Designation: D5528/D5528M – 21

Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites[1]

This standard is issued under the fixed designation D5528/D5528M; 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 describes the determination of the opening mode-I interlaminar fracture toughness, G_{Ic}, of unidirectional fiber-reinforced polymer matrix composite laminates using the double cantilever beam (DCB) specimen (Fig. 1).

1.2 This test method is limited to use with composites consisting of unidirectional carbon-fiber and glass-fiber-reinforced laminates with brittle or tough 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 6.6).

1.3 *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.

1.3.1 Within the text, the inch-pound units are shown in brackets.

1.4 This standard may involve hazardous materials, operations, and equipment.

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
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
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
D7905/D7905M Test Method for Determination of the Mode II Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites
E4 Practices for Force Calibration and 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

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. In the event of conflict between terms, Terminology D3878 shall have precedence over the other terminology standards.

[1] This test method 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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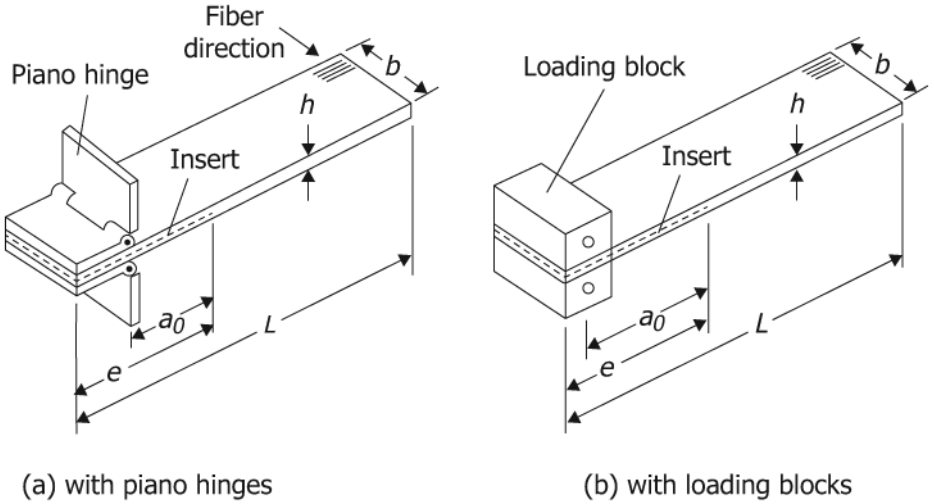
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



(a) with piano hinges (b) with loading blocks

FIG. 1 Double Cantilever Beam Specimen

NOTE 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [*M*] for mass, [*L*] for length, [*T*] for time, [*u*] for thermodynamic temperature, and [*nd*] for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *crack opening mode (mode I), n*—fracture mode in which the delamination faces open away from each other.

3.2.2 *mode I interlaminar fracture toughness, G_{Ic} [M/T²], n*—the critical value of strain energy release rate, *G*, *[M/T²]* for delamination growth [*L*] as a result of an opening force [*M·L/T²*] or opening displacement [*L*].

3.2.3 *non-precracked (NPC) toughness [M/T²], n*—an interlaminar fracture toughness value that is determined from the preimplanted insert.

3.2.4 *precracked (PC) toughness [M/T²], n*—an interlaminar fracture toughness value that is determined after the delamination has been previously advanced from the preimplanted insert.

3.2.5 *strain energy release rate, G [M/T²], n*—the loss of strain energy, *dU* [*M·L²/T²*], in the test specimen per unit of specimen width [*L*] for an infinitesimal increase in delamination length, *da* [*L*], for a delamination growing self-similarly under a constant displacement [*L*]; in mathematical form,

$$G = -\frac{1}{b}\frac{dU}{da} \tag{1}$$

where:

U = elastic strain energy in the specimen,
b = width of DCB specimen, and
a = delamination length.

3.3 *Symbols:*

A_1—slope of plot of *a/b* versus $(C/N)^{1/3}$.

a—delamination length: horizontal distance between load-application point and delamination front (see Fig. 2).

a_0—initial delamination length: horizontal distance between load-application and end of preimplanted insert (see Fig. 2).

a_I—i^{th} delamination length measured during fracture testing.

b—width of DCB specimen.

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

C_i—compliance of DCB specimen corresponding to the i^{th} delamination length measured during fracture testing.

CV—sample coefficient of variation, in percent.

da—differential increase in delamination length.

dU—differential increase in elastic strain energy.

E_{11}—lamina modulus of elasticity in the fiber direction.

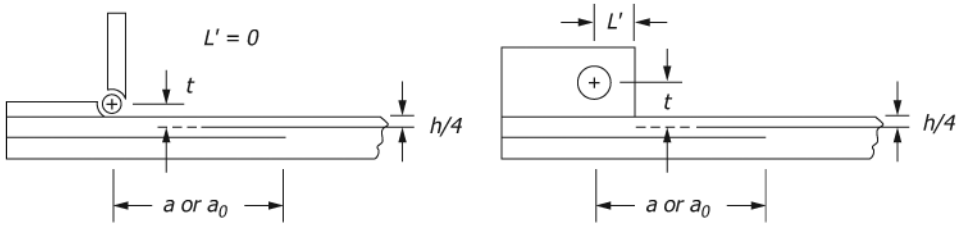
e—total insert length (see Fig. 1).

F—large displacement correction factor.

G—strain energy release rate.

G_I—mode I strain energy release rate.

G_{Ic}—mode I interlaminar fracture toughness.



(*a*) piano hinge (*b*) end block

FIG. 2 Methods for Introducing Opening Load to DCB Specimen