Designation: D8287/D8287M – 22

Standard Test Method for Compressive Residual Strength Properties of Damaged Sandwich Composite Panels[1]

This standard is issued under the fixed designation D8287/D8287M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers compression residual strength properties of sandwich constructions that have been subjected to quasi-static indentation or drop-weight impact per Practice D7766/D7766M.

NOTE 1—When used to determine the residual strength of drop-weight impacted plates, this test method is commonly referred to as the Sandwich Compression After Impact test method.

1.2 Several important test specimen parameters (for example, facesheet thickness, core thickness, and core density) are not mandated by this test method; however, repeatable results require that these parameters be specified and reported.

1.3 The method utilizes a flat, rectangular specimen, previously subjected to a damaging event, which is tested under edgewise compressive loading using a stabilization fixture.

1.4 The properties generated by this test method are highly dependent upon several factors, which include; specimen geometry, sandwich component materials and dimensions (facesheet, core, and adhesive), methods of fabrication, the type, size, and location of damage and boundary conditions. Thus, results are generally not scalable to other sandwich constructions, and are particular to the combination of geometric and physical conditions tested.

1.5 This test method can be used to test undamaged specimens, but care should be taken to prevent undesirable failure modes such as end crushing. Test Methods C364 and D7249/D7249M are the recommended test methods for undamaged sandwich panel compression strength by edgewise compression or long beam flexure, respectively.

1.6 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

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

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C364 Test Method for Edgewise Compressive Strength of 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
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D7137 Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates
D7249/D7249M Test Method for Facesheet Properties of Sandwich Constructions by Long Beam Flexure
D7766/D7766M Practice for Damage Resistance Testing of Sandwich Constructions
D8388/D8388M Practice for Flexural Residual Strength

[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.

Testing of Damaged Sandwich Constructions
E4 Practices for Force Calibration and Verification of Testing Machines
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 conflict between terms, Terminology D3878 shall have precedence over the other terminology standards.

NOTE 2—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 *Symbols:*

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

h—specimen thickness

l—specimen length

n—number of specimens per sample population

N^{CAI}—ultimate normalized compressive force in the test direction

P_{max}—maximum force carried by test specimen prior to failure

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

t—nominal facesheet thickness

w—specimen width

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

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

Δ—percent difference

ε—indicated strain from gage

4. Summary of Test Method

4.1 A uniaxial compression test is performed using a specimen which has been damaged and inspected prior to the application of compressive force. The damage state is imparted through out-of-plane loading caused by quasi-static indentation or drop-weight impact.

4.1.1 *Quasi-Static Indentation*—The rectangular specimen is damaged due to application of an out-of-plane static indentation force in accordance with Practice D7766/D7766M Procedure A or Procedure B.

4.1.2 *Drop-Weight Impact*—The rectangular specimen is damaged due to application of an out-of-plane drop-weight impact in accordance with Practice D7766/D7766M Procedure C.

4.2 The damaged specimen is installed in a multi-piece support fixture, that has been aligned to minimize loading eccentricities and induced specimen bending. The specimen/fixture assembly is placed between flat platens and end-loaded under compressive force until failure. Applied force, crosshead displacement, and strain data are recorded while loading.

4.3 Preferred failure modes pass through the damage in the specimen. However, acceptable failures may initiate away from the damage site, in instances when the damage produces a relatively low stress concentration or if the extent of damage is small, or both. Unacceptable failure modes are those related to load introduction by the support fixture, local edge support conditions, and specimen instability (unless the specimen is dimensionally representative of a particular structural application).

5. Significance and Use

5.1 Susceptibility to damage from concentrated out-of-plane forces is one of the major design concerns of many structures made of sandwich constructions. Knowledge of the damage resistance and residual strength properties of a sandwich construction is useful for product development and material selection.

5.2 The residual strength data obtained using this test method is most commonly used in material selection, research and development activities, and establishing design allowables.

5.3 The properties obtained using this test method can provide guidance in regard to the anticipated residual strength capability of sandwich constructions of similar facesheet and core material, adhesive, facesheet and core thickness, facesheet stacking sequence, and so forth. However, it must be understood that the residual strength of sandwich constructions is highly dependent upon several factors including geometry, thickness, stiffness, support conditions, and so forth. Significant differences in the relationships between the damage state and the residual compressive strength can result due to differences in these parameters.

5.4 The compression strength from this test may not be equivalent to the compression strength of sandwich structures subjected to flexural compression testing.

5.5 The reporting section requires items that tend to influence residual compressive strength to be reported; these include the following: facesheet and core materials, core density, cell size and wall thickness if applicable, film adhesive, methods of material fabrication, accuracy of lay-up orientation, facesheet stacking sequence and thickness, core thickness, overall specimen thickness, specimen geometry, specimen preparation, specimen conditioning, environment of testing, type, size and location of damage (including method of non-destructive inspection), specimen/fixture alignment and gripping, time at temperature, and speed of testing.

5.6 Results from the residual strength assessment include the following: normalized compressive residual strength N^{CAI}, compressive force as a function of crosshead displacement, and far-field surface strains as functions of crosshead displacement.

6. Interferences

6.1 The response of a damaged specimen is dependent upon many factors, such as facesheet material, facesheet thickness, facesheet ply thickness, facesheet stacking sequence, facesheet surface flatness (toolside or bagside surface), core material, core thickness, core density, cell size, cell wall thickness, adhesive, construction methods, 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 sandwich constructions are used. Therefore, all deviations from the standard 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 and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, poor core bonding, and damage induced by improper specimen machining are known causes of high material data scatter in composites in general. Important aspects of sandwich construction preparation that contribute to data scatter include incomplete or nonuniform core bonding to facesheets, misalignment of core and facesheet elements, the existence of joints, voids or other core and facesheet discontinuities, out-of-plane curvature, facesheet thickness variation, surface roughness, and failure to meet the dimensional and squareness tolerances (parallelism and perpendicularity) specified in 8.2.

6.3 *Damage Mode*—Variations in the specimen damage modes produced during the damaging event can contribute to strength, stiffness, and strain data scatter.

6.4 *Damage Geometry and Location*—The size, shape, and location of damage (both within the plane of the specimen and through-the-thickness) can affect the deformation and strength behavior of the specimen significantly. 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. The damage size, as measured in accordance with Practice D7766/D7766M, is limited to one-third of the unsupported specimen width (65 mm [2.6 in.]) to minimize interaction between damage and edge-related stress/strain fields.

NOTE 3—It is recommended that the damage be limited to one-fifth the specimen unsupported width (40 mm [1.6 in.]); however, this may not be practical in all cases. Also, it may not be possible to accurately predict the damage sizes prior to fabrication of the specimens; therefore, a pre-test impact survey program is recommended prior to specimen fabrication.

6.5 *Test Fixture Characteristics*—The configuration of the panel edge-constraint structure can have a significant effect on test results. In the standard test fixture, the top and bottom supports provide no clamp-up force, but provide some restraint to local out-of-plane rotation due to the fixture geometry. The knife-edge side supports provide resistance to out-of-plane movement at the edges, which increases the compressive force that would result in global buckling of the specimen. Edge supports must be co-planar. Results may be affected by the geometry of the various slide plates local to the specimen. Results may also be affected by the presence of gaps between the slide plates and the specimen, which can reduce the effective edge support and can result in concentrated load introduction conditions at the top and bottom specimen surfaces. Additionally, results may be affected by variations in torque applied to the slide plate fasteners; loose fasteners may also reduce the effective edge support.

6.6 *System Alignment*—Errors can result if the test fixture is not centered with respect to the loading axis of the test machine, and aligned or shimmed to apply an essentially uniaxial displacement to the loaded end of the specimen.

6.7 *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.

6.8 *Specimen Instability*—Accurate detection of instability or incipient instability of the facesheets or the specimen may not be possible. The nature of the damage can have a significant effect upon local flexural rigidity, which may complicate the failure mode, limiting results to the unique configuration tested.

6.9 *Facesheet Load Distribution*—This test method effectively applies a uniform axial displacement to the test specimen. If the stiffness of the two facesheets is different, either due to the damage inflicted on one facesheet or due to one facesheet having more dimpling due to cocuring (bagside versus toolside effects), then accurate calculation of the facesheet stress in the damaged facesheet requires the use of strain gages on both facesheets to determine the load distribution. Where there is a significant difference in facesheet stiffnesses, use of Practice D8388/D8388M with damage applied to the compressive side facesheet may be more useful and appropriate.

6.10 *Out of Plane Deformation*—Depending on the damage state, facesheets, and core material, the stiffness differences between the damaged and undamaged facesheets may be significant. Visually monitor the test for excessive out-of-plane deformation.

NOTE 4—While Digital Image Correlation (DIC) currently is not formally used for strain measurement in ASTM standards (since there are no ASTM accepted calibration methods), it may be used to help quantify the amount of out-of-plane deformation and strain distributions as well as assess test validity.

6.11 *Potting*—Potting is commonly used to avoid facesheet separation and end brooming prior to specimen failure. Potting of the core may occur during or prior to bonding to the facesheets if the potting material is compatible with the facesheet cure cycle. Potting may also occur after the specimen is cured by removing the core at the ends and inserting potting material.

7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer with a 4 mm to 8 mm [0.16 in. to 0.32 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 (for example, facesheet coarse peel ply surface 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 (for example, tooled surfaces). A micrometer or caliper with a flat anvil interface shall be used for measuring length, width other than machined surface dimensions and damage dimensions. 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 ±0.0025 mm [±0.0001 in.] is adequate for thickness measurement, whereas an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for length, width, other machined surface dimensions and damage dimensions.

7.2 *Support Fixture*—The compressive test fixture, shown in Fig. 1 and Fig. 2, utilizes adjustable retention plates to support the specimen edges and inhibit buckling when the specimen is end-loaded. The side supports are knife edges that overlap the specimen by 8 mm [0.30 in.] and provide resistance to out-of-plane movement at the edges, which increases the compressive force that would result in global buckling of the specimen. The fixture consists of one base plate, two base slide plates, two angles, four side plates, one top plate, and two top slide plates. Alternate fixtures with angles integrated into the base plate are permissible. The top and bottom supports provide no clamp-up, but provide some rotational restraint due to the fixture geometry (the slide plates have a squared geometry and overlap the specimen by 8 mm [0.30 in.]). The fixture is adjustable to accommodate small variations in specimen length, width, and thickness. The top plate and slide plates, which are not directly attached to the lower portion of the fixture, slip over the top edge of the specimen. The side plates are sufficiently short to ensure that a gap between the side rails and the top plate is maintained during the test.

7.2.1 *Support Fixture Details*—A suitable support fixture is shown in Figs. 1 and 2, but other designs that perform the necessary functions are acceptable. The fixture shall be constructed of sufficient stiffness and precision as to satisfy the loading uniformity requirements of this test method. The following general notes apply to these figures:

NOTE 5—Experience has shown that fixtures may be damaged due to handling in use, thus periodic re-inspection of the fixture dimensions and tolerances is important.

NOTE 6—Ensure that the fixture design is sufficient that if using shims to align that the fixture does not deflect at the shims.

7.3 *Testing Machine*—The testing machine shall be in conformance with Practice E4, and shall satisfy the following requirements:

7.3.1 *Testing Machine Configuration*—The testing machine shall have both an essentially stationary head and a movable head. A short loading train and flat end-loading platens shall be used.

7.3.2 *Flat Platens*—The test machine shall be mounted with well-aligned flat platens capable of providing a fixed surface. If

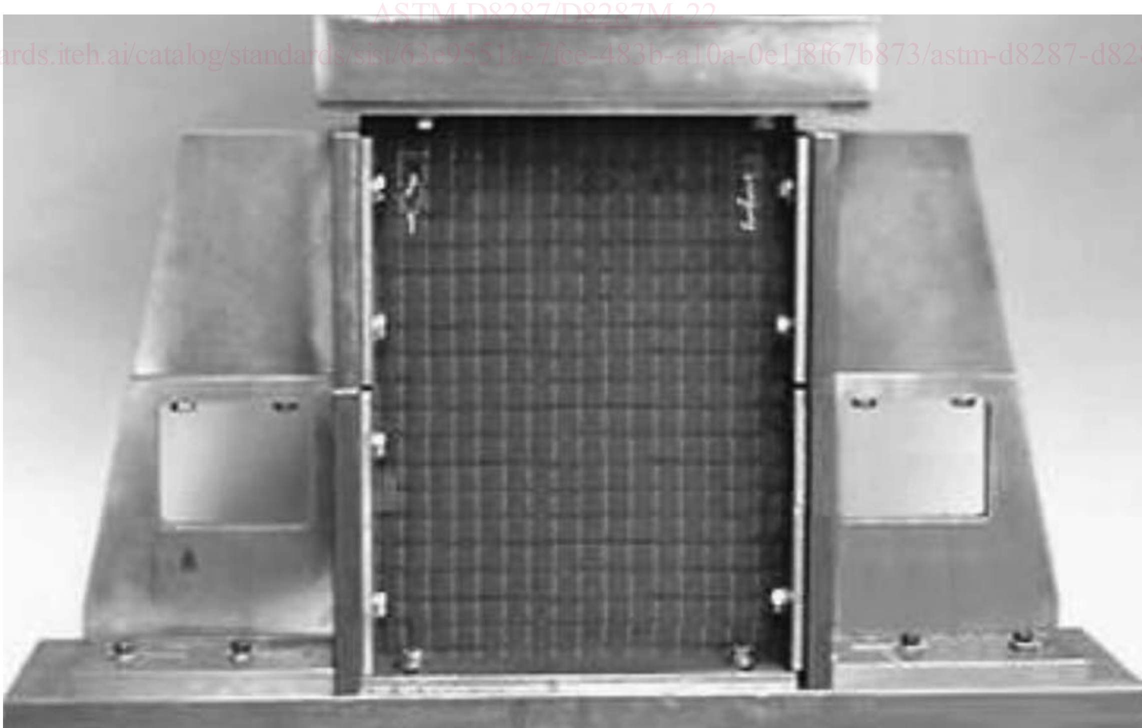

FIG. 1 Assembled Support Fixture with Specimen in Place

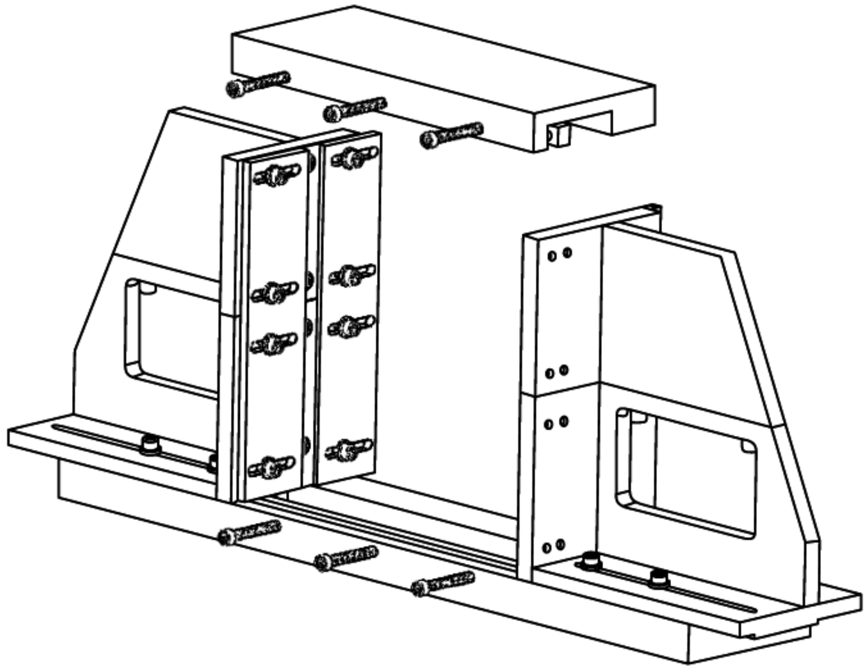

FIG. 2 Support Fixture Base Assembly and Top Assembly

the platens are not sufficiently hardened, or simply to protect the platen surfaces, a hardened plate (with parallel surfaces) can be inserted between each end of the fixture and the corresponding platen. The lower platen should be marked to help center the test fixture between the platens.

7.3.2.1 The use of a spherical seat platen that includes a position locking feature is encouraged; however, the use of fixed flat platens is acceptable. When using fixed flat platens, the platen surfaces shall be parallel within 0.025 mm [0.001 in.] across the test fixture top plate length of 215 mm [8.5 in.]. When using a spherical seat platen, it must be locked into a fixed position after either aligning it with the fixed platen or aligning the specimen through the use of strain gages bonded to the specimen surface. The spherical seat platen may be placed either below or above the support fixture.

NOTE 7—While the use of a locking spherical seat platen is preferred for specimen alignment, the use of thin metallic shims placed between the fixture and the fixed flat platens is permissible for specimen alignment.

NOTE 8—When using a spherical seat platen, it is preferable to place the platen above the loading fixture for specimen alignment.

7.3.3 *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 11.5.

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

7.3.5 *Crosshead Displacement Indicator*—The testing machine shall be capable of monitoring and recording the crosshead displacement (stroke) with a precision of at least ±1 %. If machine compliance is significant, it is acceptable to measure the displacement of the movable head using a LVDT or similar device with ±1 % precision on displacement.

7.4 *Conditioning Chamber*—When conditioning materials at non-laboratory environments, a temperature-/vapor-level controlled environmental conditioning chamber is required that shall be capable of maintaining the required temperature to within ±3 °C [±5 °F] and the required relative humidity level to within ±3 %. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.5 *Environmental Test Chamber*—An environmental test chamber is required for test environments other than ambient testing laboratory conditions. This chamber shall be capable of maintaining the test specimen and fixture at the required test environment during the mechanical test. The test temperature shall be maintained within ±3 °C [±5 °F] of the required temperature, and the relative humidity level shall be maintained to within ±3 % of the required humidity level.

7.6 *Strain-Indicating Device*—Strain measurement of the specimens is required. The longitudinal strain should be measured simultaneously at four locations (two locations on opposite faces of the specimen as shown in Fig. 3 and Fig. 4) to aid in ensuring application of pure compressive loading and to detect bending or buckling, or both, if any. If the ends of the specimens are potted, the vertical location of the strain gages shall be either 25 mm [1.0 in.] below the top of the specimen or 12 mm [0.5 in.] below the top of the potting, whichever is greater. The same type of strain transducer shall be used for all strain measurements on any single specimen. The gages, surface preparation, and bonding agents should be chosen to provide for optimal performance on the subject material for the

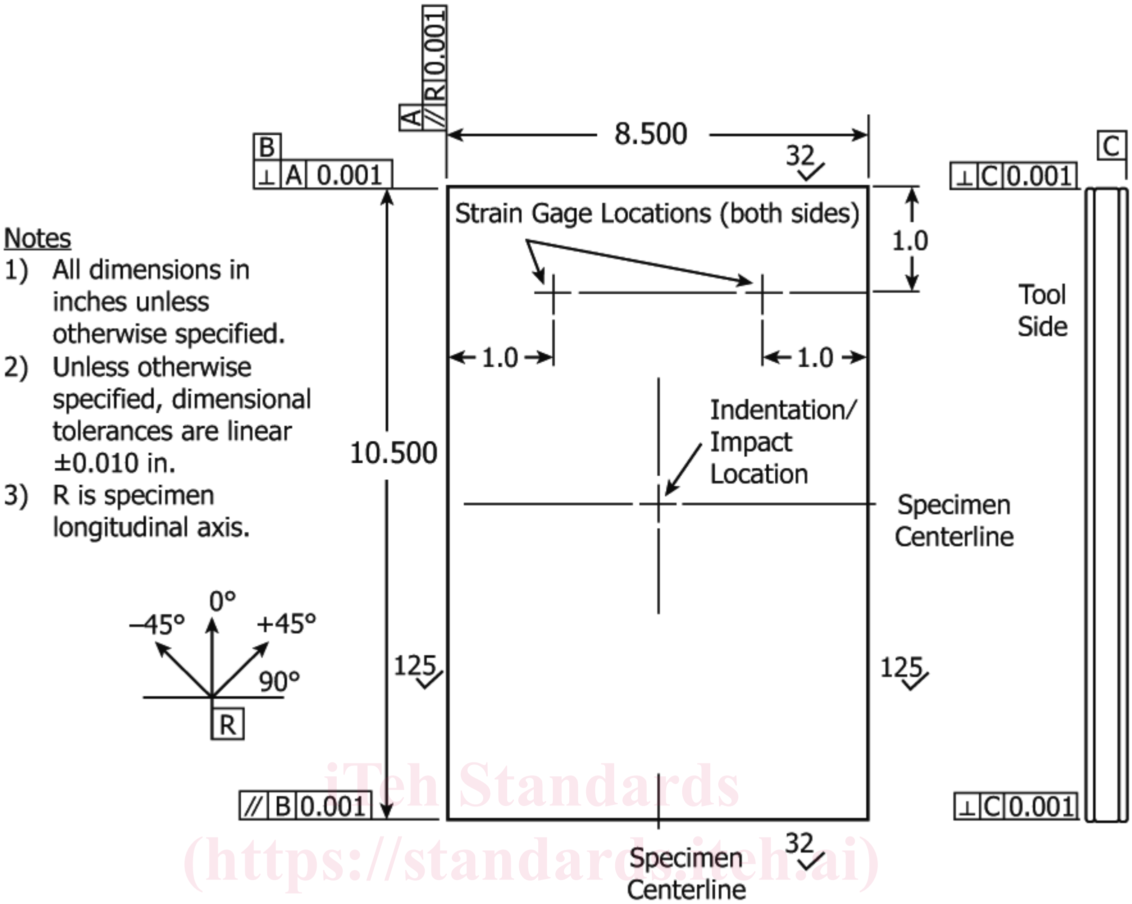

FIG. 3 Compressive Residual Strength Specimen (Inch-Pound Version)

prescribed test environment. Attachment of the strain-indicating device to the specimen shall not cause damage to the specimen surface.

NOTE 9—Although the compression test may be performed without the use of strain-indicating devices, lack of instrumentation for the damaged specimens makes the detection of poor alignment or undesirable specimen instability, or both, much more difficult. For this reason, strain measurement of the specimens during compressive loading is required.

NOTE 10—Moisture proofing of the strain gage installations on the specimen needs to be done very carefully with multiple layers of protective coatings (such as microfined wax, high temperature Teflon tape, adhesively-bonded aluminum foil, and room temperature curing vulcanizing (RTV) compound) before subjecting them to moisture conditioning inside the environmental conditioning chamber[3]. Foil strain gages, protected simply with RTV compound, are likely to become corroded and unfit for hot-wet testing after approximately 100 days of moisture conditioning.

7.7 *Data Acquisition Equipment*—Equipment capable of recording force, crosshead displacement, and strain data is required.

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, the procedures outlined in Practice E122 should be consulted. The method of sampling shall be reported.

8.2 *Standard Specimen Configuration*—The test specimen shall be a uniform specimen with a constant thickness. The core and facesheet thickness should be representative of intended use. The standard width is 215 mm [8.5 in.] and length of 265 mm [10.5 in.]. The geometry of the specimen is shown in Fig. 3 and Fig. 4.

8.3 *Non-Standard Specimen Configuration*—For non-standard specimen geometries, the width shall be not less than three times the damage diameter as measured in accordance with Practice D7766/D7766M. The recommended specimen width is five times the damage diameter. The specimen length shall be at least 1.2 times the width.

NOTE 11—If using a non-standard specimen configuration, the length and width of the specimen must be sufficient so that strain gages can be placed in the far-field strain field.

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

8.4.1 *Facesheets*—Control of fiber alignment is critical. Improper fiber alignment as well as intra-cell facesheet dimpling of co-cured composite sandwich panels with honeycomb cores will change the measured properties. The facesheets must

[3] Vijayaraju, K., Mangalgiri, P. D., and Parida B. K., "Hot-Wet Compression Testing of Impact Damaged Composite Laminates," Proceedings of the Ninth International Conference on Fracture (ICF-9), Sydney, Australia, 1997, pp. 909–916.

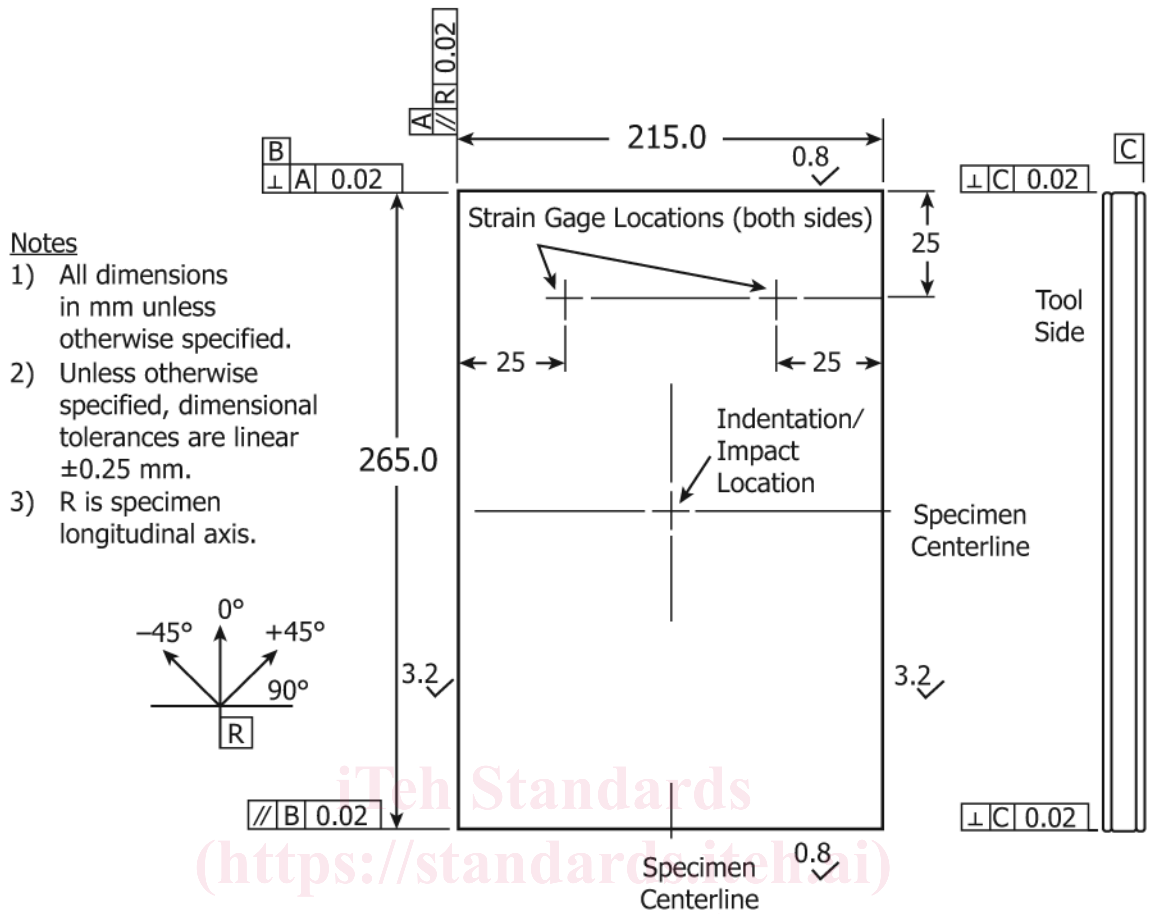

FIG. 4 Compression Residual Strength Specimen (SI Version)

be flat and of uniform thickness to assure even loading. Erratic fiber alignment and facesheet dimpling will also increase the coefficient of variation. For the standard test configuration, facesheets consisting of a laminated composite material shall be symmetric about the sandwich beam mid-plane. Report the facesheet fabrication method. Facesheets 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 *Core*—The core material shall be selected to provide sufficient local compression and shear strength under the impact point to avoid facesheet failure of the opposite facesheet.

NOTE 12—If the composite sandwich configuration has facesheets of insufficient thickness to prevent end brooming prior to specimen failure through the damaged region, the core material within 13.0 mm [0.5 in.] of the specimen ends may be removed and a higher density, low-shrinkage potting material may be inserted or the core filled during manufacturing to increase the compression load capacity of the specimen.

8.4.3 *Adhesive*—Adhesive may be utilized at the core-to-facesheet 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.

8.4.4 *Panel Fabrication*—Control of fiber and core alignment is critical. Improper fiber alignment will change the measured properties. The panel must be flat and of uniform thickness to assure even loading. 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 0.64 mm [0.025 in.] in any direction across the length and width of the specimen. The coefficient of variation for thickness measurements taken in 11.2.2 should be less than 2 %.

8.4.5 *Machining Methods*—Guide D5687/D5687M provides recommended specimen preparation practices and should be followed where practical. Specimen preparation is extremely important for this test. Take precautions when cutting specimens from larger panels to avoid notches, undercuts, rough or uneven surfaces, or delaminations due to inappropriate machining methods. Obtain final dimensions by water-lubricated precision sawing, milling, or grinding. The use of diamond-tipped tooling has been found to be extremely effective for many material systems. Of particular note in this end-loaded compression test is the machining quality and