Designation: D7766/D7766M – 11

StandardPractice for Damage Resistance Testing of Sandwich Constructions[1]

This standard is issued under the fixed designation D7766/D7766M; 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 practice provides instructions for modifying laminate quasi-static indentation and drop-weight impact test methods to determine damage resistance properties of sandwich constructions. Permissible core material forms include those with continuous bonding surfaces (such as balsa wood and foams) as well as those with discontinuous bonding surfaces (such as honeycomb, truss cores and fiber-reinforced cores).

1.2 This practice supplements Test Methods D6264/D6264M (for quasi-static indentation testing) and D7136/D7136M (for drop-weight impact testing) with provisions for testing sandwich specimens. Several important test specimen parameters (for example, facing thickness, core thickness and core density) are not mandated by this practice; however, repeatable results require that these parameters be specified and reported.

1.3 Three test procedures are provided. Procedures A and B correspond to D6264/D6264M test procedures for rigidly-backed and edge-supported test conditions, respectively. Procedure C corresponds to D7136/D7136M test procedures. All three procedures are suitable for imparting damage to a sandwich specimen in preparation for subsequent damage tolerance testing.

1.4 In general, Procedure A is considered to be the most suitable procedure for comparative damage resistance assessments, due to reduced influence of flexural stiffness and support fixture characteristics upon damage formation. However, the selection of a test procedure and associated support conditions should be done in consideration of the intended structural application, and as such Procedures B and C may be more appropriate for comparative purposes for some applications.

1.5 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 exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

1.6 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C274 Terminology of Structural Sandwich Constructions
D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to 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
D6264/D6264M Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force
D7136/D7136M Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event
E6 Terminology Relating to Methods of Mechanical Testing
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E456 Terminology Relating to Quality and Statistics
E2533 Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications

2.2 *Military Standards:*

MIL-HDBK-17-3F Composite Materials Handbook, Volume 3—Polymer Matrix Composites Materials Usage,

[1] This practice is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.09 on Sandwich Construction.

Current edition approved Nov. 15, 2011. Published December 2011. DOI: 10.1520/D7766_D7766M-11.

[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.

Design and Analysis[3]
MIL-HDBK-728/1 Nondestructive Testing[4]
MIL-HDBK-731A Nondestructive Testing Methods of Composite Materials—Thermography[4]
MIL-HDBK-732A Nondestructive Testing Methods of Composite Materials—Acoustic Emission[4]
MIL-HDBK-733A Nondestructive Testing Methods of Composite Materials—Radiography[4]
MIL-HDBK-787A Nondestructive Testing Methods of Composite Materials—Ultrasonics[4]

3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology C274 defines terms relating to sandwich constructions. 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 a conflict between terms, Terminology D3878 shall have precedence over the other terminologies.

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 *dent depth, d [L], n*—residual depth of the depression formed by an indenter after removal of applied force during a quasi-static indentation test, or by an impactor after the impact event during a drop-weight impact test. 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 or impacted surface that is undisturbed by the dent.

3.2.3 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

3.2.4 *recorded contact force, F* $[MLT^{-2}]$*, n*—the force exerted by the indenter on the specimen during a quasi-static indentation test, or by the impactor on the specimen during a drop-weight impact test, as recorded by a force indicator.

3.2.5 *tip, n*—the portion or component of the indenter or impactor which comes into contact with the test specimen first during a quasi-static indentation or drop-weight impact test.

3.3 *Symbols:*

3.3.1 *E* —potential energy of impactor prior to drop

3.3.2 *t* —thickness of impacted sandwich facing

4. Summary of Practices

4.1 *Procedure A*—In accordance with Test Method D6264/D6264M, but with a sandwich specimen, perform a quasi-static indentation test of a rigidly-backed specimen. Damage is imparted through an out-of-plane, concentrated force applied by slowly pressing a displacement-controlled hemispherical indenter into the face of the specimen. The damage resistance is quantified in terms of the resulting size, location and type of damage in the specimen.

4.2 *Procedure B*—In accordance with Test Method D6264/D6264M, but with a sandwich specimen, perform a quasi-static indentation test of an edge-supported specimen. Damage is imparted through an out-of-plane, concentrated force applied by slowly pressing a displacement-controlled hemispherical indenter into the face of the specimen. The damage resistance is quantified in terms of the resulting size, location and type of damage in the specimen.

4.3 *Procedure C*—In accordance with Test Method D7136/D7136M, but with a sandwich specimen, perform a drop-weight impact test of an edge-supported specimen. Damage is imparted through an out-of-plane, concentrated impact using a drop weight with a hemispherical striker tip. The damage resistance is quantified in terms of the resulting size, location and type of damage in the specimen.

5. Significance and Use

5.1 This practice provides supplemental instructions that allow Test Methods D6264/D6264M (for quasi-static indentation testing) and D7136/D7136M (for drop-weight impact testing) to determine damage resistance properties of sandwich constructions. Susceptibility to damage from concentrated out-of-plane forces is one of the major design concerns of many structures made using sandwich constructions. Knowledge of the damage resistance properties of a sandwich panel is useful for product development and material selection.

5.2 Sandwich damage resistance testing can serve the following purposes:

5.2.1 To establish quantitatively the effects of facing geometry, facing stacking sequence, facing-to-core interface, core geometry (cell size, cell wall thickness, core thickness, etc.), core density, core strength, processing and environmental variables on the damage resistance of a particular sandwich panel to a concentrated quasi-static indentation force, drop-weight impact force, or impact energy.

5.2.2 To compare quantitatively the relative values of the damage resistance parameters for sandwich constructions with different facing, core or adhesive materials. The damage response parameters can include dent depth, damage dimensions and location(s), indentation or impact force magnitudes, impact energy magnitudes, as well as the force versus time curve.

5.2.3 To impart damage in a specimen for subsequent damage tolerance tests.

5.2.4 Quasi-static indentation tests can also be used to identify a specific sequence of damage events (only the final damage state is identifiable after a drop-weight impact test).

[3] Available from U.S. Army Research Laboratory, Materials Directorate, Aberdeen Proving Ground, MD 21001.
[4] Available from U.S. Army Materials Technology Laboratory, Watertown, MA 02471.

5.3 The properties obtained using these practices can provide guidance in regard to the anticipated damage resistance capability of sandwich structures with similar materials, geometry, stacking sequence, and so forth. However, it must be understood that the damage resistance of a sandwich structure is highly dependent upon several factors including geometry, thickness, stiffness, mass, support conditions, and so forth.

5.3.1 Significant differences in the relationships between force/energy and the resultant damage state can result due to differences in these parameters. For example, properties obtained using edge-supported specimens would more likely reflect the damage resistance characteristics of a sandwich panel away from substructure attachments, whereas rigidly-backed specimens would more likely reflect the behavior of a panel local to substructure which resists out-of-plane deformation. Similarly, edge-supported impact test specimen properties would be expected to be similar to those of a sandwich panel with equivalent length and width dimensions, in comparison to those of a panel significantly larger than the test specimen, which tends to divert a greater proportion of the impact energy into elastic deformation.

5.3.2 Procedure A (quasi-static indentation using a rigidly-backed specimen) is considered to be the most suitable procedure for comparison of the damage resistance characteristics of sandwich panels of varying material, geometry, stacking sequence and so forth. This is because the rigid backing plate resists out-of-plane deformation of the specimen, such that the sandwich flexural stiffness and support geometry have less influence on damage initiation and growth behavior than in edge-supported tests. However, it should be noted that damage resistance behavior observed using rigidly-backed specimens may not strictly translate to edge-supported applications. For example, sandwich constructions using cores with high compression stiffness or strength, or both (e.g., balsa wood) may exhibit superior performance in rigidly-backed tests, but that performance may not strictly translate to edge-supported tests in which the core shear stiffness, core shear strength and sandwich panel flexural stiffness have greater influence upon the test results. Consequently, it is imperative to consider the intended assessment and structural application when selecting a test procedure for comparative purposes, and as such the use of Procedures B and C may be more appropriate for some applications.

5.3.3 For some structural applications, the use of a rigidly-backed specimen in drop-weight impact testing may be appropriate. Specific procedures for such testing are not included in this practice, but the general approach detailed for Procedure C may be useful as guidance material when conducting such assessments. Such tests should be performed in consideration of the implications of using rigidly-backed support conditions, such as their effect upon contact forces and sandwich deformation under impact, as well as the potential for damage to the test apparatus.

5.4 The standard indenter and impactor geometries have blunt, hemispherical tips. Historically, these tip geometries have generated a larger amount of internal damage for a given amount of external damage, when compared with that observed for similar indentations or impacts using sharp tips. Alternative indenter and impactor geometries may be appropriate depending upon the damage resistance characteristics being examined. For example, the use of sharp tip geometries may be appropriate for certain facing penetration resistance assessments.

5.5 Some testing organizations may desire to use these practices in conjunction with a subsequent damage tolerance test method to assess the residual strength of specimens containing a specific damage state, such as a defined dent depth, damage geometry, damage location, and so forth. In this case, the testing organization should subject several specimens, or a large panel, to multiple indentations or impacts, or both, at various energy levels using these practices. A relationship between force or energy and the desired damage parameter can then be developed. Subsequent residual strength tests can then be performed using specimens damaged using an interpolated energy or force level that is expected to produce the desired damage state.

6. Interferences

6.1 The response of a sandwich specimen to an out-of-plane force or impact is dependent upon many factors, such as facing material, facing thickness, facing ply thickness, facing stacking sequence, facing surface flatness, facing-to-core adhesive material, adhesive thickness, core material, core geometry (cell size, cell wall thickness, core thickness, etc.), core density, facing void content, adhesive void content, environment, panel geometry, impactor mass, tip geometry, ratio of tip diameter to core cell size, impact velocity, impact energy, and boundary conditions. Consequently, comparisons cannot be made between sandwich constructions unless identical test configurations, test conditions, and sandwich panel configurations are used. Damage resistance properties may vary based upon the processing and build sequence (e.g., precured/bonded versus co-cured facings).

6.2 *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 data scatter in composites in general. Specific material factors that affect sandwich composites include variability in core density and degree of cure of resin in both facing matrix material and core bonding adhesive. Important aspects of sandwich panel specimen preparation that contribute to data scatter are incomplete or nonuniform core bonding to facings, misalignment of core and facing elements, the existence of joints, voids or other core and facing discontinuities, out-of-plane curvature, facing thickness variation, and surface roughness.

6.3 *Support Fixture Characteristics*—Results are affected by geometry, material, and bending rigidity of the support fixture. Test results are influenced by the rigidity of the support fixture and its constituents (e.g., support plate, restraints) relative to both the flexural rigidity and the through-thickness shear rigidity of the sandwich specimen. Edge-supported test results are affected by the support fixture cut-out dimensions. Drop-weight impact tests are affected by the rigidity of the surface that the support fixture is located upon, the location of the support fixture clamps, clamp geometry, and the clamping force.

6.4 *Non-Destructive Inspection*—Non-destructive inspection (NDI) results are affected by the particular method utilized, the inherent variability of the NDI method, the experience of the operator, and so forth. Different NDI methods may be required for assessing the various damage modes that may arise during sandwich damage resistance testing. Damage location may also influence the selection of NDI methods.

6.5 *Environment*—Results are affected by the environmental conditions under which the tests are conducted. Critical environments must be assessed for each specific combination of core material, facing material and core-to-facing interfacial adhesive (if used).

6.6 *Indentation, Impact and Relaxation Behavior*—Different core materials may exhibit different indentation, impact and dent relaxation characteristics, failure mechanisms and failure locations. For example, brittle cores (e.g., fiberglass honeycomb and foam) may shatter upon impact, allowing the facing to spring back to its un-impacted geometry with minimal residual indentation. Conversely, other cores (e.g., aramid and aluminum honeycomb) may crush and remain bonded to the facing after impact, resulting in measurable dent geometry. While dent relaxation begins immediately after impact, both the rate of relaxation and the time to reach an equilibrium state may vary for different core materials and environments. For example, aramid honeycomb cores tend to relax more than aluminum honeycomb cores, and exhibit accelerated relaxation at elevated temperatures and humidity levels. Similarly, core failure mode and location are influenced by the relative contributions of bending, shear and contact loadings and associated core properties during indentation or impact.

6.7 *Other*—Additional sources of potential data scatter are documented in Test Method D6264/D6264M for quasi-static indentation tests and in Test Method D7136/D7136M for drop-weight impact tests.

7. Apparatus

7.1 *General Apparatus:*

7.1.1 *Procedure A*—General apparatus shall be in accordance with Test Method D6264/D6264M with flat rigid support.

7.1.2 *Procedure B*—General apparatus shall be in accordance with Test Method D6264/D6264M, with edge support consisting of a single plate with a 125.0 ± 3.0 mm [5.00 ± 0.10 in.] diameter opening. Alternative opening geometries may be appropriate, depending upon the sandwich specimen geometry (especially thickness), flexural stiffness, through-thickness shear stiffness, etc. It may be necessary to use alternative geometries to avoid core failure local to the edge support if the core has insufficient compression or shear strength. Tests conducted using alternative opening geometries must be designated as such, with the opening geometry reported with any test results.

7.1.3 *Procedure C*—General apparatus shall be in accordance with Test Method D7136/D7136M, with edge support utilizing a plate with a rectangular cut-out. The cut-out in the plate shall be 75 ± 1 mm by 125 ± 1 mm [3.0 ± 0.05 in. by 5.0 ± 0.05 in.]. Clamps shall be used to restrain the specimen during impact. Alternative cut-out geometries and support conditions may be appropriate, depending upon the sandwich specimen geometry (especially thickness), flexural stiffness, through-thickness shear stiffness, etc. It may be necessary to use alternative geometries to avoid core failure local to the edge support if the core has insufficient compression or shear strength. Tests conducted using alternative cutout geometries or support conditions, or both, must be designated as such, with the cut-out geometry and support conditions reported with any test results.

NOTE 1—If the measured damage area exceed half the unsupported specimen width, it is recommended to examine alternative specimen and fixture designs, which are larger and can accommodate larger damage areas without significant interaction from edge support conditions.

7.2 *Indenter or Impactor Tip:*

7.2.1 *Procedures A and B*—The standard indenter tip shall be in accordance with Test Method D6264/D6264M.

7.2.2 *Procedure C*—The standard impactor tip shall be in accordance with Test Method D7136/D7136M.

7.2.3 Alternative tip geometries may be appropriate depending upon the core characteristics. For example, it may be necessary to use a tip of larger diameter to ensure that multiple cells are indented or impacted when testing honeycomb core. Conversely, the use of sharp tip geometries may be appropriate for certain facing penetration resistance assessments. Alternate tip geometries may also be used to study relationships between visible damage geometry (e.g., dent depth, dent diameter) and the internal damage state. Tests conducted using alternative tip geometries must be designated as such, with the tip geometry reported with any test results.

NOTE 2—Damage resistance behavior and failure modes can vary depending upon the tip diameter utilized. For example, decreasing the indentation or impactor tip diameter in edge-supported tests can shift the damage resistance characteristics from being core shear-dominated to being core compression-dominated.

7.3 *Dent Depth Indicator*—The dent depth shall be measured using a dial depth gage to permit concurrent determination of the dent periphery. The measuring probe shall have a spherical tip with a maximum radius of curvature of 8.0 mm (0.35 in.). An instrument with an accuracy of ± 25 micrometers [± 0.001 in.] is desirable for depth measurement.

8. Sampling and Test Specimens

8.1 *Sampling*—Test at least five specimens per test condition unless valid results can be gained through the use of fewer specimens, as in the case of a designed experiment. For statistically significant data, consult the procedures outlined in Practice E122. Report the method of sampling.

8.2 *Specimen Dimensions:*

8.2.1 *Procedures A and B*—The specimen dimensions shall be in accordance with Test Method D6264/D6264M, with the specimen thickness equal to the sandwich panel thickness.

8.2.2 *Procedure C*—The specimen dimensions shall be in accordance with Test Method D7136/D7136M, with the specimen thickness equal to the sandwich panel thickness.

8.2.3 Alternative specimen dimensions may be appropriate if edge support geometries differ from those specified in 7.1.