



Designation: D6115 – 97 (Reapproved 2004)

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 D6115; 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 (DCB) 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 D5528).

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:²

D883 Terminology Relating to Plastics

D2584 Test Method for Ignition Loss of Cured Reinforced Resins

¹ This specification is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.06 on Interlaminar Properties.

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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.

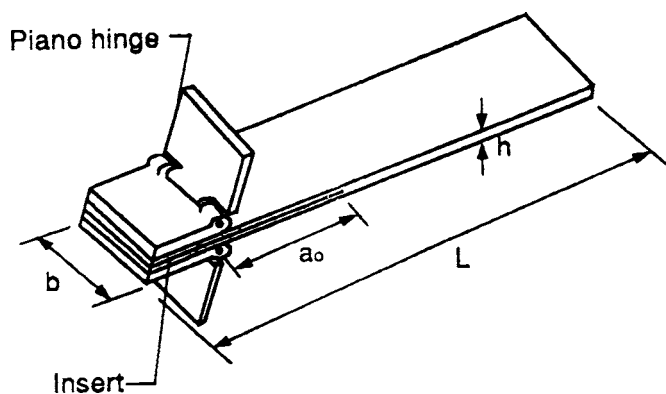


FIG. 1 DCB Specimen with Piano Hinges

D2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding

D2734 Test Methods for Void Content of Reinforced Plastics

D3171 Test Methods for Constituent Content of Composite Materials

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D5528 Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E456 Terminology Relating to Quality and Statistics

E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (S - N) and Strain-Life (ϵ - N) Fatigue Data

E1049 Practices for Cycle Counting in Fatigue Analysis
E1150 Definitions of Terms Relating to Fatigue³

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 E177 define terms relating to statistics. Definition E1150 defines terms relating to fatigue. In the event of 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 *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 D5528.

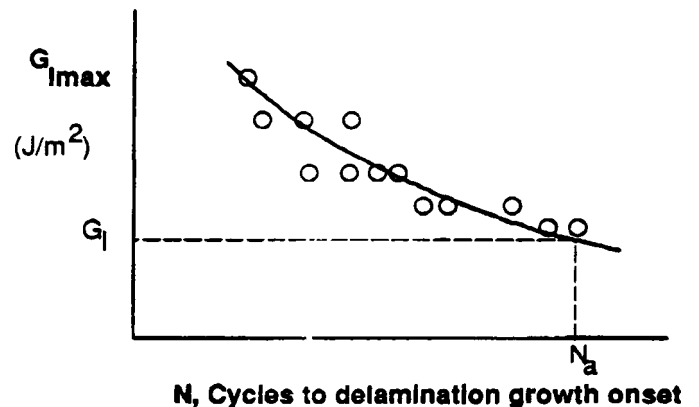


FIG. 2 $G-N$ Curve

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 under

³ Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.