ASTM INTERNATIONAL

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

ε[1] NOTE—Editorial changes were made to Table 1 in November 2019.

1. Scope

1.1 This test method covers 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 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 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.*

1.5 *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

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

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 (Withdrawn 2015)[3]
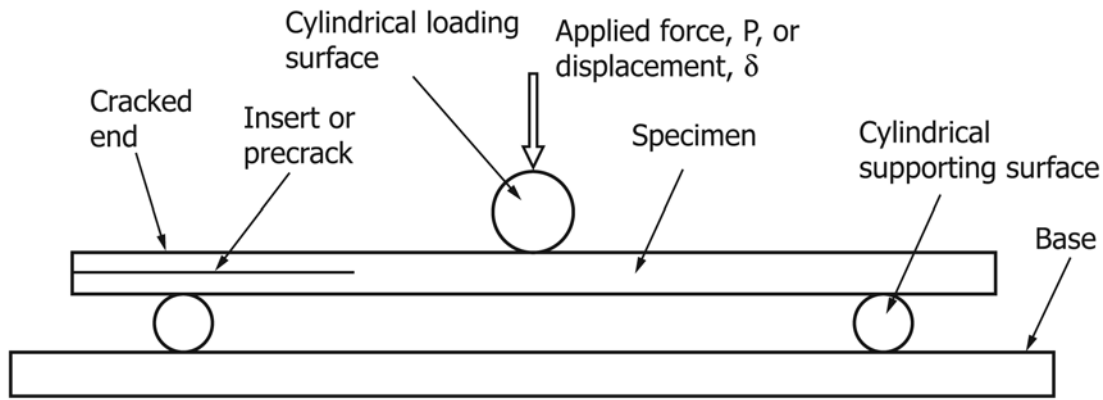

FIG. 1 ENF Test Fixture and Specimen Nomenclature

E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases (Withdrawn 2015)[3]

E1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases (Withdrawn 2015)[3]

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 precedence over the other terminology standards.

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,

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

where:

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

3.3 *Symbols:*

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

a—delamination length

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

a_i—insert length in the trimmed specimen

a_j—the jth crack length used during compliance calibration $(j = 1,2)$

a_o—delamination length used in fracture test

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

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

B—specimen width

C—specimen compliance

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

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

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

E_{If}—flexural modulus of the specimen

G—total strain energy release rate

G_{IIC}—mode II interlaminar fracture toughness

G_Q—candidate mode II interlaminar fracture toughness

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

h—specimen half-thickness (Fig. 2)

L—specimen half-span (Fig. 2)

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)
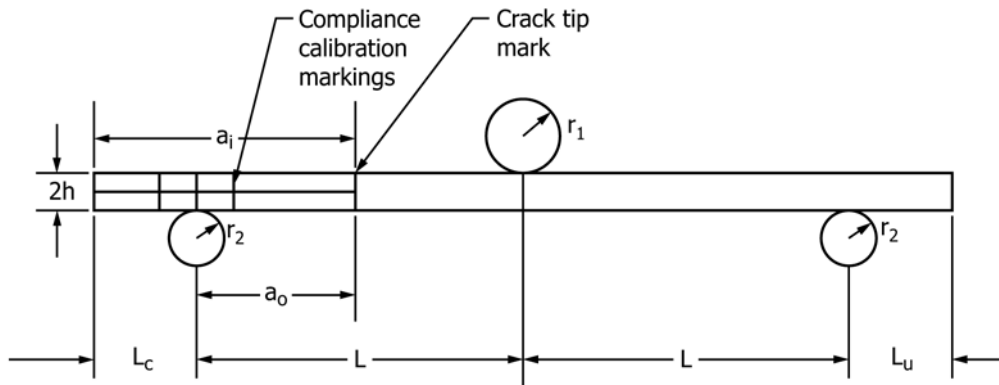
FIG. 2 ENF Specimen, Fixture, and Dimensions

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)

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

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

P_c—critical force for mode II fracture

P_j—the compliance calibration force used at crack length a_j

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

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

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

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

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

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).[4]

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

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.