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

This standard is issued under the fixed designation D7905/D7905M; 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 mode II interlaminar fracture toughness, G_{IIc}, of unidirectional fiber-reinforced polymer matrix composite laminates under mode II shear loading using the end-notched flexure (ENF) test (Fig. 1).

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

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

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

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]

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
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
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D7264/D7264M Test Method for Flexural Properties of Polymer Matrix Composite Materials
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E18 Test Methods for Rockwell Hardness of Metallic Materials
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
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
E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
E1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases

3. Terminology

3.1 Terminology D3878 defines terms relating to high-modulous 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 precendence 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.

Current edition approved Oct. 1, 2014. Published November 2014. DOI: 10.1520/D7905_D7905M-14

[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.

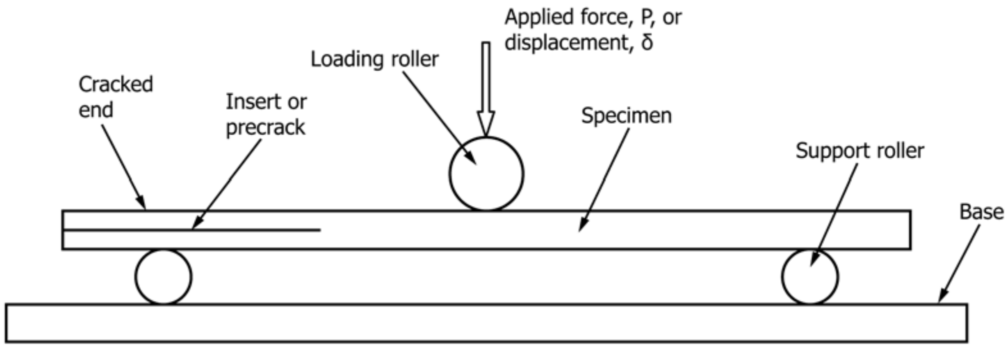

FIG. 1 ENF Test Fixture and Specimen Nomenclature

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 *Compliance Calibration (CC) Method*—the method of data reduction where the relationship between specimen compliance [T^2/M] and delamination length [*L*] is determined prior to testing by measuring specimen compliance [T^2/M] at multiple simulated delamination lengths.

3.2.2 *Mode II Interlaminar Fracture Toughness, G_{IIc} [M/T^2]*—the critical value of strain energy release rate, *G*, [M/T^2] for delamination growth [*L*] due to an in-plane shear force [M/T^2] or displacement [*L*] oriented perpendicular to the delamination front.

3.2.3 *Non-precracked (NPC) toughness [M/T^2]*—an interlaminar fracture toughness value that is determined from the preimplanted insert.

3.2.4 *Precracked (PC) Toughness [M/T^2]*—an interlaminar fracture toughness value that is determined after the delamination has been advanced from the preimplanted insert.

3.2.5 *Strain Energy Release Rate, G [M/T^2]*—the loss of strain energy, *dU* [ML^2/T^2], 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 constant displacement [*L*]. In mathematical form,

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

where:

U = total elastic strain energy in the specimen;
a = delamination length; and
B = specimen width.

3.3 *Symbols:*

3.3.1 *A*—intercept of the linear fit of compliance versus crack length cubed data

3.3.2 *a*—delamination length

3.3.3 a_i—insert length in the trimmed specimen

3.3.4 a_j—the j[th] crack length used during compliance calibration (*j = 1,2*)

3.3.5 a_o—delamination length used in fracture test

3.3.6 a_{calc}—crack length calculated from an unloading curve after the NPC test

3.3.7 a_{PC}—actual crack length used during the PC test

3.3.8 a_{vis}—visually determined crack length after the NPC test

3.3.9 *B*—specimen width

3.3.10 *C*—specimen compliance

3.3.11 C_0—specimen compliance during load-up of the fracture test (See Figure 6 in 13.1)

3.3.12 C_u—specimen compliance from unloading after the non-precracked test

3.3.13 δ—displacement of loading roller during testing perpendicular to the plane of the specimen (Fig. 1)

3.3.14 E_{1f}—flexural modulus of the specimen

3.3.15 *G*—total strain energy release rate

3.3.16 G_{IIC}—mode II interlaminar fracture toughness

3.3.17 G_Q—candidate mode II interlaminar fracture toughness

3.3.18 $\%G_Q$—peak percentage of G_Q achieved during compliance calibration

3.3.19 *h*—specimen half-thickness (Fig. 2)

3.3.20 *L*—specimen half-span (Fig. 2)

3.3.21 L_c—distance from the center of the support roller at the cracked end of the specimen to the cracked end of the specimen (Fig. 2)

3.3.22 L_u—distance from the center of the support roller at the uncracked end of the specimen to the uncracked end of the specimen (Fig. 2)

3.3.23 *m*—slope of the linear fit of compliance versus crack length cubed data

3.3.24 *P*—force applied to center loading roller and perpendicular to the plane of the specimen (Fig. 1)

3.3.25 P_c—critical force for mode II fracture

3.3.26 P_j—the compliance calibration force used at crack length a_j

3.3.27 P_{Max}—maximum value of force on the force-displacement curve

3.3.28 r_1—radius of the loading roller (Fig. 2)

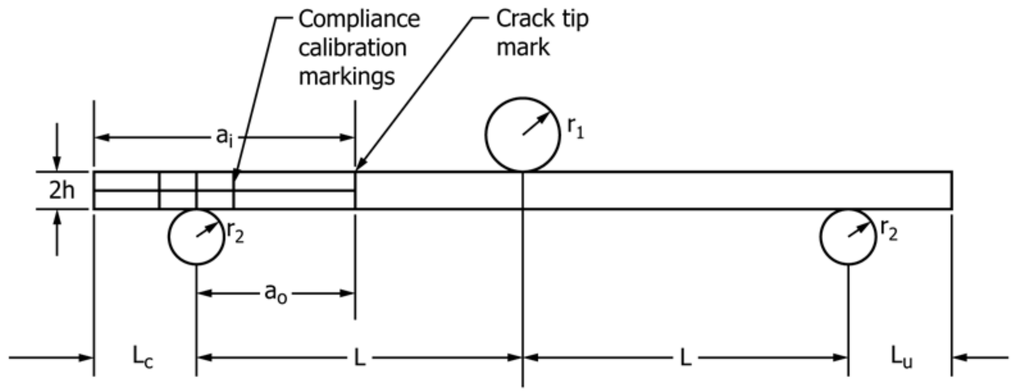

FIG. 2 ENF Specimen, Fixture, and Dimensions

3.3.29 r_2—radius of the support rollers (Fig. 2)

3.3.30 r^2—correlation coefficient of linear fit of compliance versus crack length cubed

3.3.31 Δs—Maximum measured difference in crack length along the delamination front of the precrack

3.3.32 U—total elastic strain energy in the specimen

4. Summary of Test Method

4.1 The ENF specimen shown in Fig. 1 consists of a rectangular, uniform thickness, unidirectional laminated composite specimen containing a non-adhesive insert at the midplane that serves as a delamination initiator. Forces are applied to the specimen through an ENF fixture under displacement controlled loading.

4.2 Delamination growth is not stable in the ENF test. A method is presented so that the initiation values of the mode II interlaminar fracture toughness are obtained from the preimplanted insert as well as from a precrack.

4.3 A record of the applied force versus center roller displacement is to be obtained using an *x-y* recorder or equivalent real-time plotting device, or else it may be obtained and stored digitally. The mode II interlaminar fracture toughness, G_{IIc}, is obtained using the compliance calibration (CC) method. This is the only acceptable method of data reduction for this test (**1**).[3]

4.4 This standard recommends that static mode II precracking is performed and a recommended method is described. Other precracking methods may be used provided that a record of the shape of the precracked delamination front is obtained prior to the PC test. Precracking methods that typically leave crack front markings for post-test evaluation of these values include mode I and fatigue mode II.

5. Significance and Use

5.1 Susceptibility to delamination is one of the major design concerns for many advanced laminated composite structures. Knowledge of a laminated composite material's resistance to interlaminar fracture is useful for product development and material selection. Furthermore, a measurement of the mode II interlaminar fracture toughness that is independent of specimen geometry or method of force introduction is useful for establishing design allowables used in damage tolerance analyses of composite structures. Knowledge of both the non-precracked and precracked toughnesses allows the appropriate value to be used for the application of interest.

5.2 This test method can serve the following purposes:

5.2.1 To establish quantitatively the effect of fiber surface treatment, local variations in fiber volume fraction, and processing and environmental variables on G_{IIc} of a particular composite material;

5.2.2 To compare quantitatively the relative values of G_{IIc} for composite materials with different constituents;

5.2.3 To compare quantitatively the values of G_{IIc} obtained from different batches of a specific composite material, for example, to use as a material screening criterion or to develop a design allowable; and

5.2.4 To develop delamination failure criteria for composite damage tolerance and durability analyses.

6. Interferences

6.1 Linear elastic behavior is assumed in the calculation of G used in this method. This assumption is valid when the zone of damage or nonlinear deformation at the delamination front, or both, is small relative to the smallest specimen dimension, which is typically the specimen's thickness for the ENF test.

6.2 G_{IIc} is obtained for both non-precracked and precracked specimens based on the maximum load point. G_{IIc} based on the nonlinear load point or other measures, such as a compliance offset, may also be obtained if desired. However, definitions of this type have not been related to any specific physical occurrences in the ENF test.

6.3 The three loading noses in the ENF test fixture may be fixed, rotatable, or rolling. Fixed loading noses or pins supported in a v-groove are recommended, and loading noses of this type were used in the interlaboratory test program that was conducted in support of this standard. The type of supports that are used is to be reported as described in Section 14. The loading noses should uniformly contact the specimen across its width. Lack of uniform contact can affect results, most commonly due to non-uniform loading across the width of the

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.