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Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars[1]

This standard is issued under the fixed designation D7205/D7205M; 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 longitudinal tensile strength and elongation properties of fiber reinforced polymer matrix (FRP) composite bars commonly used as tensile elements in reinforced, prestressed, or post-tensioned concrete.

NOTE 1—Additional procedures for determining tensile properties of polymer matrix composites may be found in Test Methods D3039/D3039M and D3916.

1.2 Linear elements used for reinforcing Portland cement concrete are referred to as bars, rebar, rods, or tendons, depending on the specific application. This test method is applicable to all such reinforcements within the limitations noted in the method. The test articles are referred to as bars in this test method. In general, bars have solid cross-sections and a regular pattern of surface undulations or a coating of bonded particles, or both, that promote mechanical interlock between the bar and concrete. The test method is also appropriate for use with linear segments cut from a grid. Specific details for preparing and testing of bars and grids are provided. In some cases, anchors may be necessary to prevent grip-induced damage to the ends of the bar or grid. Suggestions for a grouted type of anchor are provided in Appendix X1.

1.3 The strength values provided by this method are short-term static strengths that do not account for sustained static or fatigue loading. Additional material characterization may be required, especially for bars that are to be used under high levels of sustained or repeated loading.

1.4 *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.

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

1.5 *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.*

1.6 *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]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D3878 Terminology for Composite Materials
D3916 Test Method for Tensile Properties of Pultruded Glass-Fiber-Reinforced Plastic Rod
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
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
E83 Practice for Verification and Classification of Extensometer Systems
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E456 Terminology Relating to Quality and Statistics

[1] This test method is under the jurisidiction 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.

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

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 of Terms Specific to This Standard:*

3.2.1 *anchor, n*—a protective device placed on each end of a bar, between the bar and the grips of the tensile testing machine, to prevent grip-induced damage. Usually used on bars with irregular surfaces, as opposed to flat strips where bonded tabs are more typical.

3.2.2 *bar, n*—a linear element, often with surface undulations or a coating of particles that promote mechanical interlock with concrete.

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

3.2.4 *grid, n*—a 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. The lattice can be manufactured with integrally connected bars or constructed of mechanically connected individual bars. The grid bar elements have transverse dimensions typically greater than 3 mm [0.125 in.].

3.2.5 *measured cross-sectional area, n*—cross-sectional area of a bar, including any bond enhancing surface treatments such as deformations, lugs, and sand coating, determined over at least one representative length, measured according to 11.2.4.1.

3.2.6 *nominal cross-sectional area, n*—the cross-sectional area of a standard FRP concrete reinforcing bar as originally developed for glass FRP bars in Specification D7957/D7957M.

3.2.7 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

3.2.8 *representative length, n*—the minimum length of a bar that contains a repeating geometric pattern that, placed end-to-end, reproduces the geometric pattern of a continuous bar (usually used in reference to bars having surface undulations for enhancing interlock with concrete).

3.2.9 *surface undulation, n*—variation in the area, orientation, or shape of cross section of a bar along its length, intended to enhance mechanical interlock between a bar and concrete, made by any of a number of processes such as, for example, indentation, addition of extra materials, and twisting.

3.3 *Symbols:*

A = cross-sectional area of a bar.
CV = sample coefficient of variation, in percent.
d = effective diameter of a bar.
E = modulus of elasticity in the test direction.
F_{tu} = ultimate tensile strength.
K = total number of stress-strain data points used in the modulus calculation.
L = free length of specimen (length between anchors).
L_a = anchor length.
L_g = extensometer gage length.
n = number of specimens.
P = force carried by specimen.
P_{max} = maximum force carried by a test coupon before failure.
r^2 = coefficient of determination.
s_{n-1} = sample standard deviation.
x_i = measured or derived property.
$\bar{x}$ = sample mean (average).
δ = extensional displacement.
ε = indicated normal strain from strain transducer.
σ = normal stress.

4. Summary of Test Method

4.1 A fiber reinforced polymer (FRP) bar, preferably fitted with anchors, is mounted in a mechanical testing machine and monotonically loaded in tension to failure while recording force, longitudinal strain, and longitudinal displacement.

4.2 Anchors as described in Appendix X1 are recommended but not required. Alternative methods for attaching the specimens to the testing machine are acceptable, but must allow for the full strength of the bar to be developed and for the failure of the specimens to occur away from the attachments.

5. Significance and Use

5.1 This test method is designed to produce longitudinal tensile strength and elongation data. From a tension test, a variety of data are acquired that are needed for design purposes. Test factors relevant to the measured tensile response of bars include specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, and speed of testing. Properties, in the test direction, that may be obtained from this test method include:

5.1.1 Maximum tensile force,
5.1.2 Ultimate tensile strength,
5.1.3 Ultimate tensile strain,
5.1.4 Tensile chord modulus of elasticity, and
5.1.5 Stress-strain curve.

6. Interferences

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

6.2 *Gripping*—The method of gripping has been known to cause premature tensile failures in bars. Anchors, if used, should be designed in such a way that the full tensile capacity can be achieved without slip throughout the length of the anchor during the test.

6.3 *System Alignment*—Excessive bending may cause premature failure, as well as a highly inaccurate modulus of elasticity determination. Every effort should be made to eliminate bending from the test system. Bending may occur due to misalignment of the bar within anchors or grips or associated fixturing, or from the specimen itself if improperly installed in the grips or if it is out-of-tolerance due to poor specimen preparation. See Practice E1012 for verification of specimen alignment under tensile loading.

6.4 *Measurement of Cross-Sectional Area*—The measured cross-sectional area of the bar is determined by immersing a prescribed length of the specimen in water to determine its buoyant weight. Bar configurations that trap air during immersion (aside from minor porosity) cannot be assessed using this method. This method may not be appropriate for bars that have large variations in cross-sectional area along the length of the bar.

6.5 *Material-Related Factors*—Material-related factors such as constituent materials, void volume content, reinforcement volume content, methods of fabrication, and fiber reinforcement architecture can affect the tensile properties of bars.

7. Apparatus

7.1 *Micrometers*—The micrometer(s) shall use a suitable size diameter ball-interface on irregular surfaces and a flat anvil interface on machined edges or very-smooth tooled surfaces. The accuracy of the instruments shall be suitable for reading to within 1 % of the intended measurement.

7.2 *Testing Machine*—The testing machine shall be in conformance with Practices E4, and shall satisfy the following requirements:

7.2.1 *Testing Machine Heads*—The testing machine shall have both an essentially stationary head and a movable head.

7.2.2 *Drive Mechanism*—The testing machine drive mechanism shall be capable of imparting to the movable head a controlled displacement rate with respect to the stationary head. The displacement rate of the movable head shall be capable of being regulated as specified in 11.3.

7.2.3 *Force Indicator*—The testing machine force-sensing device 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. The force range(s) of interest may be fairly low for modulus evaluation, much higher for strength evaluation, or both, as required.

NOTE 2—Obtaining precision force data over a large range of interest in the same test, such as when both elastic modulus and ultimate force are being determined, place extreme requirements on the force transducer and its calibration. For some equipment, a special calibration may be required. For some combinations of material and force transducer, simultaneous precision measurement of both elastic modulus and ultimate strength may not be possible, and measurement of modulus and strength may have to be performed in separate tests using a different force transducer range for each test.

7.2.4 *Grips*—If grips are used, each head of the testing machine shall carry one grip for holding the specimen so that the loading direction is coincident with the longitudinal axis of the specimen. The grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the specimen or anchor. It is highly desirable to use grips that are rotationally self-aligning to minimize bending stresses in the specimen. The grips shall be aligned in accordance with Practice E1012 and shall not bias failure location in the bar.

7.3 *Anchors*—Use of a rigid pipe-shaped anchor as an interface between the bar and the grips or loading head of the testing machine is recommended to prevent stress concentrations and consequent downward biasing of measured strength. Suggestions for a grouted anchor are provided in Appendix X1.

7.3.1 Attachment of anchors to loading heads shall be by threaded connectors between the anchors and loading head or by grips. Details of this attachment are shown in Fig. X1.3.

7.4 *Strain-Indicating Device*—Longitudinal strain shall be measured by an appropriate strain transducer as long as attachment of this device does not cause damage to the bar (see Note 3).

NOTE 3—For most bars, the application of surface-bonded strain gages is impractical due to surface undulations (for example, braided, twisted, and indented bars). Strain gages of a suitable gage length can be used if the surface of the bar can be smoothed with a polymer resin such as epoxy to provide a suitable bonding surface so that measurements are equivalent to those provided by an extensometer meeting the requirements of 7.4.1.

7.4.1 *Extensometers*—Extensometers shall satisfy, at a minimum, Practice E83, Class B-2 requirements for the strain range of interest, and shall be calibrated over that strain range in accordance with Practice E83. The extensometer shall be essentially free of inertia-lag at the specified speed of testing. The gage length of the extensometer, L_g, shall be not less than eight times the effective bar diameter, nor less than one representative length. The extensometer shall be centered on the mid-length position of the bar, not less than eight effective bar diameters from either anchor.

7.4.1.1 Temperature compensation is recommended when not testing at Standard Laboratory Atmosphere. When appropriate, use either (*a*) a traveler specimen (dummy specimen) with identical bar material and extensometer(s) or (*b*) an extensometer calibrated for temperature changes.

7.5 *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 (see Section 10 and 11.4).

8. Sampling and Test Specimens

8.1 *Sampling*—Test at least five specimens per test condition unless valid results can be gained through the use of fewer specimens, such as in the case of a designed experiment. For statistically significant data, the procedures outlined in Practice E122 should be consulted. The method of sampling shall be reported.

8.2 *Geometry:*