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.

Designation: E1922/E1922M − 22

Standard Test Method for Translaminar Fracture Toughness of Laminated and Pultruded Polymer Matrix Composite Materials[1]

This standard is issued under the fixed designation E1922/E1922M; 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 covers the determination of translaminar fracture toughness, K_{TL}, for laminated, molded, or pultruded polymer matrix composite materials of various fiber orientations using test results from monotonically loaded notched specimens. If the material response is such that the K_{TL} calculation is not valid, alternate reporting methods are provided.

1.2 This test method is applicable to room temperature laboratory air environments.

1.3 Composite materials that can be tested by this test method are not limited by thickness or by type of polymer matrix or fiber, provided that the specimen sizes and the test results meet the requirements of this test method. This test method was developed primarily from test results of various carbon fiber – epoxy matrix laminates and from additional results of glass fiber – epoxy matrix, glass fiber-polyester matrix pultrusions and carbon fiber – bismaleimide matrix laminates (**1-4**, **5**, **6**).[2]

1.4 A range of eccentrically loaded, single-edge-notch tension, ESE(T), specimen sizes with proportional planar dimensions is provided, but planar size may be variable and adjusted, with associated changes in the applied test load. Specimen thickness is a variable, independent of planar size.

1.5 Specimen configurations other than those contained in this test method may be used. It is particularly important that the requirements discussed in 5.1 and 5.4 regarding contained notch-tip damage be met when using alternative specimen configurations in conjunction with the K_{TL} calculation.

1.6 *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.

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

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.*

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:*[3]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D883 Terminology Relating to Plastics

D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials

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/D5528M Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites

D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation

E4 Practices for Force Calibration and Verification of Testing Machines

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[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

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

[3] 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.

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E6 Terminology Relating to Methods of Mechanical Testing

E83 Practice for Verification and Classification of Extensometer Systems

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

E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials

E456 Terminology Relating to Quality and Statistics

E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology D3878 defines terms relating to composite materials. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E1823 defines terms relating to fracture testing. Terminology E456 and Practice E177 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 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, [θ] 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.

3.2.2 *normalized notch size [nd], n*—the ratio of notch length, a_n, to specimen width, *W*.

3.2.3 *notch-mouth displacement [L], n*—the Mode I (also called opening mode) component of crack or notch displacement due to elastic and permanent deformation. The displacement is measured across the mouth of the notch on the specimen edge (see Fig. 1).

3.2.4 *notch length [L], n*—the distance from a reference plane to the front of the machined notch. The reference plane depends on the specimen form, and normally is taken to be either the boundary, or a plane containing either the load line or the centerline of a specimen or plate. The reference plane is defined prior to specimen deformation (see Fig. 2).

3.2.5 For additional information, see Terminology D883 and Test Methods D3039/D3039M, D5229/D5229M, and D5528/D5528M.

3.3 *Symbols:*

a_n—notch length

B—specimen thickness

CV—coefficient of variation statistic of a sample population for a given property (in percent)

K—applied stress intensity factor

K_{TL}—translaminar fracture toughness

P—applied force

P_{max}—maximum applied force achieved during test

S_{n-1}—standard deviation statistic of a sample population for a given property

V_n—notch-mouth displacement

W—specimen width

x_i—test result for an individual specimen from the sample population for a given property

$\bar{x}$—mean or average (estimate of mean) of a sample population for a given property

α—normalized notch size

4. Summary of Test Method

4.1 This test method involves tension testing of eccentrically loaded, single-edge-notch, ESE(T), specimens in opening mode loading. Force versus displacement across the notch at the specimen edge, V_n, is recorded. The force corresponding to a prescribed increase in normalized notch length is determined, using the force-displacement record. The translaminar fracture toughness, K_{TL}, is calculated from this force using equations that have been established on the basis of elastic stress analysis of the modified single-edge notched specimen. When the assumptions upon which the K_{TL} calculation is based are violated, results are instead reported in terms of applied force/width, geometry, and observed distributed damage.

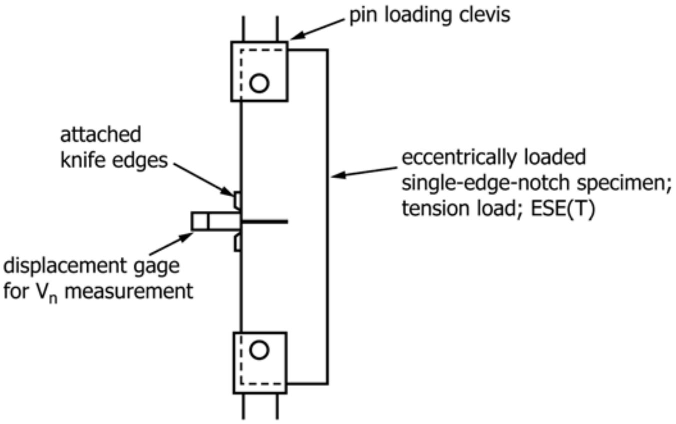
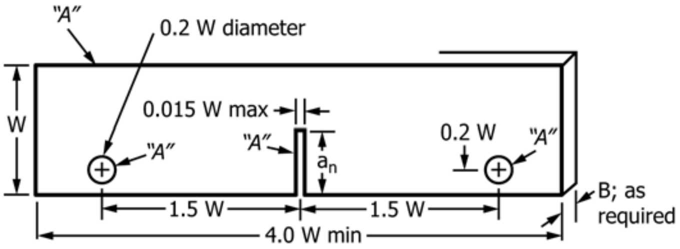


FIG. 1 Test Arrangement for Translaminar Fracture Toughness Tests



NOTE 1—All dimensions +/– 0.01 *W*, except as noted.

NOTE 2—All surfaces perpendicular and parallel as applicable within 0.01 *W*.

FIG. 2 Translaminar Fracture Toughness Test Specimen

4.2 The validity of translaminar fracture toughness, K_{TL}, determined by this test method depends on maintaining a relatively contained area of damage at the notch tip. To maintain this suitable notch-tip condition, the allowed increase in notch-mouth displacement near the maximum force point of the tests is limited to a small value. Small increases in notch-mouth displacement are more likely for relatively thick samples and for samples with a significant proportion of the near surface reinforcing fibers aligned parallel to the direction of the notch, or inherently brittle material response, or both.

4.3 For material response in which the damage is not limited to the local crack tip region, this test method results in a structural failure response that is strongly dependent on specimen geometric details (in addition to length, width, and notch geometry) such as fiber orientations, stacking sequence if laminated, weave architecture if woven, manufacturing process if liquid-molded or containing discontinuous fibers, etc. In these cases, the relevant reported data is not K_{TL} but rather then global observed structural response of the coupon, for example, the force-displacement history as a function of observed damage events (crack branching, delaminations, local fiber failures, etc).

5. Significance and Use

5.1 The parameter K_{TL} determined by this test method is a measure of the resistance of a polymer matrix composite laminate to notch-tip damage and effective translaminar crack growth under opening mode loading. The result is valid only for conditions in which the damage zone at the notch tip is small compared with the notch length and the in-plane specimen dimensions. Alternately, for materials exhibiting distributed damage in a larger volume, observed force-displacement and discrete damage events are still valid structural responses for certain specific engineering applications.

5.2 This test method can serve the following purposes. In research and development, (*a*) K_{TL} data can quantitatively establish the effects of fiber and matrix variables and stacking sequence of the laminate on the translaminar fracture resistance of composite laminates; and (*b*) quantified distributed damage measurements can be used to validate progressive composite damage models. In structural design, K_{TL} data can, within the constraints of the specimen geometry and loading, be used to assess composite laminate resistance to damage growth from edge flaws and notches.

5.3 The translaminar fracture toughness, K_{TL}, as well as distributed damage observations, determined by this test method may be a function of the testing speed and temperature. This test method is intended for room temperature and quasi-static conditions, but it can apply to other test conditions provided that the requirements of 13.2 and 13.3 are met. Application of K_{TL} in the design of service components should be made with awareness that the test parameters specified by this test may differ from service conditions, possibly resulting in a different material response than that seen in service. Distributed damage observations are also limited to the material and geometry tested, but may be more generally applied to a variety of structural analysis validation applications.

5.4 Not all types of laminated polymer matrix composite materials experience the contained notch-tip damage and effective translaminar crack growth of concern in this test method. In such circumstances, the force-displacement and discrete damage observations – not K_{TL} – shall be used.

5.5 The reporting section requires items that tend to influence translaminar fracture toughness and discrete damage progression to be reported; these include the following: material, methods of material fabrication, accuracy of lay-up orientation, laminate stacking sequence and overall thickness, specimen geometry, specimen preparation, specimen conditioning, environment of testing, void content, volume percent reinforcement, size and method of notch preparation, specimen/fixture alignment, and speed of testing.

6. Interferences

6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites in general. Important aspects of specimen preparation that contribute to data scatter include thickness variation, out-of-plane curvature, surface roughness, and failure to meet the dimensional and squareness tolerances (parallelism and perpendicularity) specified in 8.2.2.

6.2 *Notch Preparation*—Because of the dominating presence of the notch, results from this test method are relatively insensitive to parameters that would be of concern in an unnotched tensile property test. However, since the notch dominates the response, consistent preparation of the notch is