Designation: C1940 – 24

Standard Test Method for Critical Mode I Interlaminar Strain Energy Release Rate of (G_{Ic}) Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures[1]

This standard is issued under the fixed designation C1940; 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 experimental methods and procedures for the determination of the critical mode I interlaminar strain energy release rate of continuous fiber-reinforced ceramic matrix composite (CMC) materials in terms of G_{Ic}. This property is also sometimes described as the mode I fracture toughness or the mode I fracture resistance.

1.2 This test method applies primarily to ceramic matrix composite materials with a 2-D laminate structure, consisting of lay-ups of continuous ceramic fibers, in unidirectional tape or 2-D woven fabric architectures, within a brittle ceramic matrix.

1.3 This test method determines the elastic strain energy released per unit of new surface area created as a delamination grows at the interlaminar interface between two lamina or plies. The term delamination is used in this test method to specifically refer to this type of growth, while the term crack is a more general term that can also refer to matrix cracking, intralaminar delamination growth, or fiber fracture.

1.4 This test method uses a double cantilever beam (DCB) specimen to determine the critical mode I interlaminar strain energy release rate (G_{Ic}). A DCB test method has been standardized for polymer matrix composites (PMCs) under Test Method D5528. This test method addresses a similar procedure, but with modifications to account for the different physical properties, reinforcement architectures, stress-strain response, and failure mechanisms of CMCs compared to PMCs.

1.5 This test is written for ambient temperature and atmospheric test conditions, but the test method can also be used for elevated temperature or environmental exposure testing with the use of an appropriate environmental test chamber, measurement equipment for controlling and measuring the chamber temperature, humidity, and atmosphere, high temperature gripping fixtures, and modified equipment for measuring delamination growth.

1.6 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6.1 Values expressed in this test method are in accordance with the International System of Units (SI) and IEEE/ASTM SI 10.

1.7 *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.* Specific hazard statements are given in Section 8.

1.8 *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]

C1145 Terminology of Advanced Ceramics

C1275 Test Method for Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Ambient Temperature

C1359 Test Method for Monotonic Tensile Strength Testing of Continuous Fiber-Reinforced Advanced Ceramics With Solid Rectangular Cross Section Test Specimens at Elevated Temperatures

D2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding

D3878 Terminology for Composite Materials

[1] This test method is under the jurisdiction of ASTM Committee C28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.07 on Ceramic Matrix Composites.

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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.

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
E83 Practice for Verification and Classification of Extensometer Systems
E105 Guide for Probability Sampling of Materials
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
E561 Test Method for K_R Curve Determination
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1402 Guide for Sampling Design
E1823 Terminology Relating to Fatigue and Fracture Testing
IEEE/ASTM SI 10 American National Standard for Metric Practice

3. Terminology

3.1 The definitions of terms relating to mechanical testing appearing in Terminology E6 apply to the terms used in this test method. The definitions of terms relating to fracture testing appearing in Terminology E1823 apply to the terms used in this test method. The definitions of terms relating to advanced ceramics appearing in Terminology C1145 apply to the terms used in this test method. The definitions of terms relating to fiber-reinforced composites appearing in Terminology D3878 apply to the terms used in this test method. Pertinent definitions are shown in the following subsection, with the appropriate source given in bold.

3.2 *Definitions:*

3.2.1 *advanced ceramic, n*—highly engineered, high performance, predominantly nonmetallic, inorganic, ceramic material having specific functional attributes. **C1145**

3.2.2 *ceramic matrix composite, n*—material consisting of two or more materials (insoluble in one another), in which the major, continuous component (matrix component) is a ceramic, while the secondary component(s) (reinforcing component) may be ceramic, glass-ceramic, glass, metal or organic in nature; these components are combined on a macroscale to form a useful engineering material possessing certain properties or behavior not possessed by the individual constituents. **C1145**

3.2.3 *continuous fiber-reinforced ceramic matrix composite (CFCC), n*—ceramic matrix composite in which the reinforcing phase consists of a continuous fiber, continuous yarn, or a woven fabric. **C1145**

3.2.4 *fracture toughness, n*—a generic term for measures of resistance to crack extension. **C1145**

3.2.5 *interlaminar, adj*—describing objects (for example, voids), events (for example, fracture), or fields (for example, stress) between the plies of a laminate. **D3878**

3.2.6 *mode, adj*—one of the three classes of crack (surface) displacements adjacent to the crack tip; these displacement modes are associated with the stress-strain fields around the crack tip and are designated one, two, and three; arabic numerals 1, 2, and 3 are used for the general case, and they represent opening, sliding, and tearing displacements, respectively (see Fig. 8 in Terminology E1823); roman numerals are used to specialize the mode to plane strain (I and II) or to antiplane-strain (III). **E1823**

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *crack opening mode (Mode I), n*—the fracture mode in which the crack faces open away from each other and no crack face shear movement occurs.

3.3.2 *critical mode I interlaminar strain energy release rate (G_{Ic}), [FLL^{-2}, FL^{-1}], n*—the value of strain energy release rate (G) [FLL^{-2}, FL^{-1}] for the onset of delamination growth as a result of an opening force or opening displacement.

3.3.2.1 *Discussion*—When the elastic strain energy (G) stored in the specimen reaches or exceeds a critical value (G_c), energy is dissipated by the creation of new surface area (crack growth) until the stored energy is less than a critical value.

3.3.3 *load point displacement (δ) [L], n*—the force-induced separation vector between the two points of load application on the cantilever arms.

3.3.3.1 *Discussion*—For Mode I crack opening, the direction of the separation vector is normal to the crack plane and parallel to the force vector.

3.3.4 *precrack, n*—a starting delamination, artificially produced from a pre-implanted insert or machined notch, from which subsequent delamination growth occurs.

3.3.5 *resistance curve (R-curve), n*—a plot of critical mode I interlaminar strain energy release rate (G_{Ic}) versus delamination length (a) for stable delamination advance.

3.3.5.1 *Discussion*—If the material shows R-curve behavior, G_{Ic} will be different at increasing delamination lengths compared to the initial value. The changes can occur because the fracture mechanisms change in mode or amplitude, or both, during crack progression, absorbing more or less strain energy with increasing delamination length. In unidirectional tape laminates, R-curve behavior is often caused by fiber bridging. If there are no changes in energy absorption with delamination extension, the initiation G_{Ic} and the propagation G_{Ic} are equivalent and the material does not show R-curve behavior.

3.3.5.2 *Discussion*—If the propagation values of G_{Ic} reach a stable values, this is sometimes referred to as G_{IR} in reference to R-curve behavior.

3.3.6 *strain energy release rate, G [FL-1], n*—the loss of elastic strain energy, dU, in the test specimen per unit of specimen width for an infinitesimal increase in length, da, of a delamination growing self-similarly under a constant displacement. In mathematical form,

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

where:

G = strain energy release rate,