



Designation: D 6115 – 97

Standard Test Method for Mode I Fatigue Delamination Growth Onset of Unidirectional Fiber-Reinforced Polymer Matrix Composites¹

This standard is issued under the fixed designation D 6115; 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 number of cycles (N) for the onset of delamination growth based on the opening mode I cyclic strain energy release rate (G), using the Double Cantilever Beam specimen shown in Fig. 1. This test method applies to constant amplitude, tension-tension fatigue loading of continuous fiber-reinforced composite materials. When this test method is applied to multiple specimens at various G -levels, the results may be shown as a G - N curve, as illustrated in Fig. 2.

1.2 This test method is limited to use with composites consisting of unidirectional carbon fiber tape laminates with single-phase polymer matrices. This limited scope reflects the experience gained in round robin testing. This test method may prove useful for other types and classes of composite materials, however, certain interferences have been noted (see Section 6.5 of Test Method D 5528).

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

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:

- D 883 Terminology Relating to Plastics²
- D 2584 Test Method for Ignition Loss of Cured Reinforced Resins³
- D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding⁴
- D 2734 Test Method for Void Content of Reinforced Plastics³

¹ This specification is under the jurisdiction of ASTM Committee D-30 on High Modulus Fibers and Their Composites and is the direct responsibility of Subcommittee D30.06 on Interlaminar Properties.

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² Annual Book of ASTM Standards, Vol 08.01.

³ Annual Book of ASTM Standards, Vol 08.02.

⁴ Annual Book of ASTM Standards, Vol 15.06.

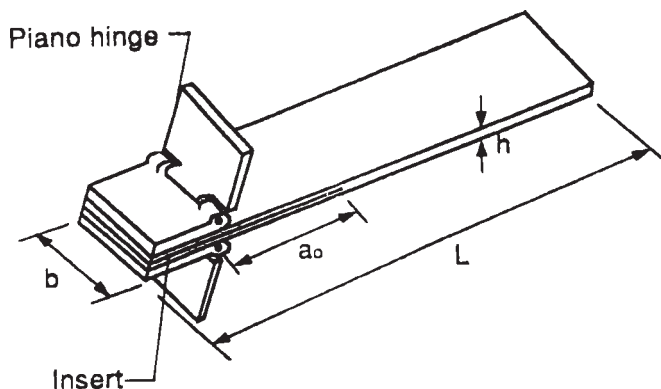


FIG. 1 DCB Specimen with Piano Hinges

D 3171 Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion⁵

D 3878 Terminology of High-Modulus Reinforcing Fibers and Their Composites⁵

D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials⁵

D 5528 Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites⁵

E 4 Practices for Force Verification of Testing Machines⁶

E 6 Terminology Relating to Methods of Mechanical Testing⁶

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process⁷

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods⁷

E 456 Terminology Relating to Quality and Statistics⁷

E 467 Practice for Verification of Constant Amplitude Dynamic Loads on Displacements in an Axial Load Fatigue Testing System⁶

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁷

⁵ Annual Book of ASTM Standards, Vol 15.03.

⁶ Annual Book of ASTM Standards, Vol 03.01.

⁷ Annual Book of ASTM Standards, Vol 14.02.

E 739 Practice for Statistical Analysis of Linear or Linearized Stress-Life ($S-N$) and Strain-Life $\epsilon-N$ Fatigue Data⁶
 E 1049 Practices for Cycle Counting in Fatigue Analysis⁶
 E 1150 Definitions Relating to Fatigue⁶

3. Terminology

3.1 Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 define terms relating to statistics. Definition E 1150 defines terms relating to fatigue. In the event of conflict between terms, Terminology D 3878 shall have precedence over the other terminology standards.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *crack opening mode (Mode I)*—fracture mode in which the delamination faces open away from each other and in which these faces do not undergo any relative sliding.

3.2.2 *cycles to onset of delamination growth*, N_a —the number of fatigue cycles elapsed until the onset of delamination growth from an implanted thin insert.

3.2.3 *fatigue delamination growth onset relationship*, $G-N$ —the relationship between the peak cyclic value of strain energy release rate to the number of fatigue cycles until the onset of delamination growth, N_a .

3.2.4 *mode I interlaminar fracture toughness*, G_{Ic} —the critical value of G for delamination growth because of an opening load or displacement.

3.2.5 *strain energy release rate*, G —the loss of strain energy, dU , in the test specimen per unit of specimen width for an infinitesimal increase in delamination length, da , for a delamination growing under a constant displacement. In mathematical form:

$$G = -\frac{1}{b} \frac{dU}{da} \quad (1)$$

where:

U = total elastic strain energy in the test specimen,

b = specimen width, and

a = delamination length.

3.3 Symbols:

3.3.1 a —delamination length.

3.3.2 a_0 —initial delamination length.

3.3.3 b —width of DCB specimen.

3.3.4 C —compliance, δ/P , of DCB specimen.

3.3.5 CV —coefficient of variation, %.

3.3.6 da —infinitesimal increase in delamination length.

3.3.7 dU —infinitesimal increase in strain energy.

3.3.8 E_{II} —modulus of elasticity in the fiber direction.

3.3.9 G —strain energy release rate.

3.3.10 G_{Ic} —opening mode I interlaminar fracture toughness.

3.3.11 $[G_{Ic}]_{av}$ —average values of G_{Ic} from the quasi-static tests.

3.3.12 $G_{I_{max}}$ —maximum or peak cyclic mode I strain energy release rate.

3.3.13 $G-N$ —relationship between the cyclic strain energy release rate and the number of cycles to onset of delamination growth.

3.3.14 h —thickness of DCB specimen.

3.3.15 N —number of elapsed fatigue cycles.

3.3.16 N_a —application dependent value of N at which delamination growth onset will occur.

3.3.17 $N_a^{1\%}$ —number of fatigue cycles for the value of P_{max} at $N = 1$ to decrease by 1 %.

3.3.18 N_a^{vis} —number of fatigue cycles at which the onset of delamination growth is observed.

3.3.19 $N_a^{5\%}$ —number of fatigue cycles for the value of P_{max} at $N = 1$ to decrease by 5 %.

3.3.20 P —applied load.

3.3.21 P_{cr} —value of load at the onset of delamination growth from the insert in the quasi-static tests.

3.3.22 P_{max} —maximum cyclic load.

3.3.23 R —ratio of minimum and peak loads P_{min}/P_{max} .

3.3.24 SD —standard deviation.

3.3.25 U —strain energy.

3.3.26 V_f —fiber volume fraction, %.

3.3.27 δ —load point deflection.

3.3.28 δ_{cr} —value of displacement at the onset of delamination growth from the insert in a quasi-static test.

3.3.29 δ_{max} —maximum value of cyclic displacement.

3.3.30 δ_{mean} —mean value of cyclic displacement.

3.3.31 δ_{min} —minimum value of cyclic displacement.

3.3.32 Δ —effective delamination extension to correct for rotation of DCB arms at delamination front.

3.3.33 $[\Delta]_{av}$ —average value of Δ from the quasi-static tests.

4. Summary of Test Method

4.1 The Double Cantilever Beam (DCB) shown in Fig. 2 is described in Test Method D 5528.

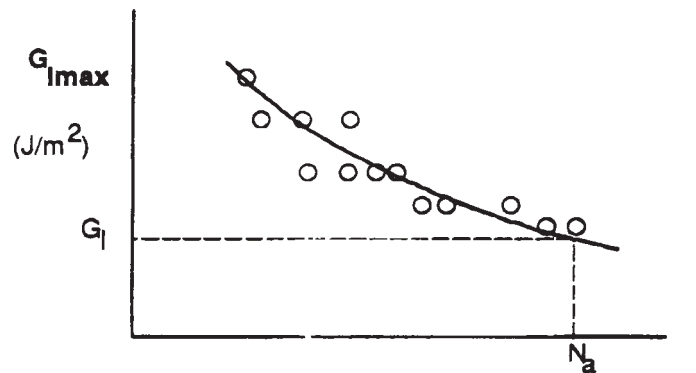


FIG. 2 $G-N$ Curve

4.2 The DCB specimen is cycled between a minimum and maximum displacement, δ_{min} , and δ_{max} , at a specified frequency. For linear elasticity and small deflections ($\delta/a < 0.4$) the displacement ratio, $\delta_{min}/\delta_{max}$, is identical to the R -ratio. The number of displacement cycles at which the onset of delamination growth occurs, N_a , is recorded. The mode I cyclic strain energy release rate, for example the maximum value, $G_{I_{max}}$, is calculated using a modified beam theory or other methods described in Test Method D 5528. By testing several specimens a relationship is developed between $G_{I_{max}}$ and N_a for the chosen frequency.