INTERNATIONAL

Designation: D6671/D6671M − 22

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

1. Scope

1.1 This test method covers the determination of interlaminar fracture toughness, G_c, of continuous fiber-reinforced composite materials at various Mode I to Mode II loading ratios using the Mixed-Mode Bending (MMB) Test.

1.2 This test method is limited to use with composites consisting of unidirectional carbon fiber tape laminates with brittle and tough single-phase polymer matrices. This test method is further limited to the determination of fracture toughness as it initiates from a delamination insert. This limited scope reflects the experience gained in round robin testing. This test method may prove useful for other types of toughness values and for other classes of composite materials; however, certain interferences have been noted (see Section 6). This test method has been successfully used to test the toughness of both glass fiber composites and adhesive joints.

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.

1.4 *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]

D883 Terminology Relating to Plastics
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 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.

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,

[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 Feb. 1, 2022. Published March 2022. Originally approved in 2001. Last previous edition approved in 2019 as D6671/D6671M – 19. DOI: 10.1520/D6671_D6671M-22.

[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.

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 and no relative crack face sliding occurs.

3.2.2 *crack sliding mode (Mode II), n*—fracture mode in which the delamination faces slide over each other in the direction of delamination growth and no relative crack face opening occurs.

3.2.3 *mixed-mode fracture toughness, G_c [M/T^2], n*—the critical value of strain energy release rate, G, for delamination growth in mixed-mode.

3.2.4 *mixed-mode ratio, G_I/G_{II} [nd], n*—the ratio of Mode I strain energy release rate to Mode II strain energy release rate.

3.2.5 *mode mixture, G_{II}/G [nd], n*—fraction of Mode II to total strain energy release rate.

3.2.5.1 *Discussion*—The mixed-mode ratio, G_I/G_{II}, is at times referred to instead of the mode mixture.

3.2.6 *Mode I strain energy release rate, G_I [M/T^2], n*—the loss of strain energy associated with Mode I deformation 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.

3.2.7 *Mode II strain energy release rate, G_{II} [M/T^2], n*—the loss of strain energy associated with Mode II deformation 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.

3.2.8 *strain energy release rate, G [M/T^2], n*—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,

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

where:

a = delamination length, mm [in.],
b = width of specimen, mm [in.],
G = total strain energy release rate, kJ/m^2 [in.-lbf/in.^{2}], and
U = total elastic strain energy in the test specimen, N-mm [in.-lbf].

3.3 *Symbols:*

a = delamination length, mm [in.]
a_o = initial delamination length, mm [in.]
$a_{1\text{-}25}$ = propagation delamination lengths, mm [in.]
b = width of specimen, mm [in.]
b_{cal} = width of calibration specimen, mm [in.]
c = lever length of the MMB test apparatus, mm [in.]
c_g = lever length to center of gravity, mm [in.]
C = compliance, δ/P, mm/N [in./lbf]
C_{cal} = calibration specimen compliance, δ/P, mm/N [in./lbf]
C_{sys} = system compliance, δ/P, mm/N [in./lbf]
CV = coefficient of variation, %
E_{11} = longitudinal modulus of elasticity measured in tension, MPa [psi]
E_{22} = transverse modulus of elasticity, MPa [psi]
E_{cal} = modulus of calibration bar, MPa [psi]
E_{1f} = modulus of elasticity in the fiber direction measured in flexure, MPa [psi]
G = total strain energy release rate, kJ/m^2 [in.-lbf/in.^{2}]
G_{13} = shear modulus out of plane, MPa [psi]
G_{12} = shear modulus in plane, MPa [psi]
G_I = opening (Mode I) component of strain energy release rate, kJ/m^2 [in.-lbf/in^2]
G_{II} = shear (Mode II) component of strain energy release rate, kJ/m^2 [in.-lbf/in^2]
G_{II}/G = mode mixture
G_c = total mixed-mode fracture toughness, kJ/m^2 [in.-lbf/in^2]
G_c^{est} = estimated value of total mixed-mode fracture toughness, kJ/m^2 [in.-lbf/in^2]
h = half thickness of test specimen, mm [in.]
L = half-span length of the MMB test apparatus, mm [in.]
m = slope of the load displacement curve, N/mm [lb/in.]
m_{cal} = slope of the load displacement curve from calibration test, N/mm [lbf/in.]
n = number of specimens
P = applied load, N [lbf]
$P_{5\%/max}$ = critical load at 5%/max point of loading curve, N [lbf]
P_{est} = estimated value of critical load, N [lbf]
P_g = weight of lever and attached apparatus, N [lbf]
P_{nl} = critical load at nonlinear point of loading curve, N [lbf]
P_{tab} = expected load on the loading tab, N [lbf]
P_{vis} = critical load when delamination is observed to grow, N [lbf]
S_{n-1} = standard deviation
t = thickness of calibration bar, mm [in.]
U = strain energy, N-mm [in.-lbf]
V = fiber volume fraction, %
xi = measured or derived property for an individual specimen from the sample population
$\bar{x}$ = sample mean (average)
α = mode mixture transformation parameter for setting lever length
β = non-dimensional crack length correction for mode mixture
χ = crack length correction parameter,

$$\chi = \sqrt{\frac{E_{11}}{11G_{13}}\left\{3 - 2\left(\frac{\Gamma}{1+\Gamma}\right)^2\right\}}$$

δ = load point deflection, mm [in.]
δ_{est} = estimated load point deflection, mm [in.]
δ_{max}= maximum allowable load point of deflection, mm [in.]
Γ = transverse modulus correction parameter,