Designation: ~~D7205/D7205M – 06 (Reapproved 2016)~~ D7205/D7205M – 21

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~~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~~or a coating of bonded ~~particles~~ 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. ~~Recommended details for the anchors~~ Suggestions for a grouted type of anchor are provided in ~~Annex A1~~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 ~~may~~are not ~~be~~necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the ~~other. Combining~~other, and values from the two systems ~~may result in non-conformance with the standard.~~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~~ safety, health, and ~~health~~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.*

[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.

Current edition approved ~~Nov. 1, 2016~~May 15, 2021. Published ~~November 2016~~June 2021. Originally approved in 2006. Last previous edition approved in ~~2011~~2016 as ~~D7205/D7205M–06(2011).~~D7205/D7205M – 06(2016). DOI: ~~10.1520/D7205_D7205M-06R16.~~10.1520/D7205_D7205M-21.

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
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
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
~~E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases (Withdrawn 2015)[3]~~
~~E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases (Withdrawn 2015)[3]~~
~~E1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases (Withdrawn 2015)[3]~~

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~~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 ~~*effective diameter,*~~ *measured cross-sectional area, 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.~~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.

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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.

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

~~3.2.8 *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~~ 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.~~
A = cross-sectional area of a bar.
CV = sample coefficient of variation, in percent.
~~d = effective bar diameter~~
d = effective diameter of a bar.
~~E_{chord} = chord modulus of elasticity in the test direction.~~
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 load carried by a test coupon before failure.~~
P_{max} = maximum force carried by a test coupon before failure.
r^2 = coefficient of determination.
~~S_{n-1} = sample standard deviation.~~
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 ~~Annex A1~~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. ~~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~~ 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 ~~ASTM~~Practice E1012 for verification of specimen alignment under tensile loading.

6.4 *Measurement of Cross-Sectional Area*—The ~~nominal~~measured cross-sectional area of the bar is ~~measured~~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 ~~Practice~~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 ~~ASTM~~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. ~~Details of recommended anchors~~ Suggestions for a grouted anchor are provided in ~~Annex A1~~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~~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~~anchor.

7.4.1.1 Temperature compensation is recommended when not testing at Standard Laboratory Atmosphere. When appropriate, use either ~~(a)~~(*a*) a traveler specimen (dummy specimen) with identical bar material and extensometer(s) or ~~(b)~~(*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]~~±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~~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:*

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.]~~ 380 mm [15 in.] nor less than 40 times the effective bar diameter for bars with effective diameter of 26 mm [1.02 in.] or less. For bars with an effective diameter larger than 26 mm [1.02 in.], the free length shall not be less than 20 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 If not otherwise specified, the recommended pre-test condition is effective moisture equilibrium at a specific relative humidity as established by 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.however, if the test requestor does not explicitly specify a pre-test conditioning environment, no conditioning is required and the specimens may be tested as prepared.

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 whenThe term "moisture," as used in Test Method D5229/D5229Mequilibrium 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., includes not only the vapor of a liquid and its condensate, but the liquid itself in large quantities, as for immersion.

10.2 The pre-test specimen conditioning process, to include specified environmental exposure levels shall be reported with the test data.

10.3 If no explicit conditioning process is performed, the specimen conditioning process shall be reported as unconditioned and the moisture content as unknown.

NOTE 5—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 6—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.

11.2.2 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.

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

11.2.4 *Bar areaArea and diameter—Diameter—*Either the nominal measured cross-sectional area or the standardnominal cross-sectional area as givendescribed in ASTMSpecification A615/A615MD7957/D7957M is used to calculate stress and modulus of elasticity. elasticity for any type of FRP bar. In either case, the nominalmeasured cross-sectional area must be measuredcalculated and reported. If the nominalmeasured cross-sectional area differs from the standard cross-sectional area for the given baris not within minimum and maximum area limits provided in Specification D7957/D7957Msize by more than 20 percent, standard , the nominal cross-sectional area may not be used.

11.2.4.1 *Nominal cross-sectional area—Measured Cross-sectional Area—*The nominalmeasured 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 Test Methods D792 for test methods). The volume of the specimen is the mass of the specimen divided by the density as measured by ASTM Test Methods D792. Nominal The measured area is then found by dividing volume by the average length of the specimen. The average length of a typical bar specimen (e.g., (for example, circular or polygonal cross-section) 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 of mm^2 [in.^{2}]. Effective bar diameter, *d*, is found by Eq 1equation (1).:

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

NOTE 7—The use of effective bar diameter may not be appropriate for bars that are not solid and not substantially round in cross section.

NOTE 8—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 Test Methods D792 (50 grams) for large diameter bars, but the procedure may still be used.

11.2.4.2 *Standard cross-sectional area—Nominal Cross-sectional Area—*The standardnominal cross-sectional area is the conventionally acceptedfor FRP bars is described in Specification D7957/D7957Marea of a steel bar with the same number designation as a FRP bar being tested..

NOTE 9—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 standardnominal area for calculating stress and modulus of elasticity in FRP bars, as this is the practice for steel bars. glass FRP bars. While Specification D7957/D7957M was developed for glass FRP bars, the nominal cross-sectional areas in the specification are considered suitable for any composite bar.

11.2.5 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 or stress rate in the gage section. The strain speed of testing 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.

11.3.1 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 8.2.1 can be used.

11.3.2 The suggested standard stress rate is 300 MPa/min. [44 ksi/min.].

11.3.3 If the ultimate strength and strain of the material cannot be reasonably estimated, conduct initial trials using standard speeds until failure is produced in 1 to 10 minutes from the beginning of force application.

11.4 *Test Environment*—Test at Standard Laboratory Atmosphere ~~(23±3° C [73±5° F]~~ (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~~A1.

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 minimum sampling rate of 2 ~~to 3~~ data recordings per ~~second, and a target minimum of 100 data points per test are~~ second is 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 10—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 2and 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]~~
σ_i = Tensile stress at *i*-th data point, MPa [psi],
~~P_i = Force at *i-th* data point, N [lbf], and~~
P_i = Force at *i*-th data point, N [lbf], and
~~A = Cross-sectional area of the bar from 11.2.5, mm² [in.²].~~
A = Cross-sectional area of the bar from 11.2.4, 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.

$$\varepsilon_i = \delta_i / L_g \quad (4)$$

where:

ε_i = tensile strain at *i*-th data point, mm/mm [in./in.]
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—Modulus of Elasticity by the Method of Least Squares*—Calculate the tensile chord modulus of elasticity, *fromE,* the stress-strain and the coefficient of determination, r^2, by fitting a straight line to the data using Eq 5. If data are not available at the exact strain range start and end points (asthe method of linear least squares regression analysis (Annex A2 often occurs with digital data), use the closest available data point. The strain range). The strain range selected for fitting the line 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 0.003.0.006. For materials that fail at a strain below 0.006, the start point shall be 25 % of ultimate strain and the 0.012, the end point shall be 50 % of ultimate strain. Report the tensile chord modulus of elasticity 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. Report *E* to three significant figures and r^2 to four significant figures.

$$E_{chord} = \Delta\sigma / \Delta\varepsilon \quad (5)$$

The value of r^2 can be used as a diagnostic aid to determine how well the straight line fits the stress-strain data. At best, the value of r^2 is exactly 1. Values of r^2 less than approximately 0.995 call for a visual examination of the quality of fit to determine whether the stress-strain data should be represented by a straight line. Possible reasons for low coefficients of determination include nonlinearity and sudden jumps in the numerical stress-strain data. If a jump occurs within the recommended strain range, then a more suitable strain range shall be used and reported.

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:

$$\bar{x} = \left(\sum_{i=1}^{n} x_i \right) / n \quad (5)$$

$$\bar{x} = (\Sigma_{i=1}^{n} x_i) / n \quad (5)$$

$$s_{n-1} = \sqrt{\left(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2 \right) / (n-1)} \quad (6)$$

$$s_{n-1} = \sqrt{(\Sigma_{i=1}^{n} x_i^2 - n\bar{x}^2) / (n-1)} \quad (6)$$

$$CV = 1 \quad \times s_{n-1} / \bar{x} \quad (7)$$

$$CV = 100 \times s_{n-1} / \bar{x} \quad (7)$$

Where:where:

x^{-} = sample mean (average),
s_{n-1} = sample standard deviation,
CV = sample coefficient of variation, in percent,
n = number of tested specimens, and
x_1 = measured or derived property.
x_i = measured or derived property.

14. Report

14.1 Report the following information, or references pointing to other documentation containing this information, to the maximum extent applicable (reporting of items beyond the control of a given testing laboratory, such as might occur with material details or bar fabrication parameters, shall be the responsibility of the requestor).~~ The format for the reporting shall make use of Guides E1309, E1471, and E1434.~~

14.1.1 The revision level or date of issue of this test method.

14.1.2 The date(s) and location(s) of the test.

14.1.3 The name(s) of the test operator(s).

14.1.4 Any variations to this test method, anomalies noticed during testing or equipment problems occurring during testing.

14.1.5 Identification of the material tested including (if ~~available) : ~~available): material specification, material type, material designation, manufacturer, manufacturer's lot or batch number, source (if not from manufacturer), date of certification, expiration of certification, filament diameter, tow or yarn filament count and twist, sizing, form or weave, and matrix type.

14.1.6 If available, description of the fabrication steps used to prepare the bar including fabrication start date, fabrication end date, process specification, cure cycle, consolidation method, and a description of the equipment used.

14.1.7 Description of fiber architecture and surface characteristics of the bar. Indicate the representative length of the bar, if appropriate.

~~14.1.8 If requested, report density, volume percent reinforcement, and void content test methods, specimen sampling method and geometries, test parameters, and test results.~~

14.1.8 Minimum, maximum, and average value of the ~~nominal~~measured area of the bar and the average effective bar diameter.

14.1.9 Definition of cross-sectional area used in stress calculations: ~~nominal~~measured area or ~~standard~~nominal area.

14.1.10 Results of any nondestructive evaluation tests.

14.1.11 Method of preparing the test specimen, including specimen labeling scheme and method, specimen ~~geometry, ~~geometry (including free length, *L*), sampling method, and bar cutting method. Identification of anchor material, geometry, bonding agent such as expansive cementitious material, and bonding agent preparation and curing information.

14.1.12 Calibration dates and methods for all measurement and test equipment.

14.1.13 Type of test machine, grips, jaws, grip pressure, grip length and texture of grip faces, and data acquisition sampling rate and equipment type.

14.1.14 Results of system alignment evaluations, if any such evaluations were done.

14.1.15 Dimensions of each test specimen.

14.1.16 Conditioning parameters (environments, temperatures, relative humidities, durations) if other than that specified in the test method.

14.1.17 Relative humidity and temperature of the testing laboratory.

14.1.18 Environment of the test machine environmental chamber (if used).

14.1.19 Number of specimens tested.

14.1.20 Speed of testing.

14.1.21 Transducer placement on the specimen and transducer type for each transducer used.

14.1.22 Type of area used for stress-strain curve calculation: ~~nominal~~measured area or ~~standard~~nominal area.

14.1.23 Stress-strain curves and tabulated data of stress versus strain for each specimen.

14.1.24 Individual strengths and average value, standard deviation, and coefficientMaximum force prior to failure and ultimate tensile strength values for each specimen, average values, standard deviations, and coefficients of variation (in percent) for the population.sample. Note if the failure force was less than the maximum force prior to failure.

14.1.25 Individual strains at failure and the average value, standard deviation, and coefficient of variation (in percent) for the population.sample.

14.1.26 If another definition of modulus of elasticity is used in addition to chord modulus, modulus of elasticity by least squares, describe the method used, the resulting correlation coefficient of determination (if applicable), and the strain range used for the evaluation.

14.1.27 Individual values of modulus of elasticity, and elasticity and coefficient of determination, and the average value, standard deviation, and coefficient of variation (in percent) for the population.sample.

14.1.28 Failure mode and location of failure for each specimen.

15. Precision and Bias

15.1 *Precision*—The data required for the development of a precision statement is not available for this test method. Precision, defined as the degree of mutual agreement between individual measurements, cannot yet be estimated because of an insufficient amount of data.

15.2 *Bias*—Bias cannot be determined for this test method as no acceptable reference standard exists.

16. Keywords

16.1 tensile properties; bars; tensile strength;composite bars; composite materials; tensile modulus of elasticity; bars; tensile properties; composite materials; tensile strengthecomposite bars.

ANNEXES

(Mandatory Information)

A1. Recommended Anchor For Testing FRP Bars Under Tension

A1.1. Scope

A1.1.1 This annex describes the recommended anchor to facilitate gripping of FRP bar specimens for various types of tests performed under tensile loading. It also specifies preparation of the specimens. Other types of anchors may be used provided it is demonstrated that (a) failure of the bar occurs outside the anchors and (b) the anchors prevent excessive slip of the bar prior to tensile failure.

A1.2. Significance and Use

A1.2.1 This anchor is recommended for performing tests for monotonic tension, creep, relaxation, fatigue, and pullout bond strength of FRP bars.

A1.2.2 This anchor is not recommended for testing FRP bars that require more than 400 000 N [90 000 pounds] of force to fail the specimen.