Designation: D 6264 – 98 (Reapproved 2004)

# Standard Test Method for Measuring Damage Resistance of Fiber-Reinforced Polymer-Matrix Composite to Concentrated Quasi-Static Indentation Force[1]

This standard is issued under the fixed designation D 6264; 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 A quasi-static indentation (QSI) test method is used to obtain quantitative measurements of the damage resistance of a continuous-fiber-reinforced composite material to a concentrated indentation force (Fig. 1). The indentation force is applied to the specimen by slowly pressing a hemispherical indenter into the surface. Procedures are specified for determining the damage resistance for a simply supported test specimen and for a rigidly backed test specimen. The damage resistance is quantified in terms of a critical contact force associated with a single event or sequence of events to cause a specific size and type of damage in the specimen. These tests may be used to screen materials for damage resistance or to inflict damage into a specimen for subsequent damage tolerance testing. This test method is limited to use with composites consisting of layers of unidirectional fibers or layers of fabric. This test method may prove useful for other types and classes of composite materials. Certain interferences, however, have been noted (see 6.7).

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information purposes only.

1.3 *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.*

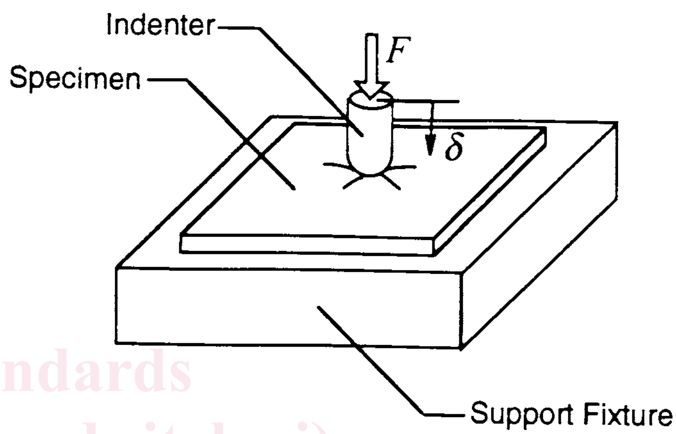


FIG. 1 Quasi-Static Indentation Test

## 2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 883 Terminology Relating to Plastics
D 2734 Test Methods for Void Content of Reinforced Plastics
D 3171 Test Method for Constituent Content of Composite Materials
D 3878 Terminology for Composite Materials
D 5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D 5687/D5687M Guide for Preparation of Flat Composite Panels With Processing Guidelines for Specimen Preparation
E 4 Practices for Force Verification of Testing Machines
E 6 Terminology Relating to Methods of Mechanical Testing
E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process

## 3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. In the event of a

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

Current edition approved Mar. 1, 2004. Published March 2004. Originally approved in 1998. Last previous edition approved in 1998 as D 6264 – 98.

[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.

conflict between terms, Terminology D 3878 shall have precedence over the other standards.

3.2 *Definitions of Terms Specific to This Standard*—The terms in this test method may conflict with general usage. There is not yet an established consensus concerning the use of these terms. The following descriptions are intended only for use in this test method.

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, [θ] for thermodynamic temperature, and [nd] for nondimensional 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.

3.2.1 *contact force, F* $[MLT^{-2}]$, *n*—the total force applied normal to the face of the specimen by the indenter.

3.2.2 *damage, n—in structures and structural materials*, a structural anomaly in a material or structure created by manufacturing or service usage.

3.2.3 *damage resistance, n—in structures and structural materials*, a measure of the relationship between the force, energy, or other parameter(s) associated with an event or sequence of events and the resulting damage size and type.

3.2.4 *dent depth, d [L], n*—residual depth of the depression formed by an indenter after removal of load. The dent depth shall be defined as the maximum distance in a direction normal to the face of the specimen from the lowest point in the dent to the plane of the indented surface that is undisturbed by the dent.

3.2.5 *$F_1$ force, $F_1$* $[MLT^{-2}]$, *n*—contact force at which the force/indenter displacement curve has a discontinuity in force or slope.

3.2.6 *indenter displacement,* δ *[L], n*—the displacement of the indenter relative to the specimen support.

3.2.7 *maximum force, $F_{max}$* $[MLT^{-2}]$, *n*—the maximum contact force a laminate will resist. This force is obtained from the *F*/δ curve after a point is reached where the contact force does not increase with increasing indenter displacement.

3.3 *Symbols:*

*d* = dent depth (see 3.2.4).
*F* = contact force (see 3.2.1).
$F_1$ = $F_1$ force (see 3.2.5).
$F_{max}$ = maximum force (see 3.2.7).
*N* = number of ply groups in a laminate's stacking sequence.
δ = indenter displacement (see 3.2.6).

## 4. Summary of Test Method

4.1 The quasi-static indentation (QSI) test is used to measure the damage resistance of a uniform-thickness laminated composite specimen. An indentation force is applied slowly by pressing a displacement-controlled hemispherical indenter into the face of the specimen. The displacement is increased until the desired damage state is reached. Procedures are specified for determining the damage resistance for a simply supported test specimen and for a rigidly backed test specimen. The damage response is a function of the test configuration.

4.2 A record of the applied contact force/indenter displacement (*F*/δ) is recorded on either an *X-Y* recorder, an equivalent real-time plotting device, or stored digitally and postprocessed.

## 5. Significance and Use

5.1 Susceptibility to damage from concentrated indentation forces is one of the major weaknesses of many structures made of advanced laminated composites. Knowledge of the damage resistance of a laminated composite material subjected to a concentrated indentation force is useful for product development and material selection.

5.2 The QSI test method can serve the following purposes:

5.2.1 To establish quantitatively the effects of stacking sequence, fiber surface treatment, variations in fiber volume fraction, and processing and environmental variables on the damage resistance of a particular composite laminate to a concentrated quasi-static indentation force.

5.2.2 To compare quantitatively the relative values of the damage resistance parameters for composite materials with different constituents. The damage response parameters include *d*, $F_1$, and $F_{max}$, as well as the *F*/δ curve.

5.2.3 To place a controlled amount of damage in a specimen for subsequent damage tolerance tests.

5.2.4 To isolate and measure the indentation response of the specimen without bending (rigidly backed configuration).



## 6. Interferences

6.1 The QSI test simulates the force/displacement relationships of many impacts governed by boundary conditions (**1-7**).[3] These are typically relatively large-mass low-velocity hard-body impacts on plates with a relatively small unsupported region. This test method does not address wave propagation and vibrations in the specimen, time-dependent material behavior, or inertia-dominated impact events.

6.2 The damage response of a specimen is dependent on many factors, including the indenter geometry and specimen support conditions. Consequently, comparisons cannot be made between materials unless identical test configurations, identical test conditions, and identical laminates are used. Therefore, all deviations from the standard test configuration should be reported in the results.

6.3 Force $F_1$ does not represent the initiation of damage, but generally represents when the displacement of the indenter is affected by large-scale damage formation. Typically, matrix cracks and small delaminations form before this force.

6.4 The dent depth may "relax" or reduce with time or upon exposure to different environmental conditions.

6.5 Treatment and interpretation of delamination growth are beyond the scope of this test method.

6.6 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper coupon machining are known causes of high material data scatter in composites.

6.7 *Application to Other Materials, Lay-Ups, and Architectures*:

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

6.7.1 The QSI test primarily has been used for testing carbon-fiber-reinforced tape and fabric laminates with polymer matrices. For other materials, a quite different response may occur.

6.7.2 Nonlaminated, 3D fiber-reinforced, or textile composites may fail by different mechanisms than laminates. The most critical damage may be in the form of matrix cracking or fiber failure, or both, rather than delaminations.

## 7. Apparatus

7.1 *Testing Machine*—The testing machine shall be in conformance with Practices E 4 and shall satisfy the following requirements:

7.1.1 *Testing Machine Heads*—The testing machine shall have both an essentially stationary head and a movable head.

7.1.2 *Drive Mechanism*—The testing machine drive mechanism shall be capable of imparting to the movable head a controlled velocity with respect to the stationary head. The velocity of the movable head shall be capable of being regulated as specified in 11.6.

7.1.3 *Load Indicator*—The testing machine load-sensing device shall be capable of indicating the total load being carried by the test specimen. This device essentially shall be free from inertia lag at the specified rate of testing and shall indicate the load with an accuracy over the load range(s) of interest of within ±1 % of the indicated value.

7.1.4 *Grips*—The top head of the testing machine shall carry a grip to hold the indenter such that the direction of load applied to the specimen is coincident with the axis of travel. The grip shall apply sufficient pressure to prevent slippage of the indenter. The lower head shall have a means of attaching a flat rigid support.

7.2 *Flat Rigid Support*—A flat rigid surface shall be attached to the lower head and used to support the specimen or test fixture. The support surface shall be normal to the axis of travel of the testing machine head and have a large enough surface to support completely the specimen or test fixture. A convenient means of providing this surface is through the use of a metal "T" in which the lower part of the "T" is clamped in the lower grips and the top part of the "T" provides the support surface. If the rigidly backed configuration is to be used, this support shall be made from steel with a minimum thickness of 12.7 mm (0.5 in.).

7.3 *Indenter*—The indenter shall have a smooth hemispherical tip with a diameter of 12.7 ± 0.1 mm (0.500 ± 0.003 in.) and a hardness of 60 to 62 HRC as specified in Test Methods E 18. If a different indenter is used as part of the testing, the shape and dimensions shall be noted.

7.4 *Indenter Displacement Indicator*—The axial displacement of the indenter relative to the support fixture may be estimated as the crosshead travel, provided the deformation of the testing machine and support fixture is less than 2 % of the crosshead travel. If not, the indenter displacement shall be obtained from a properly calibrated external gage or transducer located between the indenter and the support fixture or the rigid support surface. The displacement indicator shall indicate the displacement with an accuracy of ±1 % of the thickness of the specimen.

7.5 *Load Versus Indenter Displacement (F Versus* δ*) Record*—An *X-Y* plotter, or similar device, shall be used to make a permanent record during the test of load versus indenter displacement. Alternatively, the data may be stored digitally and postprocessed.

7.6 *Specimen Support*—The damage resistance may be determined for a specimen that is simply supported or rigidly backed. For both configurations, the specimen's face shall be held normal to the axis of the indenter.

7.6.1 *Simply Supported Configuration*—The fixture shall consist of a single plate with a 127.0 ± 2.5 mm (5.00 ± 0.10 in.) diameter opening made from a structural metal such as aluminum or steel. The top rim of the opening shall be rounded with a radius of 0.75 ± 0.25 mm (0.03 ± 0.01 in.). The plate shall be sufficiently large to support the entire lower surface of the specimen, excluding the circular opening. The thickness of the plate shall be a minimum of 25 mm (1.0 in.) and greater than the expected maximum indenter displacement. A typical support fixture is shown in Fig. 2.

7.6.2 *Rigidly Backed Configuration*—The specimen shall be placed directly on the flat rigid support that is mounted in the lower head of the testing machine. For this configuration, the support shall be made from steel with a minimum thickness of 12.7 mm (0.5 in.).

7.7 *Micrometers*—The micrometer(s) shall use a suitable size diameter ball-interface on irregular surfaces such as the bag-side of a laminate, and a flat anvil interface on machined or very smooth tooled surfaces. The accuracy of the instruments shall be suitable for reading to within 1 % of the sample width and thickness. For typical specimen geometries, an instrument with an accuracy of ±2.5 µm [±0.0001 in.] is desirable for thickness measurement, while an instrument with an accuracy of ±25 µm [±0.001 in.] is desirable for width measurement.

7.8 *Dent Depth Indicator*—The dent depth can be measured using a dial depth gage, a depth gage micrometer, or a properly calibrated displacement transducer. The measuring probe shall have a hemispherical tip with a diameter between 1.5 and 5.0 mm (0.06-0.20 in.). An instrument with an accuracy of ±25 µm [±0.001 in.] is desirable for depth measurement.

## 8. Sampling and Test Specimens

8.1 *Sampling*—Test at least five specimens per condition, unless valid results can be gained through the use of fewer specimens, such as in the case of a designed experiment. For statistically significant data, the procedures outlined in Practice E 122 should be consulted. Report the method of sampling.

8.2 *Specimen Lay-Up*—The laminate shall be flat and have a cross section of constant thickness.

8.2.1 For comparison screening of the damage resistance of different materials, the following laminate is suggested. A quasi-isotropic lay-up with a specimen thickness in the range of 3.5 to 5.0 mm (0.14 to 0.20 in.) with a target thickness of 4.2 mm (0.17 in.) shall be obtained as follows:

8.2.1.1 *Tape*—Laminate construction shall consist of the appropriate number of unidirectional plies to achieve a total cured thickness nearest to 4.2 mm (0.17 in.) with a stacking sequence of $[45/0/-45/90]_{NS}$ where *N* is a whole number. If the "nearest" thickness is less than 3.5 mm (0.14 in.), the next