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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 and/or a coating of bonded particles 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. Recommended details for the anchors are provided in Annex A1.

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 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

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

D3171 Test Methods for Constituent Content of 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

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[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.

3. Terminology

3.1 Terminology in D3878 defines terms relating to high-modulus fibers and their composites. Terminology in D883 defines terms relating to plastics. Terminology in E6 defines terms relating to mechanical testing. Terminology in E456 and in Practice E122 define terms relating to statistics and the selection of sample sizes. In the event of a conflict between terms, Terminology in 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 *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.].

3.2.4 *effective 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.

3.2.5 *nominal cross-sectional area, n*—a measure of cross-sectional area of a bar, determined over at least one representative length, used to calculate stress.

3.2.6 *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.

3.2.7 *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).

3.2.8 *standard cross-sectional area, n*—the cross-sectional area of a standard numbered steel concrete reinforcing bar as given in ASTM A615/A615M, Table 1.

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	=	nominal cross-sectional area of a bar.
CV	=	sample coefficient of variation, in percent.
d	=	effective bar diameter
E_{chord}	=	chord modulus of elasticity in the test direction.
F_{tu}	=	ultimate tensile strength.
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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

P_{max} = maximum load carried by a test coupon before failure.
S_{n-1} = sample standard deviation.
x_i = measured or derived property.
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 Annex A1 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. Material-related factors that influence the tensile response of bars and should therefore be reported include the following: constituent materials, void content, volume percent reinforcement, methods of fabrication, and fiber reinforcement architecture. Similarly, 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 Ultimate tensile strength,

5.1.2 Ultimate tensile strain,

5.1.3 Tensile chord modulus of elasticity, and

5.1.4 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 ASTM E1012 for verification of specimen alignment under tensile loading.

6.4 *Measurement of Cross-Sectional Area*—The nominal cross-sectional area of the bar is measured 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.

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 Practice 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 ASTM 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. Details of recommended anchors are provided in Annex A1.

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. A1.3.

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 section 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 Sections 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:*

8.2.1 *Overall Specimen Length and Gage Length*—The total length of the specimen shall be the free length plus two times the anchor length, L_a. The free length between the anchors, L, shall be not less than 380 mm [15 in.] nor less than 40 times the effective bar diameter. The length of the specimen in the grips and anchors (if used) shall be sufficient for adequate anchorage.

8.2.2 *Labeling*—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.

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 *Standard Conditioning Procedure*—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.

NOTE 4—If tensile specimens are to undergo environmental conditioning to equilibrium, and are of such type or geometry that the weight change of the material cannot be properly measured by weighing the specimen itself (such as a bar with anchors), then a traveler specimen of the same cross-section geometry and appropriate size (but without anchors) shall be used to determine when equilibrium has been reached for the specimens being conditioned. The ends of tensile specimens and traveler specimens shall be sealed with a water resistant sealant such as a high grade, room-temperature curing epoxy to avoid end effects during conditioning.

11. Procedure

11.1 Parameters to be specified prior to test:

11.1.1 The specimen sampling method, specimen type and geometry, conditioning, and if required, traveler specimen geometry.

11.1.2 The tensile properties and data reporting format desired.

Note 5—Determine specific material property, accuracy, and data reporting requirements before test for proper selection of instrumentation and data-recording equipment. Estimate operating stress and strain levels to aid in transducer selection, calibration of equipment, and determination of equipment settings.

11.1.3 The environmental conditioning test parameters and sealant used for the ends of the specimens.

11.1.4 If performed, the sampling method, specimen geometry, and test methods used to determine density, void fraction, and reinforcement volume.

11.2 *General Instructions:*

11.2.1 Report any deviations from this test method, whether intentional or inadvertent.

11.2.2 If specific gravity, density, reinforcement volume or void volume are to be reported, use ASTM D792 (specific gravity, density) and ASTM D3171 (reinforcement volume, void volume) for the determination of these properties and select specimens from the same batch of bar as that used for the tensile and traveler specimens.

11.2.3 Condition the specimens (specify either before or after attachment of anchors), as required. If test conditions are to be different from ambient laboratory conditions, it is recommended that anchors be applied before conditioning. Condition the traveler coupons if they are to be used.

11.2.4 Following final specimen machining and any conditioning, but before the tension testing, measure and report the free length of specimen.

11.2.5 *Bar area and diameter*—Either the nominal measured cross-sectional area or the standard cross-sectional area as given in ASTM A615/A615M is used to calculate stress and modulus of elasticity. In either case, the nominal cross-sectional area must be measured and reported. If the nominal cross-sectional area differs from the standard cross-sectional area for the given bar size by more than 20 percent, standard cross-sectional area may not be used.

11.2.5.1 *Nominal cross-sectional area*—The nominal area is calculated as the average of 5 representative specimens cut from the same bar stock as that used for the tensile test. Conditioning of the cross-sectional area specimens is the same as that for the bars used for the tensile test. The volume of each specimen shall be measured indirectly by the difference in mass of the specimen in the dry and fully immersed states (refer to ASTM D792 for test methods). The volume of the specimen is the mass of the specimen divided by the density as measured by ASTM D792. Nominal area is then found by dividing volume by the average length of the specimen. The average length of a typical bar specimen (e.g., circular or polygonal cross-section) is found by measuring the length of the outer edge of the specimen three times at the outer edge, rotating the specimen by 120 degrees for each measurement. Record the area in units mm^2 [in.^{2}]. Effective bar diameter, *d*, is found by equation (1):

$$d = 2\sqrt{(A/3.1416)} \tag{1}$$

Note 6—For a representative determination of area, specimens of at least 100 mm [4 in.] or one representative length (whichever is greater) shall be used. The mass of a specimen may exceed the limit imposed by ASTM D792 (50 grams) for large diameter bars, but the procedure may still be used.

11.2.5.2 *Standard cross-sectional area*—The standard cross-sectional area is the conventionally accepted area of a steel bar with the same number designation as a FRP bar being tested.

Note 7—Standard cross-sectional areas are taken as the cross-sectional areas of steel reinforcing bars as given in ASTM A615/A615M. FRP bars are often manufactured as substitutions for steel reinforcing bars, and are typically numbered using the same designations as steel bars, for example, a No. 4 bar has an effective diameter of 13 mm [0.5 in.] and a standard cross-sectional area of 129 mm^2 [0.20 in.^{2}]. For some applications it is considered appropriate to use the standard area for calculating stress and modulus of elasticity in FRP bars as this is the practice for steel bars.

11.2.6 Apply extensometers or strain gages to the specimen.

11.3 *Speed of Testing*—The speed of testing shall be set to effect a nearly constant strain rate in the gage section. The strain rate shall be selected so as to produce failure within 1 to 10 minutes from the beginning of force application. If the ultimate strain of the material cannot be reasonably estimated, conduct initial trials using standard speeds until the ultimate strain of the material and the compliance of the system are known, and the strain rate can be adjusted. The suggested standard strain rate is 0.01 min.$^{-1}$. If strain control is not available on the testing machine, a nominal cross-head speed of 0.01 min.$^{-1}$ times the specimen free length selected according to Section 8.2.1 shall be used.

11.4 *Test Environment*—Test at Standard Laboratory Atmosphere (23±3° C [73±5° F] and 50±10 % RH) unless a different environment is specified as part of the experiment. Recommendations for testing at other than standard laboratory conditions are given in Annex A2.

11.5 *Specimen Insertion*

11.5.1 If grips are used, place the specimen in the grips of the testing machine, taking care to align the longitudinal axis of the gripped specimen with the test direction. Tighten the grips, recording the pressure used on pressure controllable (hydraulic or pneumatic) grips.

11.5.2 If the anchor is attached to the loading head by threading or clevis, attach the specimen to the loading heads and removed any excess slack from the test fixture.

11.6 *Testing*—Apply extension to the specimen at the specified rate until failure occurs, while recording data.

11.7 *Data Recording*—Record force versus strain (or transducer displacement) continuously, or at frequent regular intervals; for this test method, a sampling rate of 2 to 3 data recordings per second, and a target minimum of 100 data points per test are recommended. If the specimen is to be failed, record the maximum force, the failure force, and the strain (or transducer displacement) at, or as near as possible to, the moment of rupture.

Note 8—Other valuable data that can be useful in understanding testing anomalies and gripping or specimen slipping problems includes force versus head displacement data and force versus time data.

11.8 *Failure Modes*—Record the mode and the location of failure of the specimen.

12. Validation

12.1 Values for ultimate properties shall not be calculated for any specimen that fails at some obvious flaw, unless such a flaw constitutes a variable being studied. Retests shall be performed for any specimen on which values are not calculated.

12.2 Re-examine the means of force introduction into the material if a significant fraction of failures in a sample population occur within or just outside any anchor or grip. Factors considered should include the anchor-to-test frame alignment, anchor material, anchor-to-specimen alignment, anchor filler and bonding agent, grip type, grip pressure, and grip alignment.

13. Calculation

13.1 *Tensile Stress/Tensile Strength*—Calculate the ultimate tensile strength using Eq 2 and report the results to three significant figures. If the tensile modulus is to be calculated, determine the tensile stress at each required data point using Eq 3.

$$F_{tu} = P_{max}/A \tag{2}$$

$$\sigma_i = P_i/A \tag{3}$$

where:

F_{tu} = Ultimate tensile strength, MPa [psi],
P_{max} = Maximum force prior to failure, N [lbf],
σ_i = Tensile stress at i-th data point, MPa [psi]
P_i = Force at i-th data point, N [lbf], and
A = Cross-sectional area of the bar from 11.2.5, mm^2 [in.^{2}].

13.2 *Tensile Strain/Ultimate Tensile Strain*—If tensile modulus or ultimate tensile strain is to be calculated, and material response is being determined by an extensometer, determine the tensile strain from the indicated displacement at each required data point using Eq 4 and report the results to three significant figures.

$$\varepsilon_i = \delta_i/L_g \tag{4}$$

where:

ε_i = tensile strain at i-th data point, mm/mm [in./in.]
δ_i = extensometer displacement at i-th data point, mm [in.], and
L_g = extensometer gage length, mm [in.].

13.3 *Tensile Modulus of Elasticity:*

13.3.1 *Tensile Chord Modulus of Elasticity*—Calculate the tensile chord modulus of elasticity from the stress-strain data using Eq 5. If data are not available at the exact strain range start and end points (as often occurs with digital data), use the closest available data point. The strain range is to be within the lower half of the stress-strain curve, with the start point being a strain of 0.001 and the end point being a strain of 0.003. For materials that fail at a strain below 0.006, the start point shall be 25 % of ultimate strain and the end point shall be 50 % of ultimate strain. Report the tensile chord modulus of elasticity to three significant figures.

$$E_{chord} = \Delta\sigma/\Delta\varepsilon \tag{5}$$

where:

E_{chord} = chord modulus of elasticity, MPa [psi],
$\Delta\sigma$ = difference in applied tensile stress between the starting and ending strain points, MPa [psi], and
$\Delta\varepsilon$ = difference in the average tensile strain between starting and ending strain points at the lower and upper bound of the selected strain range.

13.4 *Statistics*—For each series of tests calculate the average value, standard deviation, and coefficient of variation (in percent) for each property determined: