Designation: D7956/D7956M – 16

Standard Practice for Compressive Testing of Thin Damaged Laminates Using a Sandwich Long Beam Flexure Specimen[1]

This standard is issued under the fixed designation D7956/D7956M; 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 covers an approach for compressive testing thin damaged multidirectional polymer matrix composite laminates reinforced by high-modulus fibers using a sandwich long beam flexure specimen. It provides a test configuration in which the core does not constrain any protruding back side damage. It is limited to testing of monolithic solid laminates which are too thin to be tested using typical anti-buckling fixtures. It does not cover compressive testing of damaged sandwich panel facings. The composite material forms are limited to continuous-fiber or discontinuous-fiber (tape or fabric, or both) reinforced composites in which the laminate is balanced and symmetric with respect to the test direction

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D883 Terminology Relating to Plastics
D3878 Terminology for Composite Materials
D3410 Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading
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
D7137/D7137M Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates
D7249/D7249M Test Method for Facing Properties of Sandwich Constructions by Long Beam Flexure
E6 Terminology Relating to Methods of Mechanical Testing
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
E456 Terminology Relating to Quality and Statistics

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.

4. Summary of Practice

4.1 This practice consists of fabricating a composite laminate, damaging the laminate using either Test Method D6264/D6264M or Test Method D7136/D7136M, bonding the impacted or indented side of the laminate onto core and a back side facing to form a sandwich panel, and testing the damaged laminate in compression using Test Method D7249/D7249M.

5. Significance and Use

5.1 This practice provides a standard method of testing damaged composite laminates which are too thin to be tested

[1] This test method 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.

using typical anti-buckling fixtures, such as those used in Test Method D7137/D7137M. The laminate is first impacted or indented in order to produce a damage state representative of actual monolithic solid laminate structure. Impacting or static indentation is not performed on an assembled sandwich panel, as the damage state is altered by energy absorption in the core and by support of the core during the impact or indentation event. After damaging, the laminate is bonded onto the core with the impacted or indentation side of the laminate against the core, and with a localized un-bonded area encompassing the damage site. Fig. 1 illustrates the adhesive removal to avoid the damaged area and the assembly of the sandwich specimen with the impacted damaged laminate flipped over from the impacting or indentation orientation. The final assembled sandwich specimen is then tested using a long beam flexure setup with the damaged laminate being on the compression side. The sandwich panel configuration is used as a form of anti-buckling support for the thin damaged laminate.

5.2 Susceptibility to damage from concentrated out-of-plane forces is one of the major design concerns of many structures made of advanced composite laminates. Knowledge of the damage resistance and damage tolerance properties of a laminated composite plate is useful for product development and material selection.

5.3 The residual strength data obtained using this test method is used in research and development activities as well as for design allowables; however the results are specific to the geometry and physical conditions tested and are generally not scalable to other configurations.

5.4 The properties obtained using this test method can provide guidance in regard to the anticipated damage tolerance capability of composite structures of similar material, thickness, stacking sequence, and so forth. However, it must be understood that the damage tolerance of a composite structure is highly dependent upon several factors including geometry, stiffness, support conditions, and so forth. Significant differences in the relationships between the existent damage state and the residual compressive strength can result due to differences in these parameters. For example, residual strength and stiffness properties obtained using this test method would more likely reflect the damage tolerance characteristics of an un-stiffened monolithic skin or web than that of a skin attached to substructure which resists out-of-plane deformation.

5.5 The reporting section requires items that tend to influence residual compressive strength 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, type, size and location of damage (including method of non-destructive inspection (NDI)), fixture geometry, time at temperature, and speed of testing.

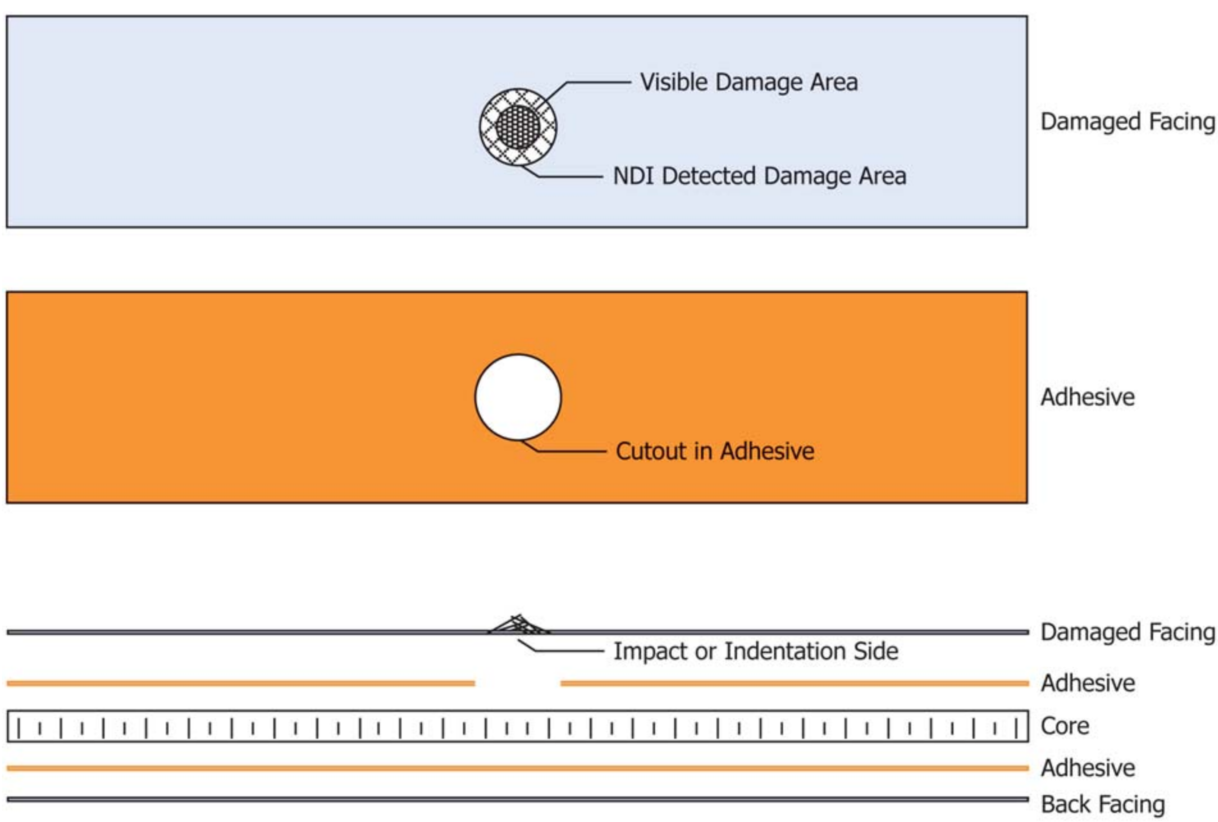

FIG. 1 Sandwich Specimen Assembly

5.6 Properties that result from the residual strength assessment include the following: compressive residual strength F^{CAI}.

6. Interferences

6.1 The response of a damaged specimen is dependent upon many factors, such as laminate thickness, ply thickness, stacking sequence, environment, damage type, damage geometry, damage location, and loading/support conditions. Consequently, comparisons cannot be made between materials unless identical test configurations, test conditions, and laminate configurations are used. Therefore, all details of the test configuration shall be reported in the results. Specific structural configurations and boundary conditions must be considered when applying the data generated using this test method to design applications.

6.2 *Material Orthotropy*—The degree of laminate orthotropy strongly affects the failure mode and measured compressive residual strength.

6.3 *Thickness Scaling*—Thick composite structures do not necessarily fail at the same strengths as thin structures with the same laminate orientation (that is, strength does not always scale linearly with thickness). Further, the damage state for a given level of impact or indentation energy or measured surface dent depth varies with laminate thickness. Thus, data gathered using this test method may not translate directly into equivalent thick-structure properties.

6.4 *Damage Geometry and Location*—The size, shape, and location of damage (both within the plane of the plate and through-the-thickness) can significantly affect the deformation and strength behavior of the specimen. Edge effects, boundary constraints, and the damaged stress/strain field can interact if the damage size becomes too large relative to the length and width dimensions of the specimen.

6.5 *Environment*—Results are affected by the environmental conditions under which specimens are conditioned, as well as the conditions under which the tests are conducted. Specimens tested in various environments can exhibit significant differences in stiffness. Critical environments must be assessed independently for each specific combination of core material, facing material, and core-to-facing interfacial adhesive (if used) that is tested.

6.6 *Core Material*—If the core material has insufficient shear or compressive strength, it is possible that the core may locally crush at or near the loading points thereby resulting in facesheet failure due to local stresses. In other cases, facing failure can cause local core crushing. When there is both facing and core failure in the vicinity of one of the loading points, it can be difficult to determine the failure sequence in a post-mortem inspection of the specimen as the failed specimens look very similar for both sequences.

6.7 *Damaging*—Refer to Test Methods D6264/D6264M or D7136/D7136M for indentation or impact related interferences.

7. Sampling and Test Specimens

7.1 *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.

7.2 *Specimen and Fixture Geometry*—The test requestor shall specify all specimen dimensions and materials along with the loading fixture dimensions. Refer to Test Method D7249/D7249M for sandwich beam specimen sizing requirements and guidelines.

7.2.1 *Specimen*—The test specimens shall be rectangular in cross section. The width of the specimen shall be at least three (3) times the width of the major damage area (as determined by NDI). The major damage area is defined as the region of impact damage that generally extends through the entire laminate thickness; generally it does not include splitting or delamination of the surface ply on the opposite side from the impact (typically, the major damage area is approximately circular on the NDI scan image). Any such backside damage that is not included in the major damage area should not be greater than one-half (½) the specimen width nor extend to near the edges of the specimen. If there is uncertainty over the damage area to use for specimen sizing, the test lab should consult the test requestor.

NOTE 1—The recommended specimen width is five (5) times the damage width, however this may not be practical in all cases, particularly when there is backside ply splitting or delamination, or both. Also, it may not be possible to accurately predict the damage sizes prior to fabrication of the test specimens; therefore a pre-test impact survey program is recommended prior to specimen fabrication. As impact or indentation damage diameters are often on the order of 25 mm [1.0 in.], a typical specimen width is 127 mm [5.0 in.]. Specimen width should be minimized to avoid excessive anti-clastic bending; a maximum width to support span ratio of 0.3 is recommended.

7.2.2 *Loading Fixture*—The loading span should be increased from the Test Method D7249/D7249M standard specimen dimension of 100 mm [4.0 in] to the minimum of a dimension equal to the specimen width or three (3) times the dimension of the damage measured in the axial direction of the specimen. The support span may have to be modified from the Test Method D7249/D7249M standard specimen dimension in order for the specimen to produce the desired facesheet failure mode.

7.3 *Back Side Facings*—The back side facings may use the same laminate as the laminate to be tested in compression, or may use a similar laminate. The back side facing should have equal or greater stiffness (Et) than the top (compressive) facing and shall have greater tensile strength than the anticipated compressive strength of the damaged laminate to be tested. The back side facing should have a similar coefficient of thermal expansion as the top facing to avoid panel warpage during fabrication.

NOTE 2—Metallic sheets are not recommended for the back facings as it can be difficult to machine a sandwich panel with dissimilar materials for the two facings.

7.4 *Core*—The core material for the sandwich panels shall have sufficient shear and compression strength to avoid failures in the core prior to facing failure. Refer to Test Method D7249/D7249M for core material selection guidelines

7.5 *Adhesive*—The adhesive material for bonding the facings to the core of the sandwich panel shall have sufficient shear strength at the test temperature to avoid failure in the bond prior to facing failure. The adhesive used to bond the damaged facing shall not significantly flow into the cutout area around the damage location.

8. Procedure

8.1 *Fabricate Laminate and Back Side Facings*—Fabricate the laminates to be tested. Also fabricate back (tension) side facings for the sandwich specimens.

NOTE 3—It is acceptable to fabricate larger panels with sufficient material for several specimens. Mark the location of each specimen, damage the large panel once in the center of each specimen, bond the laminate onto the core and back facing, then machine each individual sandwich specimen.

8.2 *Perform Damaging*—Impact damage using either Test Method D6264/D6264M or Test Method D7136/D7136M, using an impact energy or indentation depth to be supplied by the test requestor. Apply a single impact or indentation in the center of each specimen to be tested. Record the damage measurements per Test Method D6264/D6264M or Test Method D7136/D7136M.

8.3 *Fabricate Sandwich Specimens*—Fabricate the sandwich panels using the damaged laminates, the back side facings, and the selected core and adhesive. The damaged laminates shall be bonded to the core with the side of the laminate which was impacted or indented being bonded to the core (flipped upside down from the orientation during impacting or indention); see Fig. 1. The adhesive used to bond the damaged laminate shall have a circular area without adhesive, centered over the damage site, with a diameter larger than the general disbond area detected by NDI. A typical size for the cutout in the adhesive is 51 mm [2.0 inch] (it is acceptable to have a length of splitting on the exposed laminate surface [back side from the impact or indentation side] which is larger than the un-bonded area).

NOTE 4—The damaged laminates are flipped over when bonded to the core so that any damage protrusions on the back side of the laminate do not interfere with nor are supported by the core material.

NOTE 5—The damaged laminate should not be bonded with the impact or indentation side up and with the core material relieved under the damage site, as it has been found that thin laminates can "dish" into the relieved core area during bonding.

8.4 *Testing*—Conduct tests on sandwich beam specimens per Test Method D7249/D7249M. The damaged facing shall be loaded in compression

8.5 *Data Recording*—Record force-deflection curves for each test specimen using a transducer, deflectometer, or dial gage to directly measure the mid-span deflection of the specimen.

NOTE 6—The use of crosshead or actuator displacement for the beam mid-span deflection produces inaccurate results; the direct measurement of the deflection of the mid-span of the beam must be made by a suitable instrument.

9. Validation

9.1 Values for strength properties shall not be calculated at any applied force level above or beyond the point of initial specimen failure, or above a point where the specimen exhibits obvious non-linear deflection response due to excessive local or overall deflection. Retests shall be performed for any specimen on which values are not calculated.

10. Calculation

10.1 *Force-Displacement Behavior*—Plot and examine the force-displacement data to determine if there is any significant compliance change (change in slope of the force-displacement curve, sometimes referred to as a transition region) prior to ultimate failure ("significant" is defined as a 10 % or more change in slope). An example of a transition region is shown in Test Method D3410. Determine the slope of the force-displacement curve above and below the transition point using chord values over linear regions of the curve. Intersect the linear slopes to find the transition point. Report the force and displacement at such points along with the displacement values used to determine the chord slopes. Report the mode of any damage observed during the test prior to specimen failure.

10.2 *Facing Ultimate Stress*—Calculate the facing ultimate stress per Test Method D7249/D7249M, section 13.2. Report the ultimate stress as F^{CAI} = ultimate compressive residual strength, MPa [psi].

10.3 *Statistics*—For each series of tests, calculate the average value, standard deviation, and coefficient of variation (in percent) for ultimate stress per Test Method D7249/D7249M, section 13.5.

11. Report

11.1 Report the information required by Test Methods D6264/D6264M or D7136/D7136M, depending on the damaging procedure used.

11.2 Report the information required by Test Method D7249/D7249M.

12. Precision and Bias

12.1 *Precision*—The data required for the development of a precision statement is not available for this practice.

12.2 *Bias*—Bias cannot be determined for this practice as no acceptable reference standards exist.

13. Keywords

13.1 bending stress; composite materials; compression after impact; compression testing; compressive residual strength; damage; facing strength; facing stress; sandwich construction