Designation: D8069 – 17

Standard Test Method for Determining Flexural Modulus of Full Section Pultruded Fiber Reinforced Polymer (FRP) Composite Members with Doubly Symmetric Cross Sections under Bending[1]

This standard is issued under the fixed designation D8069; 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 covers the determination of Flexural Modulus of pultruded open and closed fiber reinforced polymer (FRP) composites of doubly symmetrical cross sections about their geometric centroid subjected to flexure and shear. This test method utilizes a three-point loading system applied to a simply supported beam.

1.2 The values stated in SI units are to be regarded as the standard. The values provided in parentheses are for information only.

1.3 *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
D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D3878 Terminology for Composite Materials
D4000 Classification System for Specifying Plastic Materials
D4762 Guide for Testing Polymer Matrix Composite Materials
D7290 Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases (Withdrawn 2015)[3]
E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases (Withdrawn 2015)[3]
E2309/E2309M Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines

3. Terminology

3.1 *Definitions*—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. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other terminologies.

3.2 Definitions of variables used in calculations as shown in Section 11 and 12 are as follows:

$P_{20\%}$ ≅ 20% of estimated ultimate load, N (lbf)
I = moment of inertia about the neutral axis, mm^4 ($in.^4$)
L = test span length, mm (in.)
h = total height of test specimen, mm (in.)
$P_{5\%}$ ≅ 5% of estimated ultimate load, N (lbf)
P = load value used to calculate E, N (lbf)
δ = deflection value used to calculate E, mm (in.)
$\delta_{20\%}$ ≅ deflection at 20% of estimated ultimate load, mm (in.)
$\delta_{5\%}$ ≅ deflection at 5% of estimated ultimate load, mm (in.)
E = Flexural modulus, MPa (psi)

4. Summary of Test Method

4.1 The full-scale specimen rests on two rounded solid metal cylindrical supports or pivoted end supports and is loaded by means of a loading ram located midway between the

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.18 on Reinforced Thermosetting Plastics.

Current edition approved Jan. 1, 2017. Published January 2017. DOI: 10.1520/D8069-17.

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

supports. The beam span-to-depth ratio (L/h) should be within the range of $20 \leq L/h \leq 32$ to determine the flexural modulus.

4.2 The maximum load placed on the specimen shall be approximately equal to 20 percent of the estimated ultimate load determined in accordance with 11.10.

4.3 Load and deflection are recorded at mid-span during all stages of the test procedure as outlined in Section 11.

4.4 If a span specified by the user, in the contract for a particular application, is under the span-to-depth ratio of 20 ($L/h < 20$) or over 32 ($L/h > 32$), the flexural modulus shall be reported as apparent flexural modulus.

5. Significance and Use

5.1 Determination of flexural modulus by this test method is especially useful for quality control and specification purposes.

5.2 Experimental values for flexural modulus will vary with specimen depth, span length, loading rate, ambient test temperature, and other atmospheric conditions.

5.3 Before proceeding with this test method, reference should be made to the specification of the material being tested, including constituent materials of the specimen. Any test specimen preparation, environmental or loading conditioning, dimensions, or testing parameters covered in the material specification, or both, shall take precedence over those mentioned in this test method. If there are no material specifications, then these default conditions apply. Table 1 in Classification D4000 lists the ASTM materials standards that currently exist.

6. Apparatus

6.1 *Testing Machine*—A properly installed and operated hydraulic or mechanical load actuator, ideally one which can be operated at constant rates of load or deflection, is used in combination with a properly calibrated load cell. Error in the load measuring system shall not exceed ±1% of the maximum load expected to be measured. The test setup shall also be equipped with deflection measuring devices. The stiffness of the testing apparatus shall be such that the total elastic deformation of the load frame does not exceed 1% of the total deflection of the test specimen during testing, or appropriate corrections shall be made. The accuracy of the testing machine shall be calibrated and verified in accordance with Practices E4.

6.2 *Reaction Supports and Loading Nose*—The beam specimen shall be placed over two rounded metal cylindrical supports or over pivoted bearing surfaces which can accommodate free rotation at the ends of the beam specimen. If the metal cylindrical supports or pivoted bearing surfaces cause any local crushing to the test specimen under loading, the beam specimen shall be supported by metal bearing plates to prevent damage to the beam at the point of contact between the beam specimen and reaction support. The plates shall be of sufficient length, thickness, and width to provide a firm bearing surface and ensure a uniform bearing stress across the flange width of the beam specimen. The bearing plates shall be supported by devices that provide unrestricted longitudinal deformation and rotation of the beam specimen at the reactions due to loading.

6.3 *Loading Nose*—The transverse loading at the center of the test specimen span shall be applied through a metal block with 4 in. width (along the length of the beam specimen) by ½ in. thick, with rounded edges or with a radius of curvature approximately equal to two times the beam specimen depth, extending across the entire specimen flange width. If the user chooses to test the specimen by placing an elastomeric pad in between the metal block and the top flange surface of the beam specimen to avoid any local crushing of the sample, a ½ in. thick Shore A durometer hardness 40 to 60 shall be used and the deflection shall be measured at the bottom flange surface of the test specimen using a dial gauge or LVDT.

6.4 *Measuring Devices for Sectional Dimensions*—All measuring devices used to measure cross-sectional dimensions shall be accurate to within ±0.0254 mm (±0.001 in.). Devices used to measure span length shall be accurate to within ± 1.5875 mm (±1⁄16 in.).

6.5 *Deflection Measuring Device*—A properly calibrated device to measure the deflection of the beam at mid-span shall be used. The device shall record the deflection during the test for certain magnitude of applied load (in accordance with 11.10). In the absence of an automated system, a properly calibrated deflection dial gauge may be used with at least one reading for every five seconds throughout the duration of the test. The deflection dial gauge shall be accurate to ±0.0254 mm (±0.001 in).

7. Sampling and Test Specimens

7.1 *Sampling*—Test at least five specimens per test condition unless valid results within 1 % can be gained through the use of at least three specimens, as in the case of a designed experiment.

7.2 *Specimens*—The test beam specimens shall be molded shapes manufactured using a pultrusion process. Specimens shall be full-scale samples, tested at the desired span length. The span-to-depth ratio of specimens shall never be less than 20 or greater than 32 unless the sample needs to be tested in accordance with 13.4 for apparent modulus. Sufficient overhang (a length of 5 % - 10 % of the test span) shall be provided over each end support to prevent sample from slipping from the supports.

7.3 *Specimen Preparation*—Take precautions when cutting beam specimens to the desired span length to avoid notches, rough or uneven surfaces, or delaminations due to inappropriate test specimen preparation methods. The use of diamond coated machining tools are recommended in the preparation of test specimens.

7.4 *Labeling*—Label the test specimens (date, batch number, line number) so that they will be distinct from each other and traceable back to the specimen of origin of manufacturing, and will neither influence the test nor be affected by it.

8. Hazards

8.1 Precautions shall be taken to prevent the sample from kicking out of place under increasing transverse load resulting in lateral torsional movement, to avoid any accidents while testing under 3-point bending.

9. Calibration

9.1 The accuracy of all testing and measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

10. Conditioning

10.1 If the test requestor does not explicitly specify a pre-test conditioning environment, conditioning is not required and the test specimens may be tested at normal room temperature (20-25°C or 68-77°F).

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

11. Test Setup and Procedure

11.1 If needed, condition test specimens as required. Store the test specimens in the conditioned environment until test time if the test environment is different than the conditioning environment.

11.2 Before testing, measure and record the cross-sectional shape and dimensions as necessary. Record the dimensions to three significant figures.

11.3 Measure and record the length of the support and loading spans.

11.4 *Rate of Testing*—Set the loading nose displacement to be continuous and at a rate as calculated by Eq 1:

$$R = (Z \times L^2)/(6 \times h) \tag{1}$$

where:

R = loading nose displacement rate, mm/min (in./min),
Z = rate of straining of the outer fiber, mm/mm/min (in./in./min), which shall be rangning from 0.001 to 0.0008,
L = test span length, mm (in.), and
h = depth of test specimen, mm (in.).

11.5 The actual loading nose displacement rate range shall be within ±10 % of that calculated by Eq 1.

11.6 *Fixture Installation*—Arrange the loading fixture for a three-point bend test, and place specimen in the testing apparatus accordingly.

11.7 *Specimen Insertion and Alignment*—Place the specimen into the test fixture. Align the fixture and specimen so that the longitudinal axis of the specimen is perpendicular (within 1°) to the longitudinal axis of the loading nose, and the loading nose is parallel (within 1°) to the plane of the top face of the specimen.

11.8 *Loading*—Apply force at the mid-span of the specimen for three-point bending (Section 6) at the rate calculated in 11.4 while recording data. Even though continuous recording is recommended, discrete recording of load-displacement data shall be permitted.

NOTE 1—Discrete recording may result in slightly lower bending modulus. When using any deflection measuring device, other than one that continuously records deflection vs. force (stress vs. strain) for modulus determinations a compliance correction must be applied as per the appendix of ASTM D790 under "Development of a Flexural Machine Compliance Correction."

11.9 If the user chooses to use a LVDT or a dial gauge, place a deflection measuring device under the bottom flange of the beam specimen in the line of loading at the mid-span.

11.10 The beam specimens shall be loaded up to 20 % of the estimated failure load using the formula given in Eq 2.

For SI Units, (2)

$$P_{20\%} = (230 \times S)/L$$

For US Customary Units,

$$P_{20\%} = (33600 \times S)/L$$

where:

$P_{20\%}$ ≅ 20 % of estimated ultimate load, N (lbf),
S = section modulus of the sample about the plane of bending, mm^3 ($in.^3$), and
L = test span length, mm (in.).

NOTE 2—The maximum failure load can be estimated by back calculating the stresses related to an estimated maximum strain of 15000 micro strains and an estimated bending modulus of 19,300 MPa (2.8×10^6 psi)

NOTE 3—If the EOR (Engineer of Record) or the user requires taking the sample to failure in accordance with the contract, proper precautions shall be followed as given in Section 8 to prevent any accidents. The ultimate failure load and mode of failure shall be reported. In this case, the bending modulus shall be calculated in accordance with 13.2 using the load and deflections at 20% and 5% of the ultimate failure load.

Similarly, the estimated 5% ultimate load can be calculated as given in Eq 3.

For SI Units, (3)

$$P_{5\%} = (58 \times S)/L$$

For US Customary Units,

$$P_{5\%} = (8400 \times S)/L$$

where:

$P_{5\%}$ ≅ 5 % of estimated ultimate load, N (lbf),
S = section modulus of the sample about the plane of bending, mm^3 ($in.^3$), and
L = test span length, mm (in.).

11.11 *Data Recording*—Record load and vertical mid-span deflection versus time data continuously, or at least five recordings per second in case of automatic data acquisition system usage and at least one recording per five seconds in case of manual recording use a mechanical dial gauge. Record the maximum applied load and corresponding deflection at that load.

12. Validation

12.1 Values for Flexural Modulus shall not be calculated for any sample which becomes damaged prior to or during testing. Do not exceed applied theoretical equivalent to 20 % of the assumed ultimate stress in accordance with 11.10.

12.2 If more than 50 % of the samples are damaged in a sample population, the test fixture shall be re-examined and/or the estimated 20 % failure load in accordance with 11.10 shall be re-established

13. Calculation

13.1 Determine the deflections corresponding to 20 % and 5 % of loads as determined in 11.10.

13.2 The difference in load and deflection values corresponding to load levels at 20% of the ultimate load and at 5% of the ultimate load are taken to eliminate the initial settling in the test system, thus only accounting for the linear portion of the load-deflection curve. These intermediate values are calculated as shown in Eq 4 and 5 using experimental values obtained during three-point bend testing.

$$P = P_{(20\ \%)} - P_{(5\ \%)} \quad (4)$$

$$\delta = \delta_{(20\ \%)} - \delta_{(5\ \%)} \quad (5)$$

where:

P = load value, N (lbf),
$P_{20\%}$ ≅ 20 % of estimated ultimate load, N (lbf),
$P_{5\%}$ ≅ 5 % of estimated ultimate load, N (lbf),
δ = deflection value used to calculate E, mm (in.),
$\delta_{20\%}$ ≅ deflection at 20 % of estimated ultimate load from three-point bend testing mm (in.), and
$\delta_{5\%}$ ≅ deflection at 5 % of estimated ultimate load from three-point bend testing mm (in.).

13.3 By plugging these intermediate values from Eq 4 and 5 into Eq 6, the flexural modulus for the three-point loading scenario can be obtained.

$$E = (P \times L^3)/(48 \times \delta \times I) \quad (6)$$

where:

E = flexural modulus, MPa (psi),
P = load value from Eq 4, N (lbf),
L = test span length, mm (in),
δ = deflection value from Eq 5, mm (in.), and
I = moment of inertia about the neutral axis, $in.^4$.

13.4 *Determination of Apparent Modulus*—If the span to depth ratio used to determine the modulus value is in between 6 and 20 (6 < L/h < 20) or greater than 32 (L/h > 32) then that modulus shall be reported as apparent flexural modulus as the modulus calculated is influenced by the shear deflection along with flexural deflection for 6 < L/h < 20 and by non-linearity for span-to-depth ratios over 32 (L/h > 32) respectively.

14. Report

14.1 Report the following information:

14.1.1 Identification of material tested, including manufacturer, resin system, fiber type, and cross-sectional shape.

14.1.2 Conditioning procedure (if required).

14.1.3 Cross-sectional dimensions and required section properties.

14.1.4 Span length(s) tested and L/h used for the test.

14.1.5 Radius of supports and loading ram.

14.1.6 Description of type of data acquisition method used (Automatic or Manual).

14.1.7 Rate of loading.

14.1.8 Experimental values, including maximum applied load and corresponding maximum deflection.

14.1.9 Calculated values for flexural modulus.

14.1.10 Any deviations from this test method, whether intentional or inadvertent.

15. Precision and Bias[4]

15.1 The precision of this test method is based on an intralaboratory study of ASTM D8069 conducted in 2016. A single laboratory participated in this study, testing seven different tube configurations. Every "test result" represents an individual determination. The laboratory reported duplicate test results for each material. Except for the use of only one laboratory, Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. D20-1268.

15.1.1 *Repeatability (r)*—The difference between repetitive results obtained by the same operator in a given laboratory applying the same test method with the same apparatus under constant operating conditions on identical test material within short intervals of time would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

15.1.1.1 Repeatability can be interpreted as maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

15.1.1.2 Repeatability limits are listed in Tables 1 and 2.

15.1.2 *Reproducibility (R)*—The difference between two single and independent results obtained by different operators

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1268. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Flexural Modulus (MPa)

	Average $\bar{x}$	Repeatability Standard Deviation S_r	Repeatability Limit R
152.4 mm × 9.53 mm SQTB (L/h = 24)	21718.485	223.390	624.665
152.4 mm × 9.53 mm SQTB (L/h = 30)	22959.541	91.700	256.484
101.6 mm × 9.53 mm SQTB (L/h = 30)	24407.441	117.900	329.569
101.6 mm × 6.35 mm SQTB (L/h = 30)	22545.856	213.737	597.775
88.9 mm × 6.35 mm SQTB (L/h = 30.86)	24614.283	188.916	529.517
50.8 mm × 6.35 mm SQTB (L/h = 26)	26613.763	208.911	585.364
44.5 mm × 6.35 mm SQTB (L/h = 29.71)	18340.054	106.179	297.164

TABLE 2 Flexural Modulus (psi)

	Average $\bar{x}$	Repeatability Standard Deviation S_r	Repeatability Limit R
6 in. × ⅜ in. SQTB (L/h = 24)	3.15E + 06	3.24E + 04	9.06E + 04
6 in. × ⅜ in. SQTB (L/h = 30)	3.33E + 06	1.33E + 04	3.72E + 04
4 in. × ⅜ in. SQTB (L/h = 30)	3.54E + 06	1.71E + 04	4.78E + 04
4 in. × ¼ in. SQTB (L/h = 30)	3.27E + 06	3.10E + 04	8.67E + 04
3.5 in. × ¼ in. SQTB (L/h = 30.86)	3.57E + 06	2.74E + 04	7.68E + 04
2 in. × ¼ in. SQTB (L/h = 26)	3.86E + 06	3.03E + 04	8.49E + 04
1.75 in. × ¼ in. SQTB (L/h = 29.71)	2.66E + 06	1.54E + 04	4.31E + 04

applying the same test method in different laboratories using different apparatus on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

15.1.2.1 Reproducibility can be interpreted as maximum difference between two results, obtained under reproducibility conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

15.1.2.2 Reproducibility limits cannot be calculated from a single laboratory's results.

15.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

15.1.4 Any judgment in accordance with 9.1.1 would normally have an approximate 95 % probability of being correct, however the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of laboratories reporting replicate results essentially guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the repeatability limit as a general guide, and the associated probability of 95 % as only a rough indicator of what can be expected

15.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

15.3 The precision statement was determined through statistical examination of 14 test results, from a single laboratory, on the seven tube materials.

16. Keywords

16.1 full section flexural modulus; full section testing; FRP; pultrusion

BIBLIOGRAPHY

(1) Estep, D, Hota V.S. Gangarao, Dittenber B David, Qureshi, A Muhammed. "Response of Pultruded Glass Composite Box Beams Under Bending and Shear." *Composite Part B 88*, 2016, 150-161

(2) Nagaraj, V, GangaRao, H. "Static Behavior of Pultruded GFRP Beams." *J Compos Constr*, 1997; 1(3): 120–129.

(3) Timoshenko, S. *Strength of Materials, Part II: Advanced Theory and Problems*. 3rd ed. Princeton, NJ: D. Van Nostrand Company, Inc., 1966: 300-345.

(4) Boresi, A, Schmidt, R. *Advanced Mechanics of Materials*. 6th ed. New York: John Wiley & Sons, 2003: 159-160.