Standard Practice 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]

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

[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.

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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.

E2533 Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications

2.2 *Other Documents:*

CMH-17-3G Composite Materials Handbook, Volume 3—Polymer Matrix Composites: Materials Usage, Design and Analysis[3]

CMH-17-6 Composite Materials Handbook, Volume 6—Structural Sandwich Composites[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, as well as 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

[3] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

[4] Available from U.S. Army Materials Technology Laboratory, Watertown, MA 02471.

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).

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.

7.4 *Micrometers and Calipers*—A micrometer with a 4 to 7 mm [0.16 to 0.28 in.] nominal diameter ball-interface or a flat anvil interface shall be used to measure the specimen thickness. A ball interface is recommended for thickness measurements when at least one surface is irregular (e.g. the bag-side of a thin facing laminate that is neither smooth nor flat). A micrometer or caliper with a flat anvil interface is recommended for thickness measurements when both surfaces are smooth (e.g. tooled surfaces). A micrometer or caliper with a flat anvil interface shall be used for measuring length and width. The use of alternative measurement devices is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory. The accuracy of the instruments shall be suitable for reading to within 1 % of the sample dimensions. For typical specimen geometries, an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for thickness measurement, whereas an instrument with an accuracy of ±0.25 mm [±0.010 in.] is adequate for length and width 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. Tests conducted using alternative specimen dimensions must be designated as such, with the dimensions reported with any test results.

NOTE 3—It is permissible to impact a panel larger than the specified dimensions, then to cut out specimens (with the indentation or impact site centered) for subsequent residual strength testing, as long as the panel dimensions and procedures utilized are recorded as a variation to the test method. Impacting a larger panel can help relieve interaction between the edge conditions and the damage creation mechanisms.

8.3 *Stacking Sequence*—For comparison screening of the damage resistance of different materials, the standard specimen shall be defined as follows:

8.3.1 *Unidirectional Tape*—The sandwich construction shall consist of unidirectional facing plies and core. The recommended layups for various nominal cured ply thicknesses are provided in Table 1.

8.3.2 *Woven Fabric*—The sandwich construction shall consist of fabric facing plies and core. The recommended layups for various nominal cured ply thicknesses are provided in Table 2, with the designations (+45/-45) and (0/90) representing a single layer of woven fabric with the warp and weft fibers oriented at the specified angles. Fabric laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise specified and noted in the report.

8.3.3 *Alternative Stacking Sequences*—Sandwich panels fabricated using other facing layups or fiber orientations may be evaluated for damage resistance using these practices. Tests conducted using alternative stacking sequences must be designated as such, with the stacking sequence recorded and reported with any test results.

8.3.4 *Core*—The standard sandwich construction shall be fabricated using 13.0 ± 0.1 mm [0.500 ± 0.005 in.] thick core. Tests conducted using alternative core thicknesses must be designated as such, with the core thickness reported with any test results.

8.3.5 *Adhesive*—Adhesive may be utilized at the core-to-facing interfaces. If utilized, the adhesive material, adhesive ply thickness, adhesive areal weight and number of adhesive plies used must be reported with any test results.

8.4 *Specimen Preparation*—Guide D5687/D5687M provides recommended specimen preparation practices and should be followed where practical.

8.4.1 *Panel Fabrication*—Control of fiber alignment is critical. Improper fiber alignment will affect the measured properties. Erratic fiber alignment will also increase the coefficient of variation. Report the panel fabrication method. Specimens shall be of uniform cross-section over the entire surface and shall not have a thickness taper greater than 0.08 mm [0.003 in.] in any direction across the length and width of the specimen.

8.4.2 *Machining Methods*—Specimen preparation is extremely important for this specimen. Take precautions when cutting specimens from large panels to avoid notches, undercuts, rough or uneven surfaces, or delaminations and disbonds due to inappropriate machining methods. Obtain final dimensions by water-lubricated precision sawing, milling, or grinding. The use of diamond-tipped tooling (as well as water-jet cutting) has been found to be extremely effective for many material systems. Edges should be flat and parallel within the specified tolerances. Machining tolerances and facing surface finish requirements are as noted in Test Method D6264/D6264M for Procedure A and B specimens and in Test Method D7136/D7136M for Procedure C specimens. Record and report the specimen cutting methods.

NOTE 4—Initial panel machining is less critical when impacting a panel larger than the specified dimensions. It is common practice to "rough machine" larger panel edges prior to impact, then to perform precision machining when extracting specimens for subsequent residual strength testing as described in Note 3.

TABLE 1 Recommended Layups for Various Nominal Cured Ply Thicknesses, Unidirectional Tape

NOTE 1—Adhesive may be used at the core-to-facing interfaces as appropriate.

Nominal Cured Ply Thickness Minimum, mm [in.]	Nominal Cured Ply Thickness Maximum, mm [in.]	Ply Count per Facing	Layup
0.085 [0.0033]	0.15 [0.006]	8	[45/0/-45/90/90/-45/0/45/core/45/0/-45/90/90/-45/0/45]
0.15 [0.006]	0.25 [0.010]	4	[45/0/-45/90/core/90/-45/0/45]

TABLE 2 Recommended Layups for Various Nominal Cured Ply Thicknesses, Woven Fabric

NOTE 1—Adhesive may be used at the core-to-facing interfaces as appropriate.

Nominal Cured Ply Thickness Minimum, mm [in.]	Maximum, mm [in.]	Ply Count per Facing	Layup
0.085 [0.0033]	0.13 [0.005]	8	[((45/-45)/(0/90))$_{2S}$/core/((45/-45)/(0/90))$_{2S}$]
0.13 [0.005]	0.18 [0.007]	6	[(45/-45)/(0/90)/((45/-45)/(0/90))$_S$/core/((45/-45)/(0/90))$_S$/(0/90)/(45/-45)]
0.18 [0.007]	0.25 [0.010]	4	[(45/-45)/(0/90)/(0/90)/(45/-45)/core/(45/-45)/(0/90)/(0/90)/(45/-45)]
0.25 [0.010]	0.50 [0.020]	2	[(45/-45)/(0/90)/core/(0/90)/(45/-45)]

8.4.3 *Labeling*—Label the specimens so that they will be distinct from each other and traceable back to the raw materials, and will neither influence the test nor be affected by it.

9. Calibration

9.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

10. Conditioning

10.1 The recommended pre-test condition is effective moisture equilibrium at a specific relative humidity as established by Test Method D5229/D5229M; however, if the test requestor does not explicitly specify a pre-test conditioning environment, no conditioning is required and the test specimens may be tested as prepared.

10.2 The pre-test specimen conditioning process, to include specified environmental exposure levels and resulting moisture content, shall be reported with the test data.

NOTE 5—The term moisture, as used in Test Method D5229/D5229M, includes not only the vapor of a liquid and its condensate, but the liquid itself in large quantities, as for immersion.

10.3 If no explicit conditioning process is performed, the specimen conditioning process shall be reported as "unconditioned" and the moisture content as "unknown."

11. Procedure

11.1 *Parameters to be Specified Prior to Test:*

11.1.1 *Procedure A*—Specify parameters prior to test in accordance with Test Method D6264/D6264M. The rigidly-backed specimen support configuration shall be specified.

11.1.2 *Procedure B*—Specify parameters prior to test in accordance with Test Method D6264/D6264M. The edge-supported specimen support configuration shall be specified.

11.1.3 *Procedure C*—Specify parameters prior to test in accordance with Test Method D7136/D7136M.

11.2 *General Instructions:*

11.2.1 Report any deviations from these practices, whether intentional or inadvertent.

11.2.2 If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from the same panels being tested. Specific gravity and density may be evaluated by means of Test Method D792. Volume percent of the constituents may be evaluated by one of the procedures of Test Methods D3171.

11.2.3 Following final specimen machining, but before conditioning, perform a baseline non-destructive inspection of the specimen to detect flaws or defects which may exist prior to indentation or impact testing. A variety of NDI techniques are available for detecting both surface and interior flaws in sandwich constructions. Visual inspection and liquid penetrant methods can be used for identifying surface defects, while more sophisticated techniques are required for detecting internal flaws such as cracks, splits, delaminations and disbonds. These techniques include ultrasonics, radiography, thermography, acoustic emission, modal analysis (such as instrumented tap testing) and eddy-current testing. Guidance on available techniques and selection of appropriate methods for specific composite sandwich construction applications is provided in Guide E2533, as well as section 6.3.2 and 13.2.1 of CMH-17-3G and section 6.3.2 of CMH-17-6. Basic principles and procedures for these methods are covered in the MIL-HDBK-728/1 series, while more specific information on the theory and interpretation of data can be found in MIL-HDBK-731A for thermography, MIL-HDBK-732A for acoustic emission, MIL-HDBK-733A for radiography, and MIL-HDBK-787A for ultrasonics. Record the method(s), specification(s) and parameters used in the NDI evaluation(s).

NOTE 6—The NDI techniques discussed in Guide E2533, CMH-17-3G, and CMH-17-6 each have particular attributes in regard to sensitivity to different damage types, damage location, ability to detect different types of damage in three dimensions, and so forth. It may be necessary to utilize a combination of NDI techniques to properly characterize the three-dimensional damage state in some instances (for example, when both facing delaminations and core-to-facing disbonds are present). Historically, ultrasonic techniques have been most effective in detecting sandwich facing damage. Thermography and shearography have been effective in detecting facing-to-core disbonds, whereas radiography, computed tomography and through-thickness ultrasonic transmission methods have been effective in detecting core damage.

11.2.4 Condition the specimens as required. Store the specimens in the conditioned environment until test time, if the test environment is different than the conditioning environment.

11.2.5 Following final specimen machining and any conditioning, but before all testing, measure the specimen width, w, and length, l, at two locations in the vicinity of the location to be damaged. The thickness of the specimen shall be measured at four locations near the impact location, and recorded as the average of the four measurements. The accuracy of all measurements shall be within 1 % of the dimension. Record the dimensions to three significant figures in units of millimetres [inches].

11.3 *Test Environment*—If possible, test the specimen under the same fluid exposure level used for conditioning. However, cases such as elevated temperature testing of a moist specimen place unrealistic requirements on the capabilities of common environmental chambers. In such cases the mechanical test environment may need to be modified, for example, by testing at elevated temperature with no fluid exposure control, but with a specified limit on time to test after withdrawal from the conditioning chamber. Record any modifications to the test environment.

NOTE 7—When testing a conditioned specimen at elevated temperature with no fluid exposure control, the percentage moisture loss of the specimen prior to test completion may be estimated by placing a conditioned traveler coupon of known weight within the test chamber at the same time the specimen is placed in the chamber. Upon completion of the test, the traveler coupon is removed from the chamber, weighed, and the percentage weight calculated and reported.

11.4 *Test Procedure:*

11.4.1 *Procedure A*—For quasi-static indentation tests of rigidly-backed sandwich specimens, the test machine preparation, specimen installation, loading and data recording shall be performed in accordance with Test Method D6264/D6264M. The suggested standard crosshead displacement rates are 0.25 mm/min [0.01 in./min] for cores with high compression strength (e.g., balsa wood) and 1.25 mm/min [0.05 in./min] for cores with low compression strength (e.g., foams, honeycombs). The test should be terminated before penetrating the back-side sandwich facing to avoid damaging the test apparatus. The unloading rate shall be the same as the loading rate.

NOTE 8—For some sandwich constructions, the force versus displacement response observed in rigidly-backed Procedure A testing may more closely mimic the edge-supported laminate response shown in Test Method D6264/D6264M, in that sharp drops in force may result when the indenter penetrates a facing. Conversely, sandwich constructions using cores with high compression strength (e.g., balsa wood) may exhibit the rigidly-backed force versus displacement response shown in Test Method D6264/D6264M.

11.4.2 *Procedure B*—For quasi-static indentation tests of edge-supported sandwich specimens, the test machine preparation, specimen installation, speed of testing, loading and data recording shall be performed in accordance with Test Method D6264/D6264M. The suggested standard crosshead displacement rate is 1.25 mm/min [0.05 in./min]. The unloading rate shall be the same as the loading rate.

11.4.3 *Procedure C*—For drop-weight impact of sandwich specimens, the specimen installation, impactor preparation, impact and data recording shall be performed in accordance with Test Method D7136/D7136M, except that impact energy shall be calculated as defined in 13.1.

11.5 *Dent Depth and Diameter*—Measure the dent depth in accordance with Test Method D6264/D6264M for Procedure A and B specimens and in accordance with Test Method D7136/D7136M for Procedure C specimens. Additionally, measure the dent diameter using a depth gage as defined in 7.3. The dent diameter shall be measured immediately after the indentation force is removed for Procedure A and B specimens, or immediately after impact for Procedure C specimens. As shown in Fig. 1, the periphery of the dent shall be determined at eight points relative to the center of the specimen. The periphery of the dent shall be identified by starting 25 to 50 mm [1.0 to 2.0 in.] from the center of the specimen where the specimen surface is clearly flat, zeroing the depth gage, then moving the depth gage towards the center of the specimen. The peripheral point shall be identified as the location where the measured depth begins to change. Determine the maximum dent diameter as shown in Fig. 1. Alternative measurement locations may be required to characterize the dent periphery for non-standard layups or fiber orientations, or both. Alternatively, automated algorithms may be used to define the dent periphery and to calculate the dent diameter.

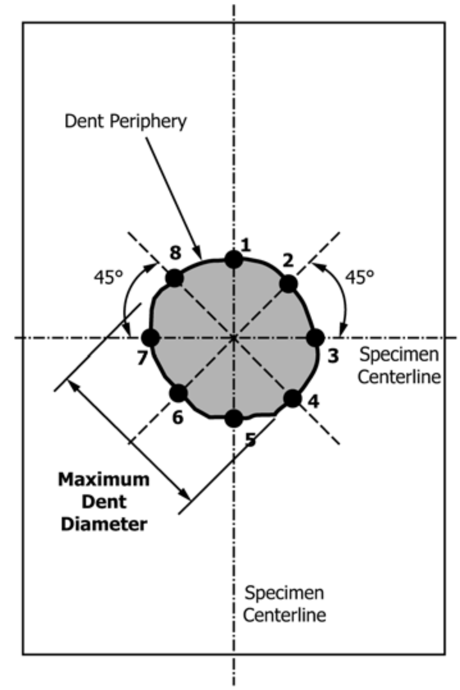

FIG. 1 Measurement of Dent Periphery and Diameter

11.6 *Dent Relaxation*—Over time, or under environmental exposure, the dent depth can decrease due to relaxation of the composite material. If information on short-term dent relaxation is desired, measure the dent depth and dent diameter 7 days after testing as in 11.5. Record the dent depth, dent diameter, the time duration after testing that the measurement was taken, and the environmental conditions prior to measurement.

11.7 *Non-Destructive Inspection:*

11.7.1 Evaluate the extent and location of damage caused by the indentation or impact event using non-destructive inspection (NDI) techniques. Utilize NDI method(s), specification(s), and parameters consistent with those used to evaluate the specimen prior to testing in 11.2.3. Record the method(s), specification(s), and parameters used in the NDI evaluation(s).

11.7.2 Measure and record geometric dimensions and locations for the detected damage in accordance with Test Method D6264/D6264M for Procedure A and B specimens and in accordance with Test Method D7136/D7136M for Procedure C specimens.

11.7.3 Record the damage mode(s) observed for each specimen, and the surface(s) or through-thickness location(s), or both, at which the damage modes are observed. More than one damage mode may be present in a damaged specimen. Fig. 2 illustrates commonly observed damage modes in sandwich construction damage resistance testing. Fig. 3 identifies locations where damage may be found resulting from sandwich indentation or impact. Note that in comparison to the laminate indentation and impact damage characterization performed under Test Method D6264/D6264M and Test Method D7136/D7136M, there are nine potential damage locations (two facings, two facing-to-adhesive interfaces, two adhesive layers, two adhesive-to-core interfaces, and core).

NOTE 9—If specimens are not used for subsequent residual strength assessments, sectioning of the specimens may be useful for characterizing the modes, size and through-thickness location of damage.

12. Validation

12.1 Property values shall not be calculated for any specimen that forms damage or breaks at some obvious flaw, unless such flaw constitutes a variable being studied. Retests shall be performed for any specimen on which values are not calculated.

12.2 If a significant number of specimens in a sample population exhibit damage originating or extending significantly away from the indentation or impact location, the support conditions shall be re-examined. Factors considered should include fixture alignment, indenter alignment, impactor guide alignment, gaps between the specimen and restraints, and specimen thickness taper.

13. Calculation

13.1 *Impact Energy*—For Procedure C specimens, calculate the standard impact energy level using Eq 1 unless otherwise specified. Record the impact energy level to three significant figures. This calculation shall be used to define the sandwich specimen impact energy level in lieu of Eq 1 of Test Method D7136/D7136M. Alternative impact energy levels may be appropriate depending upon the support geometry, support conditions, facing thickness, sandwich bending stiffness, etc. Tests conducted using alternative impact energies must be designated as such, with the impact energy and drop height reported with any test results.

$$E = C_F t \tag{1}$$

where:

E = potential energy of impactor prior to drop, J [in.-lbf],
C_F = specified ratio of impact energy to thickness of the impacted sandwich facing, 6.7 J/mm [1500 in.-lbf/in.], and
t = nominal thickness of impacted sandwich facing, mm [in.]

13.2 Perform all other calculations specified by Test Method D6264/D6264M for Procedure A and B tests and by Test Method D7136/D7136M for Procedure C tests.

14. Report

14.1 The report shall include all appropriate parameters in accordance with Test Method D6264/D6264M for Procedure A and B tests and Test Method D7136/D7136M for Procedure C tests.

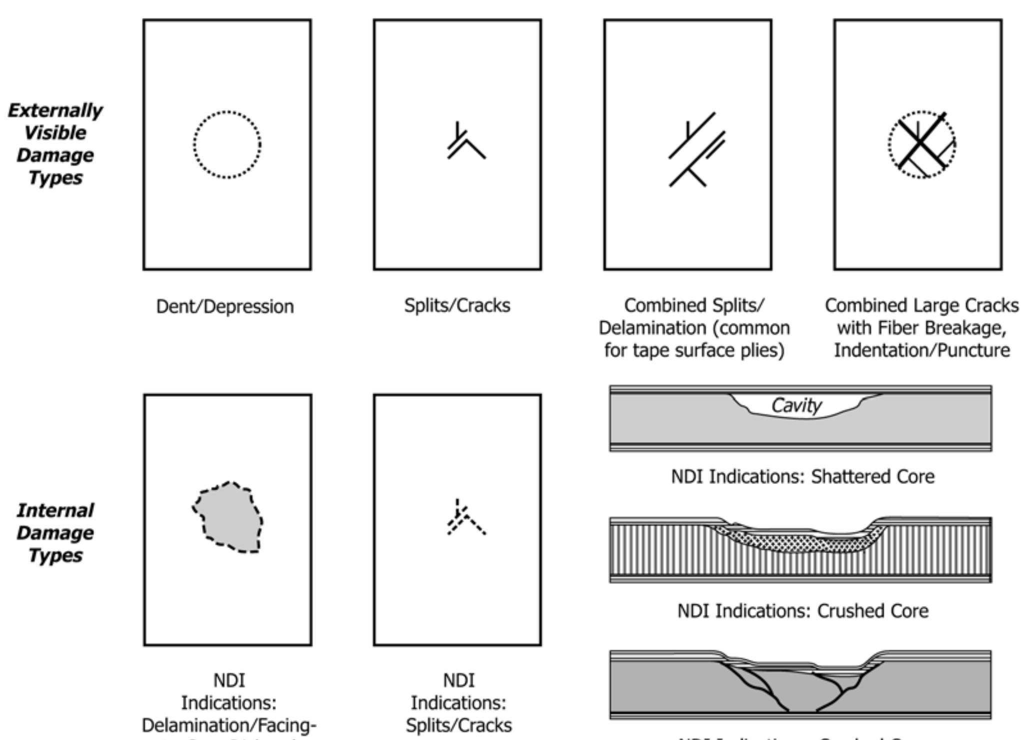

FIG. 2 Commonly Observed Damage Modes from Out-of-Plane Indentation or Drop-Weight Impact

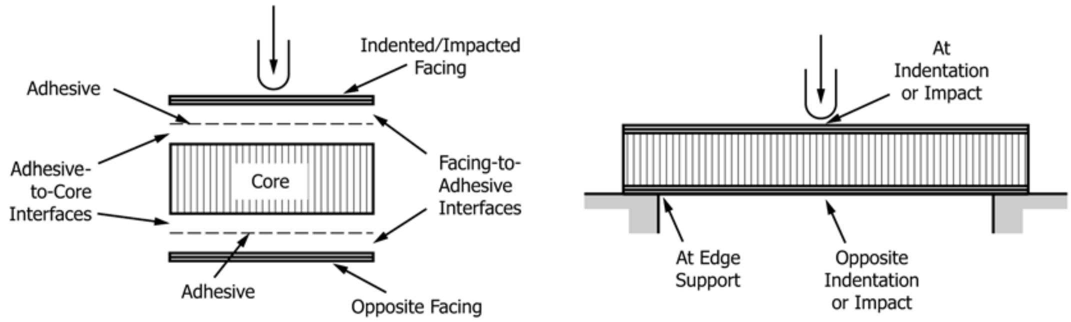

FIG. 3 Indentation/Impact Damage Locations

14.2 In addition, the report shall include the following information, or references pointing to other documentation containing this information, to the maximum extent applicable (reporting of items beyond the control of a given testing laboratory, such as might occur with material details or panel fabrication parameters, shall be the responsibility of the requestor):

14.2.1 The revision level or date of issue of this practice.

14.2.2 Any variations to these practices, anomalies noticed during testing, or equipment problems occurring during testing.

14.2.3 Identification of all the materials constituent to the sandwich specimen tested, including for each: material specification, material type, manufacturer's material designation, manufacturer's batch or lot number, source (if not from manufacturer), date of certification, and expiration of certification. For each facing material, include the facing filament diameter, tow or yarn filament count and twist, sizing, form or weave, fiber areal weight, matrix type, matrix content and volatiles content. If utilized, report the adhesive material, adhesive ply thickness, adhesive areal weight and number of adhesive plies used.

14.2.4 Description of the fabrication steps used to prepare the sandwich panel including: fabrication start date, fabrication end date, process specification, and a description of the equipment used.

14.2.5 Ply orientation and stacking sequence of the facing laminate and sandwich panel.

14.2.6 If requested, report facing density, volume percent reinforcement, and void content test methods, specimen sampling method and geometries, test parameters and test results.

14.2.7 If requested, core density test method, specimen sampling method and geometries, test parameters, and test results.

14.2.8 Individual values of maximum dent diameter, along with average value, standard deviation, and coefficient of variation (in percent) for the population.

14.2.9 Time interval between the indentation or impact and the dent depth and diameter measurements.

14.2.10 If dent relaxation is evaluated, individual values of maximum dent diameter after relaxation, along with the time duration after testing and the environmental conditions prior to measurement.

14.2.11 Damage mode(s) and location(s) observed for each specimen, using Fig. 2 and Fig. 3 as guidance.

15. Precision and Bias

15.1 *Precision*—The data required for the development of a precision statement is not available for these methods.

15.2 *Bias*—Bias cannot be determined for this method as no acceptable reference standards exist.

16. Keywords

16.1 core; damage resistance; delamination; dent; disbond; drop-weight impact; facing; impact testing; quasi-static indentation; sandwich; sandwich construction