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

This standard is issued under the fixed designation D7337/D7337M; 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 outlines requirements for tensile creep rupture testing of fiber reinforced polymer matrix (FRP) composite bars commonly used as tensile elements in reinforced, prestressed, or post-tensioned concrete.

1.2 Data obtained from this test method are used in design of FRP reinforcements under sustained loading. The procedure for calculating the one-million hour creep-rupture capacity is provided in Annex A1.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *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]

D883 Terminology Relating to Plastics
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
E4 Practices for Force Verification of Testing Machines
E456 Terminology Relating to Quality and Statistics
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

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 defines 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 apparatus, 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 *anchoring section, n*—the end parts of the specimen where an anchor is fitted to transmit the forces from the testing apparatus to the test section.

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

3.2.4 *creep, n*—time-dependent deformation (or strain) under sustained force (or stress).

3.2.5 *creep rupture, n*—material failure caused by sustained force (or stress) over time.

3.2.6 *creep rupture capacity, n*—the force at which failure occurs after a specified period of time from initiation of a sustained force. The predicted force causing failure at 1 million hours is referred to as the million-hour creep rupture capacity. This capacity is determined by the method described in the Annex.

3.2.7 *creep rupture strength, n*—the stress causing failure after a specified period of time from initiation of a sustained force.

3.2.8 *creep rupture time, n*—the lapsed time between the start of a sustained force and failure of the test specimen.

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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.

3.2.9 *failure, n*—rupture of the bar under test into two separate pieces.

3.2.10 *force ratio, n*—the ratio of a constant sustained force applied to a specimen to its tensile capacity as determined according to Test Method D7205/D7205M.

3.2.11 *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 [0.12 in.].

3.2.12 *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.

3.2.13 *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).

3.2.14 *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.

3.2.15 *test section, n*—the portion of a specimen between the anchoring sections of the test specimen.

3.3 *Symbols:* a_1, b_1 = empirical constants

A = nominal or standard cross-sectional area of a bar, see Test Method D7205/D7205M

F_r = stress carried by specimen at rupture

P_r = force carried by specimen at rupture

t = time, hours

Y_c = creep rupture trend line

4. Summary of Test Method

4.1 This test method consists of measuring the time to rupture of a bar subjected to a constant tensile force. Multiple force levels are specified by the method so that a relationship between force and time-to-failure can be derived.

5. Significance and Use

5.1 This method for investigating creep rupture of FRP bars is intended for use in laboratory tests in which the principal variable is the size or type of FRP bars, magnitude of applied force, and duration of force application. Unlike steel reinforcing bars or prestressing tendons subjected to significant sustained stress, creep rupture of FRP bars may take place below the static tensile strength. Therefore, the creep rupture strength is an important factor when determining acceptable stress levels in FRP bars used as reinforcement or tendons in concrete members designed to resist sustained loads. Creep rupture strength varies according to the type of FRP bars used.

5.2 This test method measures the creep rupture time of FRP bars under a given set of controlled environmental conditions and force ratios.

5.3 This test method is intended to determine the creep rupture data for material specifications, research and development, quality assurance, and structural design and analysis. The primary test result is the million-hour creep rupture capacity of the specimen.

5.4 Creep properties of reinforced, post-tensioned, or prestressed concrete structures are important to be considered in design. For FRP bars used as reinforcing bars or tendons, the creep rupture shall be measured according to the method given herein.

6. Interferences

6.1 *Gripping*—The method of gripping has been known to cause premature creep rupture in bars. Anchors, if used, shall be designed in such a way that the creep rupture capacity can be achieved without excessive slip throughout the length of the anchor during the test.

6.2 *System Alignment*—Excessive bending may cause premature failure. Every effort shall 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.

6.3 *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.

6.4 *Test Conditions*—Creep rupture is highly dependent upon environmental conditions such as, for example, temperature, humidity, and chemical agents. Every effort shall be made to test FRP bars for creep rupture under tightly controlled and monitored conditions (see Sections 7, 10 and 11 for requirements).

7. Apparatus

7.1 The testing apparatus shall be capable of applying and maintaining a force on the specimen within ±1 % of the desired sustained force.

7.2 *Test Apparatus*—Use a testing apparatus with a force capacity in excess of the tensile capacity of the specimen and calibrated according to Practices E4.

7.3 *Anchors*—Anchors, if used, shall be in accordance with Test Method D7205/D7205M.

7.4 *Temperature Control*—The temperature of the test environment shall be maintained at the specified temperature ±2°C [±4°F] during the test period. If no temperature is specified, maintain the temperature at 23°C [73°F].

7.5 *Environmental Test Chamber*—An environmental test chamber may be required for test environments other than ambient testing laboratory conditions. For environments where temperature is specified, the chamber shall be capable of maintaining the required temperature to within ±2°C [±4°F]. In addition, the chamber may have to be capable of maintaining environmental conditions such as fluid exposure or relative humidity during the test. For environments where relative humidity is specified, the chamber shall be capable of maintaining the required humidity to within ±10 %RH.

8. Sampling and Test Specimens

8.1 Specimens shall be representative of the lot or batch being tested. For grid-type FRP specimens, linear test specimens may be prepared by cutting away extraneous material in such a way as not to affect the performance of the part to be used. Leaving a minimum 2 mm [0.08 in.] projection of the cross bars is recommended. In the test section of the specimen, no postproduction machining, abrading, or other such processing is permitted. Such processing may be used in the anchoring sections to promote bond of the rod to the anchoring device.

8.2 During the sampling and preparation of test specimens, all deformation, heating, outdoor exposure to ultraviolet light, and other conditions possibly causing changes to the material properties of the specimen shall be avoided, unless these conditions are specified as part of the test procedure.

8.3 The length of the specimen shall be in accordance with Test Method D7205/D7205M.

8.4 The cross-sectional area of the specimen shall be determined in accordance with either of the two methods described in Test Method D7205/D7205M: nominal area or standard area.

8.5 If a specimen fails at or slips out of an anchoring section, an additional test shall be performed on a separate specimen taken from the same lot as the failed specimen.

8.6 A100 mm [4 in.] long specimen of the bar shall be used to determine the average moisture content of the as-received or as-conditioned bar before the start of creep rupture testing. The average moisture content shall be determined according to Procedure D, section 3.2.2, of Test Method D5229/D5229M.

8.7 A100 mm [4 in.] long traveler specimen of the same cross-section geometry and appropriate size (but without anchors) shall be used to determine the average moisture content of each bar after creep rupture testing. The ends of creep rupture 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. The average moisture content shall be determined according to Procedure D, section 3.2.2, of Test Method D5229/D5229M.

9. Test Matrix

9.1 The quasi-static tensile strength of the bars as determined by Test Method D7205/D7205M is used as a basis for selecting the applied tensile forces for creep rupture tests. At each given force ratio—for example, 80 %, 70 %, 60 % of the tensile strength—the applied force must be maintained constant until failure occurs while the time elapsed to rupture of each test specimen is recorded.

NOTE 1—The selection of force ratios is dependent on the fiber architecture and fiber volume fraction for the bar. Material systems with a high resistance to creep rupture (for example, carbon FRP composite) will necessitate the selection of closely-spaced force ratios at stress levels approaching 100 % of the quasi-static tensile strength. Material systems with less resistance to creep rupture (for example, glass FRP composite) will necessitate the selection of widely-spaced force ratios.

9.2 A minimum of four force ratios are required (see Fig. A1.1 for example). A minimum of 5 valid test results are required for each force ratio. For the entire group of tests reported, the range between the longest and shortest recorded rupture times shall be at least three decades. Data from specimens that break before the applied tensile force is fully applied to the specimen shall be disregarded.

NOTE 2—It is suggested that additional specimens be tested at each force ratio, especially for those force ratios that require long times to rupture.

9.2.1 The highest force ratio shall be selected such that at least four specimens in this group ruptures at a time of greater than 1 h.

NOTE 3—The highest force is specified with the aim of minimizing the effects of the initial loading ramp on the creep rupture time.

9.2.2 The lowest force ratio shall be selected such that at least one specimen in this group ruptures at a time of greater than 8000 h.

NOTE 4—The lowest force is specified with the aim of limiting the extent of extrapolation required to determine the one million hour creep rupture capacity.

9.2.3 The remaining force ratios shall be roughly equally spaced in relation to the highest and lowest force ratios determined in 9.2.1 and 9.2.2, respectively.

10. Conditioning

10.1 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.

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

NOTE 5—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.

10.3 If no explicit conditioning process is performed the specimen conditioning process shall be reported as "unconditioned".

11. Procedure

11.1 The mounting of the specimen in the test fixture shall be in accordance with Test Method D7205/D7205M.

11.2 Test specimens shall not be subjected to any dynamic effects, vibration, or torsion during testing.

11.3 The full load shall be applied to the specimen in a time between 20 s and 5 min. Time to creep rupture shall be measured from the moment when the specimen has attained the prescribed force.

NOTE 6—The load should be applied in a manner that precludes impact forces on the specimen. For frames using weights to load the specimen, it is suggested that the weights be supported temporarily on a hydraulic jack or pneumatic bladder, and then the load transferred linearly to the specimen by slowly releasing the pressure on the jack or bladder.

12. Validation

12.1 Failure times should not be recorded for any specimen that fails at some obvious flaw, unless such a flaw constitutes a variable being studied.

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. Report

13.1 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):

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

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

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

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

13.1.5 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.

13.1.6 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.

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

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

13.1.9 Minimum, maximum and average value of the nominal area of the bar and the average bar diameter.

13.1.10 Results of any nondestructive evaluation tests.

13.1.11 Method of preparing the test specimen, including specimen labeling scheme and method, specimen geometry, 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.

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

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

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

13.1.15 Dimensions of each test specimen.

13.1.16 Conditioning parameters and results, use of travelers and traveler geometry, and the procedure used, if other than that specified in the test method.

13.1.17 Moisture content of specimen sample at start of creep rupture testing.

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

13.1.19 Number of specimens tested at each force ratio.

13.1.20 Time duration of initial loading of each specimen.

13.1.21 Average tensile capacity and quasi-static tensile strength of similar specimens from same batch of material as used for the creep rupture specimens.

13.1.22 Type of area used for stress calculation: nominal area or standard area.

13.1.23 Force ratio, rupture strength and rupture time for each specimen. Include elapsed time of testing for specimens that did not fail. Force ratio versus time curve as defined in Annex A1.

13.1.24 Empirical constants a_1 and b_1 from Eq A1.1 of Annex A1, along with regression coefficient R^2.

13.1.25 The million-hour creep-rupture force ratio, rupture capacity, and rupture strength, as defined in Annex A1.

13.1.26 Average moisture content of the unloaded traveler specimens, at the end of each test.

13.1.27 Failure mode and location of failure for each specimen.

14. Precision and Bias

14.1 *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.

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

15. Keywords

15.1 bars; composite bars; composite materials; creep rupture; rebar; reinforcing bars; tensile properties; tensile strength

ANNEX

(Mandatory Information)

A1. METHOD FOR CALCULATING MILLION-HOUR CREEP RUPTURE CAPACITY

A1.1 Scope

A1.1.1 This Annex describes the method for calculating the million-hour creep rupture capacity of FRP bars given the reported test results.

A1.2 Significance and Use

A1.2.1 The million-hour creep rupture capacity can be used for material screening purposes and in structural design codes to limit the sustained-level stresses in FRP bars.

A1.3 Calculation

A1.3.1 The force ratio versus creep rupture time curve shall be plotted on a semi-logarithmic graph where the force ratio is represented on an arithmetic scale along the vertical axis and creep rupture time in hours is represented on a logarithmic scale along the horizontal axis (see Fig. A1.1). Tests resulting in no failure (run-outs) shall be included in this plot but should not be included in the calculation of the creep rupture trend line. Run outs should clearly be identified as such on the graph.

A1.3.2 A creep rupture trend line shall be plotted from linear regression of the data by means of the least-square method according to Eq A1.1:

$$Y_c = a_1 - b_1 \log t \tag{A1.1}$$

where:

Y_c = force ratio, expressed as a percentage of quasi-static tensile strength,
a_1, b_1 = empirical constants, and
t = time, h.

A1.3.3 The force ratio at 1 million hours, as determined from the linear extrapolation of the trendline, shall be taken as the million-hour creep-rupture force ratio. The force and stress corresponding to the million-hour creep rupture force ratio are the million-hour creep rupture capacity and the million-hour creep rupture strength, respectively. The million-hour creep rupture strength is calculated according to Eq A1.2, with a precision to three significant digits:

$$F_r = \frac{P_r}{A} \tag{A1.2}$$

where:

F_r = million-hour creep rupture strength of FRP bar, MPa [psi],
P_r = million-hour creep rupture capacity, N [lbf], and
A = cross-sectional area of specimen, mm^2 [$in.^2$] as determined according to Section 11 of Test Method D7205/D7205M.

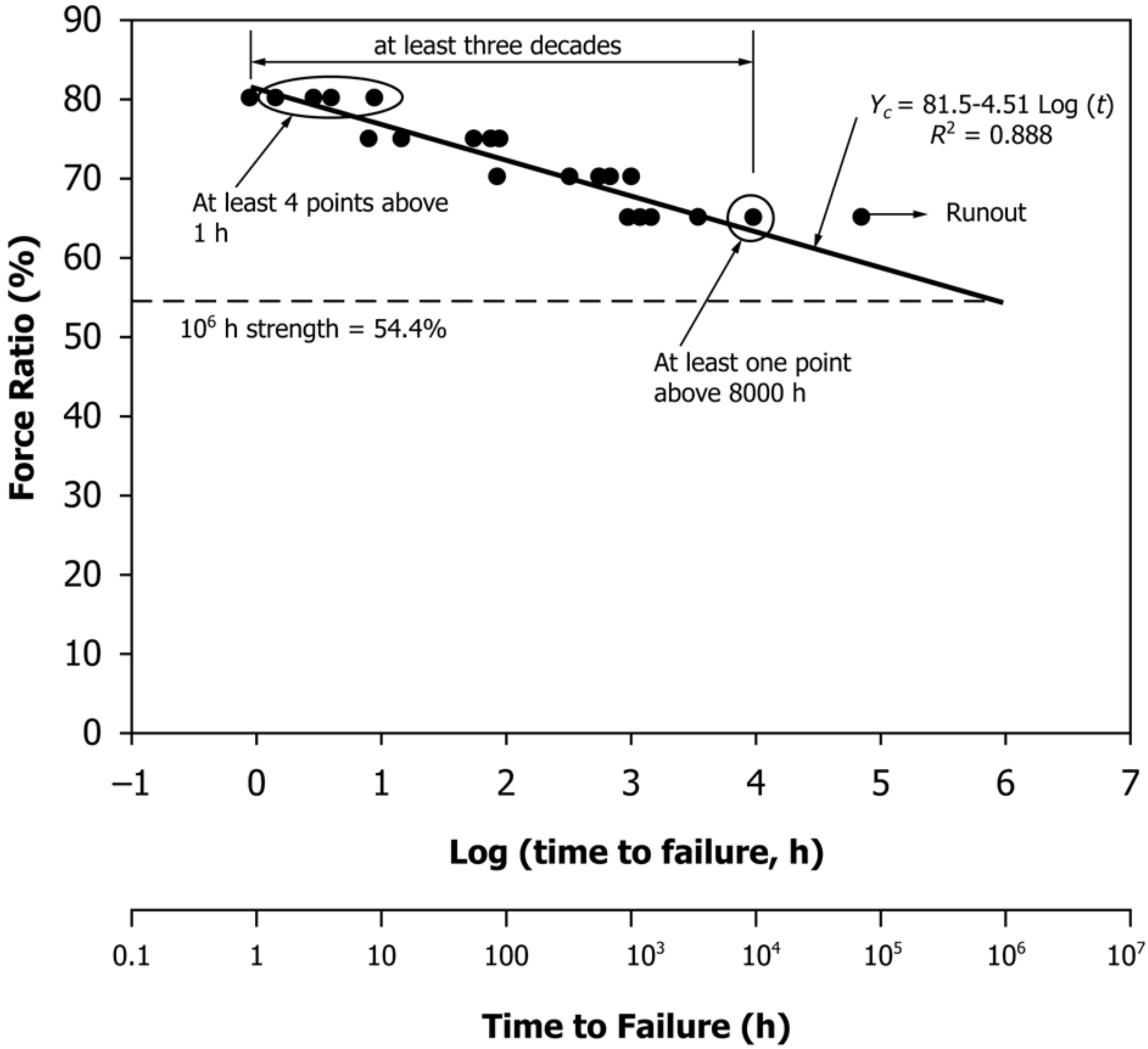

FIG. A1.1 Example Logarithmic Time to Failure (Stress Rupture) Curve