Designation: D7914/D7914M − 21

Standard Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations[1]

This standard is issued under the fixed designation D7914/D7914M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method determines the quasi-static ultimate strength of fiber reinforced polymer (FRP) composite bent bars commonly used as anchorages for stirrups in reinforced, prestressed, or post-tensioned concrete structures. This test method only applies to bars with a solid cross section.

1.2 FRP bent bars are often used in reinforced concrete applications to shorten the development length of the bar or to act as a tie or a stirrup to resist shear forces. Bent bars can be produced with varying angles of bend in order to fit their intended purpose.

1.3 For this test method, the FRP bars are bent at a 90 degree angle. In general, bars have a regular pattern of surface undulations, a coating of bonded particles, or both, that promote mechanical interlock between the bar and concrete.

1.4 This test method may be completed on standardized bars, produced according to Specification D7957/D7957M. In this case, the nominal cross-sectional areas and effective diameters are taken from D7957/D7957M. This test method may also be used for bars that are not standardized. In this case, the cross-sectional areas and effective diameters should be measured and calculated as described in Test Method D7205/D7205M.

1.5 The strength values provided by this method are short-term, quasi-static tensile strengths that do not account for sustained static or cyclic loading. If bars are to be used under high levels of sustained or repeated loading, additional material characterization may be required.

1.6 The characteristic values obtained from this test method are intended to represent the quasi-static ultimate strength of FRP bent bars with a tail length of twelve bar diameters.

1.7 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.7.1 Within the text, the inch-pound units are shown in brackets.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
D883 Terminology Relating to Plastics
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
D7957/D7957M Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E122 Practice for Calculating Sample Size to Estimate, With

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.10 on Composites for Civil Structures.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Specified Precision, the Average for a Characteristic of a Lot or Process
E456 Terminology Relating to Quality and Statistics

3. Terminology

3.1 Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E456 and Practice E122 define terms relating to statistics and the selection of sample sizes. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other terminology standards.

3.2 *Definitions:*

3.2.1 *bar, n*—a linear element, with a substantially round cross-section, often with surface undulations or a coating of particles that promote mechanical interlock with concrete.

3.2.2 *bend diameter, n*—inside diameter of a bent bar as shown in Fig. 1.

3.2.2.1 *Discussion*—For standardized bars, the bend diameters should be as described in Table 4 of Specification D7957/D7957M.

3.2.3 *bend strength, n*—ultimate tensile stress that can be carried by the FRP bent bar provided that failure occurs in the bend.

3.2.4 *bent bar, n*—a bar with a section formed in such a manner as to deviate from its primary axis.

3.2.5 *effective bar diameter, n*—a geometric value representing the diameter of a circle which has an enclosed area equal to the nominal or measured cross-sectional area of a bar, as appropriate.

3.2.6 *measured cross-sectional area, n*—the average cross-sectional area of a bar, including deformations, lugs, sand coating, or any bond-enhancing surface treatment, measured according to Test Method D7205/D7205M.

3.2.7 *nominal cross-sectional area, n*—a standard cross-sectional area of a bar, as described in Table 3 of Specification D7957/D7957M.

3.2.8 *quasi-static, adj*—loading where inertial effects (time and inertial mass) are irrelevant.

3.2.9 *standardized bar, n*—a bar produced according to Specification D7957/D7957M.

3.2.10 *stirrup, n*—a bar shape comprised of one or more bent bars used to resist shear forces in reinforced concrete.

3.2.11 *tail length, n*—the length provided beyond the bend portion of a bent bar.

3.2.12 *tensile strength, n*—ultimate tensile strength of FRP bars in the direction parallel to the fibers.

3.3 *Symbols:*

3.3.1 A—nominal or measured cross-sectional area of a single leg of the FRP bent bar, as appropriate, mm^2 [in.^{2}]

3.3.2 CV—sample coefficient of variation, in percent

3.3.3 D—inside diameter of the bent portion of an FRP bent bar as shown in Fig. 1, mm [in.]

3.3.4 d_b—effective bar diameter determined based on nominal or measured cross-sectional area, as appropriate, mm [in.]

3.3.5 F_{fb}—ultimate bend strength of the FRP bent bar, MPa [psi]

3.3.6 L_t—tail length of the FRP bent bar occurring after the bent portion of the bar, mm [in.]

3.3.7 n—number of specimens

3.3.8 P_{fb}—ultimate force capacity of the FRP bent bar, N [lb]

3.3.9 r—repeatability limit, the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with a probability of approximately 0.95 (95 %)

3.3.10 S_{n-1}—sample standard deviation

3.3.11 x_i—measured or derived property

3.3.12 $\bar{x}$—sample mean (average)

4. Summary of Test Method

4.1 One or more FRP bent bars, cast into two blocks of concrete, are loaded in tension until failure occurs at the bent

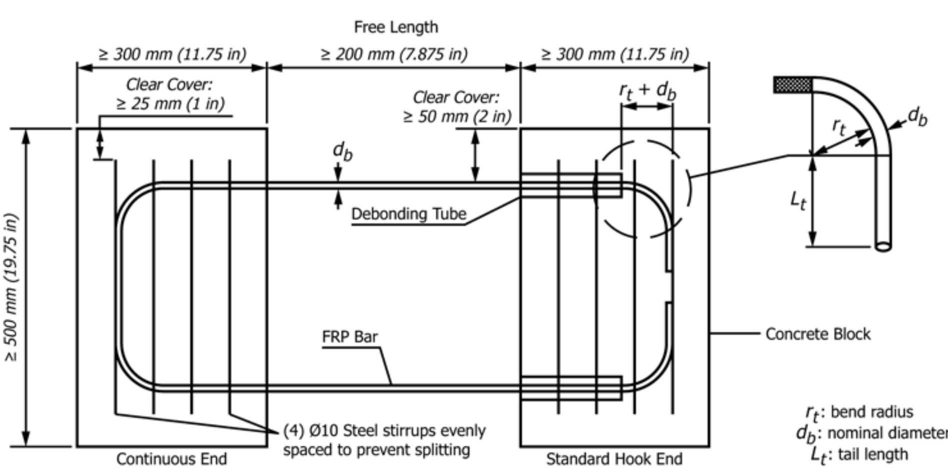

FIG. 1 Specimen Configuration

portion of the bar. An actuation device is placed in between the two concrete blocks so that the blocks are forced apart, inducing tension on the FRP bent bars.

4.2 Force is recorded throughout the test.

4.3 The principal variables used in the tests are the bar cross-sectional area, bend diameter, and type of FRP bent bar.

5. Significance and Use

5.1 This test method is intended to determine the bend strength of FRP composite concrete reinforcements, developed at a standard twelve bar diameters of embedment. From this test, a variety of data are acquired that are needed for design purposes. Material-related factors that influence the tensile response of bars include the following: constituent materials, void content, volume percent reinforcement, methods of fabrication, and fiber reinforcement architecture. Similarly, factors relevant to the measured tensile response of bars include specimen preparation, specimen conditioning, environment of testing, specimen alignment, and speed of testing. The results may be used for material specifications, research and development, and structural design and analysis.

NOTE 1—Two FRP bends are tested simultaneously in this test method, but in some cases, only one bend may fail. While resulting in a valid failure, notice should be taken that only one bend has been effectively measured and that the final compiled test results using this method could differ from those resulting from single FRP bend testing.

6. Interferences

6.1 The results from the procedures presented are limited to the material and test factors listed in Section 5.

6.2 *Loading Provisions*—The test is completed using a hydraulic cylinder that exerts equal and opposite forces onto two concrete blocks. The block containing the test section of the FRP bent bar must be free to translate so that force exerted on the bent bars can be accurately measured. Bending of the bent bars during casting of the concrete or testing of the specimen may cause premature failure outside of the bend. Every effort shall be made to minimize bending and uneven loading of the bent bars.

6.3 *Bend Geometry*—In this test method, the bend in the FRP bar comprises a 90 degree change of direction with a constant radius of curvature through the bend. Bends other than 90 degrees may produce different test results, and are not covered by this test method.

6.4 *Specimen Handling*—During the handling and preparation of specimens, all deformation, heating, outdoor exposure to ultraviolet light, and other conditions possibly causing changes to material properties of the specimen shall be avoided.

6.5 *Splitting of Concrete Prisms*—Specimens failing by way of splitting the concrete block do not return a valid test result. If splitting occurs, block dimensions may be increased, and steel stirrups may be included in the blocks as necessary.

7. Apparatus

7.1 *Hydraulic Cylinder*—The hydraulic cylinder shall have force capacity in excess of the capacity of the specimen, and be capable of applying force at the required loading rate. Hand operated testing machines, electro-mechanical cylinders, or motorized pumps having sufficient volume in one or more strokes to complete a test may be used if they satisfy the loading provisions in 11.2.5.

7.2 *Force Indicator*—The testing apparatus force-sensing device (a load cell or similar) shall be capable of indicating the total force being carried by the specimen. This device shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the force with an accuracy over the load range(s) of interest of within ± 1 % of the indicated value, as specified by Practices E4.

7.3 *Environmental Test Chamber*—An environmental chamber is required for conditioning and test environments other than ambient laboratory conditions. These chambers shall be capable of maintaining the required relative temperature to within ±3 °C [±5 °F] and the required relative humidity level to within ±5 % RH. In addition, the chambers may have to be capable of maintaining environmental conditions such as fluid exposure or relative humidity during the conditioning and testing.

7.4 The test set-up, shown in Fig. 2, consists of a hydraulic cylinder to distribute the applied force to the surface of the concrete. A plywood bearing pad 200 mm square and at least 6 mm deep [8 in. square and 0.25 in. deep] in conjunction with steel spreader plates 100 mm square and 6 mm deep [4 in. square and 0.25 in. deep], or similar provisions shall be used at the end of the actuator to spread the force on the concrete blocks and minimize bending forces on the bent bars. The hydraulic cylinder shall be placed in the same plane as the FRP bars, and shall be centrally located between the legs (± 6 mm [0.25 in.]). The block containing the test section of the bar shall be placed on top of steel rollers to minimize the friction forces between the block and testing bed. When moving the specimens, special care shall be taken to avoid damaging or displacing the cast FRP bars.

8. Sampling and Test Specimens

8.1 *Sampling*—At least five specimens shall be tested per test condition. For statistically significant data, the procedures outlined in Practice E122 should be consulted. The method of sampling shall be reported.

8.2 *Geometry:*

8.2.1 FRP bent bars shall be representative of the lot or batch being tested. In general, specimens shall not be subjected to any processing beyond manufacturing.

8.2.2 The cross-sectional area of the FRP bent bar shall be the nominal value, according to Specification D7957/D7957M, for standardized bars, or the measured value, according to Test Method D7205/D7205M, for all other bars. The cross-sectional area and method used to obtain it shall be reported and used for all calculations.

8.2.3 Bend angle of FRP bar shall be 90 ± 5 degrees off of straight.

8.2.4 The configuration of a typical specimen is shown in Fig. 2.

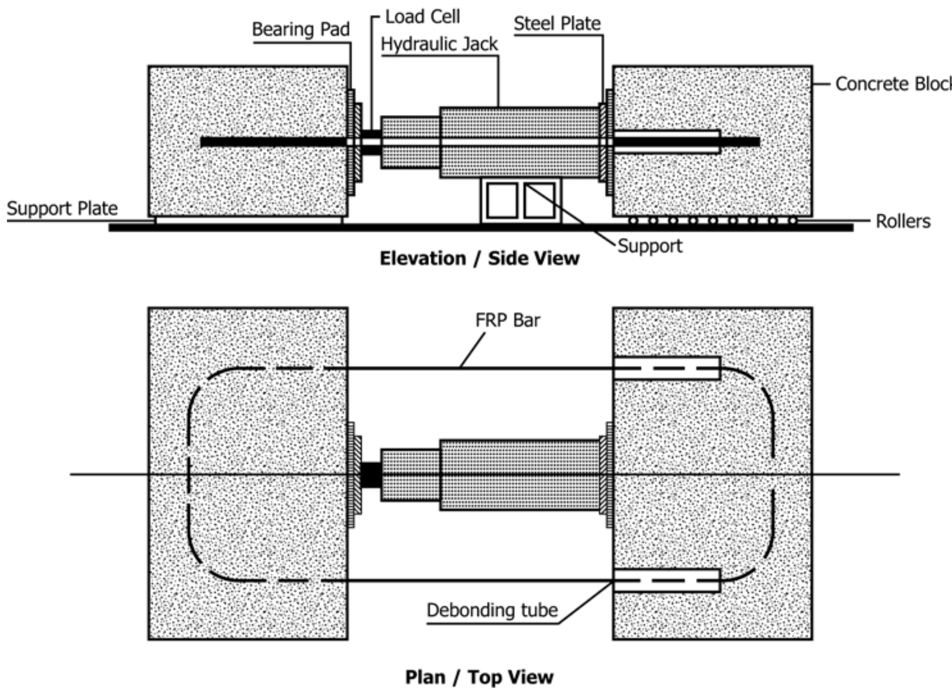

FIG. 2 Test Setup

8.2.5 The free length of the FRP bars between the two concrete blocks shall not be less than 200 mm [8 in.] with a suggested length of 400 mm [16 in.].

8.2.6 Concrete blocks are dimensioned as shown in Fig. 1. Steel stirrups are optional and may be required to prevent splitting of the concrete blocks prior to a valid FRP failure in the case of large diameter FRP bars. Use of stirrups shall be reported. The concrete blocks shall be arranged in such a matter that each corresponding face is parallel to the other to ensure proper loading of the samples.

NOTE 2—In some cases, large diameter FRP bars may cause splitting of the concrete blocks. An increased clear cover or horizontal steel stirrups may be used to prevent this splitting, but such use shall be reported.

8.2.7 FRP bent bar dimensions are variable, but shall have a tail length (L_t) of 12±1 bar diameters per bend to minimize slippage and to help ensure a valid failure mode. To allow for easier FRP bent bar production, two "C"-shaped bars arranged and used in the same manner as the single FRP bar shown in Fig. 1 may be used in place of a single FRP bar.

8.2.8 A debonding tube is to be used to eliminate straight-bar development of the bent bar. The debonding tube shall fit over the reinforcing bar and cover the straight length of the FRP bar up to the bent portion, and shall be capped or plugged to prevent the tube from filling with concrete during casting.

NOTE 3—The debonding tube may be made of any rigid or flexible encasement that exhibits a surface that will not bond to concrete during curing (such as PVC tubing or other suitable materials).

8.3 *Labeling:*

8.3.1 The specimens shall be labeled so that they will be distinct from each other and traceable back to the raw material, and in a manner that will both be unaffected by the test and not influence the test.

8.4 *Concrete Mix Properties:*

8.4.1 The concrete shall be a standard mixture, with coarse aggregates having a maximum dimension of 10 to 25 mm [3⁄8 to 1 in.]. It shall be batched and mixed in accordance with the applicable portions of Practice C192/C192M. Deviations to prevent concrete failure or to allow for rapid curing samples shall be reported.

NOTE 4—To ensure that the integrity of the bar is not compromised by the exothermic properties of rapid curing concrete, care should be taken that the temperature of the bars does not exceed the glass transition temperature of the FRP composite bars.

8.4.2 The concrete shall have slump of at least 100 + 20 mm [4 + 0.75 in.] in accordance with Test Method C143/C143M. The compressive strength at 28 days shall be at least 30 + 3 MPa [4350 + 400 psi] in accordance with Test Method C39/C39M. A minimum of five standard 150 × 300 mm [6 × 12 in.] or 100 × 200 mm [4 × 8 in.] control cylinders shall be made for determining compressive strength from each batch of concrete.

9. Calibration

9.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

10. Conditioning

10.1 Condition per Procedure C of Test Method D5229/D5229M; store at standard laboratory atmosphere (23 ± 3 °C [73 ± 5 °F] and 50 ± 10 % RH) unless a different conditioning environment is specified as part of the experiment

11. Procedure

11.1 Parameters to be specified prior to test:

11.1.1 FRP bar type and size, sampling method and pre-conditioning of bars before casting of the concrete, if any.