(2011)—Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

ASTM E4-10—Standard Practices for Force Verification of Testing Machines

ASTM E6-09—Standard Terminology Relating to Methods of Mechanical Testing

B.12.3 *Significance and use*

B.12.3.1 Tension tests are conducted using a unique test fixture. The testing fixture consists of three components: upper and lower parts and interchangeable corner inserts made of any suitable metal, such as aluminum or steel (Fig. B.12.3.1a). Detailed dimensions are shown in Fig. B.12.3.1b through B.12.3.1f. The FRP specimen in the form of a bent bar is placed in the groove that runs along the sides and the top of the test fixture and corner inserts. Instrumentation is mounted depending on the variables being monitored. If modulus and strain distribution are required, strain gauges can be mounted around the corner areas. The load is applied until failure of the FRP specimen.



(a) Test setup, bending angle of 180°

(b) Test setup, bending angle "α"

Fig. B.11.7.1—Typical bending tensile test setups.

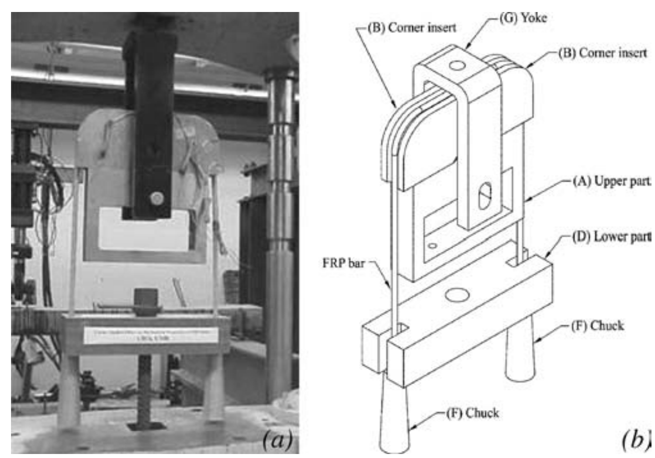


Fig. B.12.3.1a—(a) Assembled test fixture; and (b) assembled test fixture: sketch.

B.12.3.2 This tension test can provide accurate information with regard to the effect of corner radius on the tensile properties of FRP bent bars when applied under conditions with similar interaction mechanisms to those of the test method.

B.12.3.3 The method can be used for testing FRP bent bars with any fiber or resin type in rectangular or round solid shape.

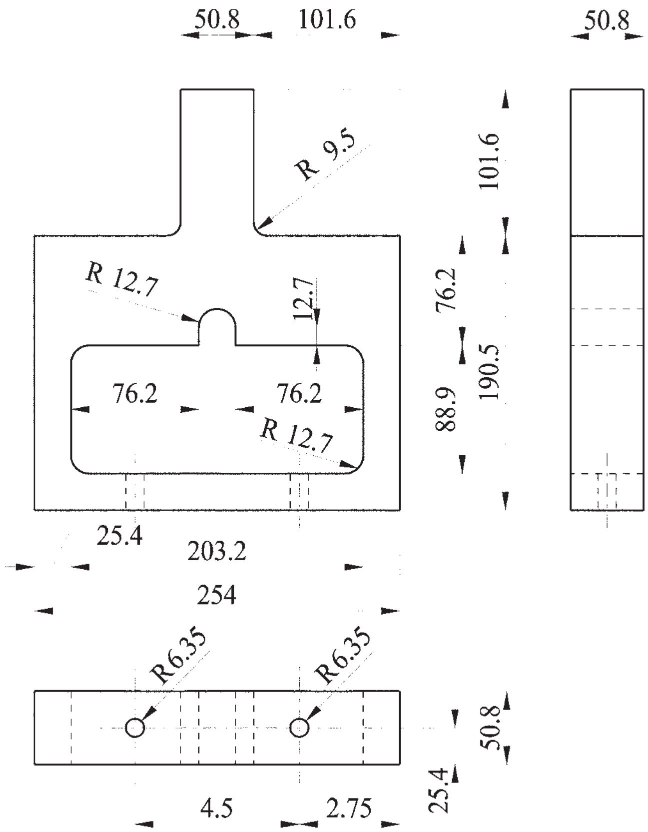


Fig. B.12.3.1b—Upper part of test fixture (in mm).

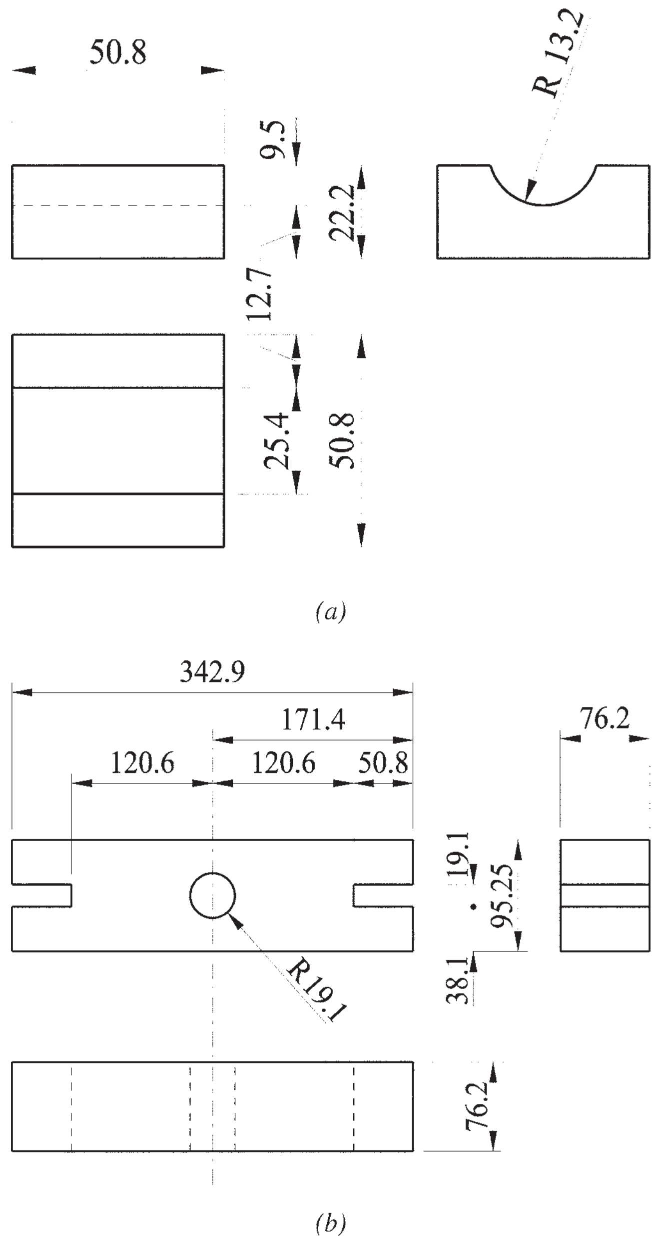


Fig. B.12.3.1c—Lower part of test fixture: (a) wedge; and (b) lower part (in mm).

B.12.3.4 The data provided by this test can be used for research and development, design, and acceptance/rejection criteria.

B.12.4 *Test equipment*

B.12.4.1 *Gauges*—Gauges should be accurate to at least 0.01 mm for measuring the width of the specimen.

B.12.4.2 *Testing machine*—The testing machine should be comprised of the following:

a) Fixed member—fixed or essentially stationary member supporting the load fixture

b) Movable member—member capable of applying a tensile load to the tensile loading fixture and transfer the load to the test fixture

c) Drive mechanism—drive for imparting to the movable member a controlled speed with respect to the stationary member

d) Load indicator—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test fixture. This mechanism should indicate the load with an accuracy of 1 percent or better of the actual value. The accuracy should be verified in accordance with ASTM E4

B.12.4.3 *Strain recording*—A suitable strain-recording system is required for modulus determination and strain distribution.

B.12.4.4 *Test fixture*—The test fixture consists of the upper and lower parts around which the FRP bar is placed. The upper part is used as the testing area with interchangeable corner inserts located at its two corners. The lower part is used to anchor the specimen through anchors. Two bolts and two steel rods are used to hold the upper and lower fixture sections together during specimen installation.

B.12.4.5 *Tensile loading fixture*—The fixture is used to transfer the load from the testing machine to the test fixture (Fig. B.12.3.1e). All drilled holes in the tensile loading fixture and test fixture should be oversized to avoid any twisting and tightening when the rods and nuts are installed. All holes should be drilled 1.60 mm larger than nominal value.

B.12.5 *Specimen preparation*

B.12.5.1 *Geometry*—The FRP test specimen should conform to the dimensions of the test fixture shown in Fig. B.12.3.1b and B.12.3.1c.

B.12.5.1.1 *Anchorage*—An anchorage system at the ends of the test bar should be provided with a sufficient length

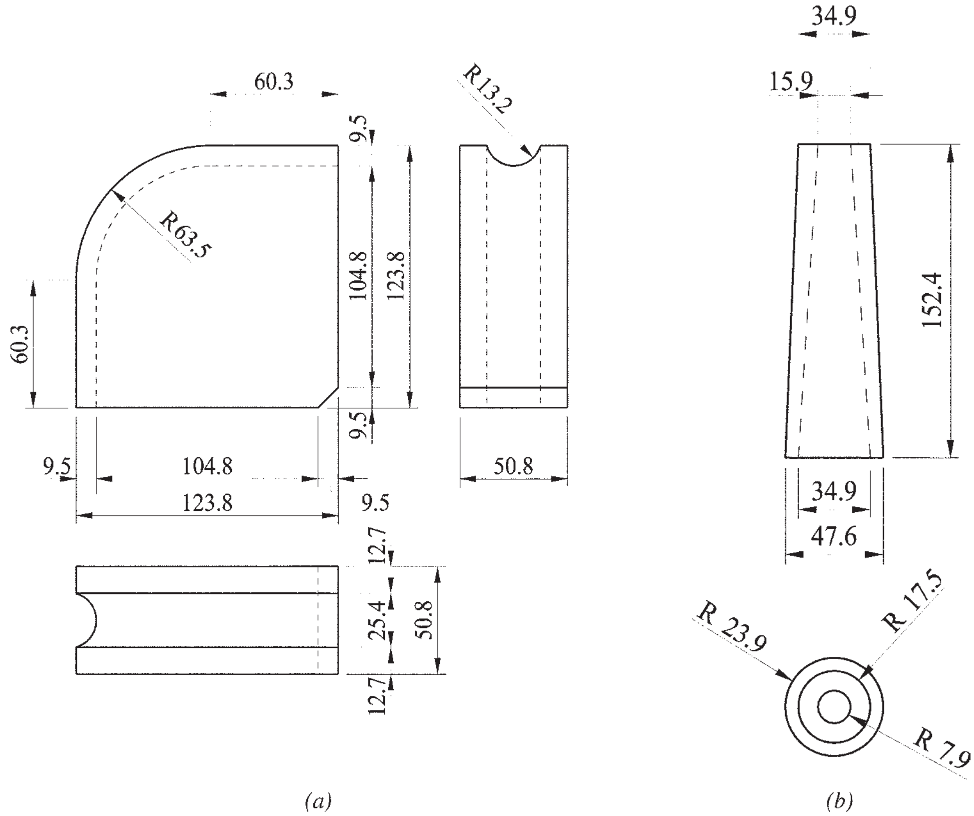


Fig. B.12.3.1d—Interchangeable corner inserts and wedge: (a) corner insert; and (b) chuck (in mm).

and size in accordance with ASTM D7205/D7205M so that failure occurs at the bent portion.

B.12.5.1.2 *Alignment*—The specimen should be centered in the grooves of the test fixture.

B.12.5.2 *Strain*—Where load-strain data are desired, the specimen may be instrumented with strain gauges. The strain gauges should be oriented parallel to the fiber direction. Strain gauges should be mounted in the straight regions of the bar in between and outside the corners. A recommended strain gauge arrangement is shown in Fig. B.12.3.1f.

B.12.5.3 *Number of specimens*—A minimum of five specimens is recommended for each material.

B.12.6 *Conditioning*—Store and test at the standard laboratory conditions of 23 ± 3°C and 50 ± 10 percent relative humidity, unless a different environment, such as temperature or alkaline solution, is specified as part of the experiment.

B.12.7 *Test method*

B.12.7.1 The tensile loading fixture is placed onto the upper cross-head of the testing machine, and the upper test fixture is connected to the tensile loading fixture using a short plain steel rod through the holes in the upper part. The lower part of the test fixture is placed onto the lower plate of the testing machine using a threaded steel bar and two nuts. The steel bar should be long enough to provide sufficient space for the anchor of the test bar when placed between the lower part and the lower cross-head.

B.12.7.2 There should be no misalignment between the test fixture and tensile loading frame. No twisting should be produced in the test fixture and specimen.

B.12.7.3 Connect data recording equipment.

B.12.7.4 Apply and release a small load on the specimen (less than 5 percent of expected failure load) to realign the test fixture. The strain gauges are zeroed in this step.

B.12.7.5 Set the recommended speed of testing. Speed of testing shall be determined by the specifications for the material being tested or by the client. When the speed of testing is not specified, however, a speed of 1.0 to 2.0 mm/minute is recommended.

B.12.7.6 Record the strain and load values continuously.

B.12.7.7 Record the maximum load from the load indicator of the testing machine.

B.12.7.8 Record the failure mode of the specimen. The failure zone is normally located around the corner.

B.12.8 *Calculations*

B.12.8.1 *Reduced tensile strength*—Calculate the reduced tensile strength using Eq. (B.12.8.1). Report the results to three significant figures

$$S = P/(2A) \qquad \text{(B.12.8.1)}$$

B.12.8.2 *Tensile modulus*—Calculate the tensile modulus of different points using Eq. (B.12.8.2). Report the results to three significant figures. The modulus should be calculated using the load and strain values corresponding to 20 and 50 percent of the reduced tensile strength *S*.

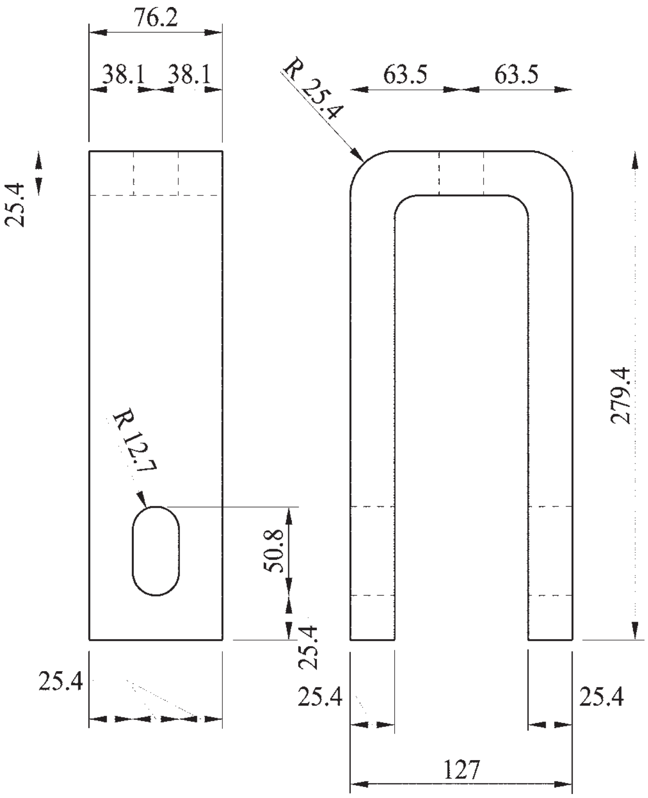


Fig. B.12.3.1e—Tensile fixture (two sets needed) (yoke) (in mm).

$$E_L = \Delta P/(2A\Delta\varepsilon) \quad \text{(B.12.8.2)}$$

B.12.9 *Test report*—The test report should include the following items:

a) Complete identification of the material tested, including source, manufacturer's code number, form, previous history, resin type, processing details, specimen quality control, description of equipment used, deviations from this standard test method, and description of the fabrication process of the specimen compared with the specified one provided by the manufacturer

b) Method of preparing test specimen and verification of quality

c) Test specimen dimensions and corner radius

d) Numbers or identification marks on test specimens

e) Speed of testing

f) Failure load

g) Individual specimen strength and average values

h) Individual specimen modulus and average values

i) Date of tests

PART 3—TEST METHODS FOR FRP LAMINATES

L.1—Test method for direct tension pulloff test

This test method has been replaced by ASTM D7522/D7522M.

L.2—Test method for tension test of flat specimen

This test method has been replaced by ASTM D7565/D7565M.

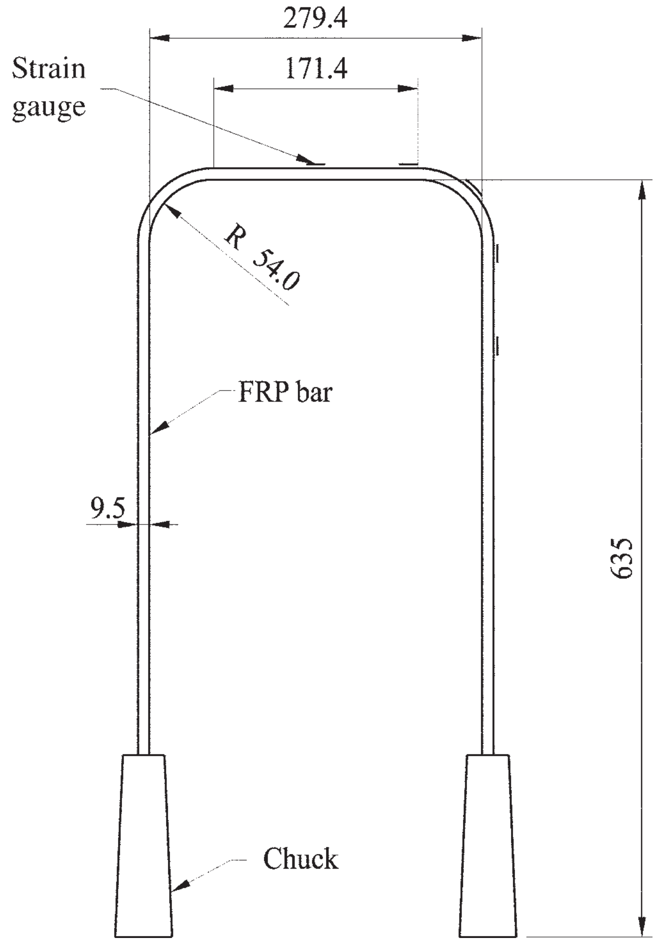


Fig. B.12.3.1f—Installation of specimen and possible strain gauge arrangement (in mm).

L.3—Test method for overlap splice tension test

This test method has been replaced by ASTM D7616/D7616M.

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Guide Test Methods for Fiber-Reinforced Polymer (FRP) Composites for Reinforcing or Strengthening Concrete and Masonry Structures