Designation: 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 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:*

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 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 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; 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—The term "moisture," as used in Test Method D5229/D5229M, 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.

11.2 *General Instructions:*

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

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 Area and Diameter*—Either the measured cross-sectional area or the nominal cross-sectional area as described in Specification D7957/D7957M is used to calculate stress and modulus of elasticity for any type of FRP bar. In either case, the measured cross-sectional area must be calculated and reported. If the measured cross-sectional area is not within minimum and maximum area limits provided in Specification D7957/D7957M, the nominal cross-sectional area may not be used.

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

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

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

11.2.4.2 *Nominal Cross-sectional Area*—The nominal cross-sectional area for FRP bars is described in Specification D7957/D7957M.

NOTE 9—For some applications, it is considered appropriate to use the nominal area for calculating stress and modulus of elasticity in FRP bars, as this is the practice for 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 speed of testing rate shall be selected so as to produce failure within 1 to 10 minutes from the beginning of force application.

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] 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 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) at frequent regular intervals; for this test method, a minimum sampling rate of 2 data recordings per 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],
P_i = Force at *i*-th data point, N [lbf], and
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.

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

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 Modulus of Elasticity by the Method of Least Squares*—Calculate the tensile modulus of elasticity, *E*, and the coefficient of determination, r^2, by fitting a straight line to the data using the method of linear least squares regression analysis (Annex A2). 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 0.006. For materials that fail at a strain below 0.012, the end point shall be 50 % of ultimate strain. 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. 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.

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

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

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

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

where:

$\bar{x}$ = sample mean (average),
s_{n-1} = sample standard deviation,
CV = sample coefficient of variation, in percent,
n = number of tested specimens, and
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).

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): 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 Minimum, maximum, and average value of the measured area of the bar and the average effective bar diameter.

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

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

14.1.24 Maximum force prior to failure and ultimate tensile strength values for each specimen, average values, standard deviations, and coefficients of variation (in percent) for the 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 sample.

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

14.1.27 Individual values of modulus of elasticity and coefficient of determination, and the average value, standard deviation, and coefficient of variation (in percent) for the 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 bars; composite bars; composite materials; tensile modulus of elasticity; tensile properties; tensile strength

ANNEXES

(Mandatory Information)

A1. RECOMMENDED PROCEDURES FOR TESTING BARS AT OTHER THAN STANDARD LABORATORY CONDITIONS

A1.1 Scope

A1.1.1 This annex provides recommendations for testing bars in conditions that are other than standard laboratory conditions. These conditions may include immersion in water or other aqueous solution or elevated temperature or moisture conditions, or both.

A1.2 Conditioning

A1.2.1 Condition the specimen in the desired environment. Store the specimen in the conditioned environment until test time, if the testing environment is different than the conditioning environment.

A1.3 Test Environment

A1.3.1 Test under the specified exposure condition (for example, temperature, relative humidity, fluid exposure).

A1.3.2 *Testing at Elevated Moisture Levels*—Cases such as elevated temperature testing of a moist specimen may be beyond the capabilities of common testing machine environmental chambers. In such cases, testing at elevated temperature with no fluid exposure control may be necessary, and moisture loss during mechanical testing may occur. This loss can be minimized by reducing exposure time in the test chamber; although care should be taken to ensure that the specimen temperature is at equilibrium. This loss may be further minimized by increasing the relative humidity in an uncontrolled chamber by hanging wet, coarse fabric inside the chamber, and keeping it moist with a drip bottle placed outside the chamber. In addition, fixtures may be preheated, temperature may be ramped up quickly, and hold time at temperature may be minimized prior to testing. Environmentally conditioned traveler specimens, consisting of a bare bar with a length equal to one or more representative lengths with the cut ends protected from moisture transmission with a high grade moisture resistant resin, may be used to measure moisture loss during exposure to the test environment. Weigh a traveler specimen prior to testing and place it in the test chamber at the same time as the specimen. Remove the traveler specimen immediately after fracture and reweigh it to determine moisture loss. Record modifications to the test environment.

A1.3.3 Monitor test temperature by placing an appropriate thermocouple within 25 mm [1.0 in.] of the gage section of the specimen. Maintain temperature of the specimen and the traveler bar if one is being used for thermal strain compensation or moisture loss evaluation, within ±3 °C [±5 °F] of the required condition. Taping thermocouple(s) to the test specimen (and the traveler) is an effective measurement method.

A1.3.4 *Required Dimensions of Environmental Exposure Chamber*—Common testing machine environmental chambers are unlikely to be of sufficient size to hold the entire specimen at the specified test conditions. Non-uniform thermal and moisture profiles can be minimized by reducing exposure time in the test chamber. Report the dimensions of the environmental exposure chamber. Record the location of specimen failures and report the location of these failures relative to the position of the environmental chamber on the specimen.

A2. LINEAR LEAST SQUARES REGRESSION ANALYSIS

A2.1 Scope

A2.1.1 This annex provides the method of calculation of the tensile modulus of elasticity, E, and the coefficient of determination, r^2, in 13.3 using the method of linear least squares regression analysis. A linear least squares regression analysis minimizes the sum of the squared residuals, where a residual is defined as the difference between the fitted line and the actual stress data point at each strain data point. The coefficient of determination of the fit, r^2, indicates the goodness of fit achieved in a single test.

A2.2 Calculation

A2.2.1 The equations that follow are standard expressions and should correspond to those used in commercially available software packages that fit a linear equation to a set of data. However, the equations used by the software should be verified and the equations defined herein are to be utilized in the event of any differences.

A2.2.2 Calculate the tensile modulus of elasticity, E, using Eq A2.1:

$$E = \frac{\Sigma_{i=1}^{K}(\varepsilon_i\ \sigma_i) - n\bar{\sigma}\bar{\varepsilon}}{\Sigma_{i=1}^{K}\varepsilon_i^2 - n\bar{\varepsilon}^2} \tag{A2.1}$$

where:

K = total number of stress-strain data pairs used in the modulus calculation,

$\bar{\varepsilon}$ = $\frac{1}{K}\Sigma_{i=1}^{K}\varepsilon_i$, the average of the strain points used in the modulus calculation, and