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INTERNATIONAL

Designation: D8454/D8454M − 22

Standard Test Method for Open-Hole Compressive Strength of Sandwich Constructions[1]

This standard is issued under the fixed designation D8454/D8454M; 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 determines the open-hole compressive strength of sandwich constructions in a direction parallel to the sandwich facesheet plane. 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).

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, with a centrally located open through-hole, 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, 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 unnotched specimens, but care should be taken to prevent undesirable failure modes such as end crushing. ASTM Test Methods C364 or D7249/D7249M are the recommended test methods for unnotched sandwich panel compression strength 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.*

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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

D6484 Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates

D7249/D7249M Test Method for Facesheet Properties of Sandwich Constructions by Long Beam Flexure

D8453/D8453M Practice for Open-Hole Flexural Strength of Sandwich Constructions

E4 Practices for Force Calibration and Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

[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.

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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 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [*M*] for mass, [*L*] for length, [*T*] for time, [*θ*] for thermodynamic temperature, and [*nd*] for nondimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *diameter-to-facesheet thickness ratio, D/t [nd], n—in an open-hole specimen*, the ratio of the hole diameter to the facesheet thickness.

3.2.1.1 *Discussion*—The diameter-to-thickness ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.2 *length-to-diameter ratio, L/D [nd], n—in an open-hole specimen*, the ratio of the specimen length to the hole diameter.

3.2.2.1 *Discussion*—The length-to-diameter ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.3 *width-to-diameter ratio, w/D [nd], n—in an open-hole specimen*, the ratio of the specimen width to the hole diameter.

3.2.3.1 *Discussion*—The width-to-diameter ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.3 *Symbols:*

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

d—sandwich total thickness

D—diameter of hole

F^{ohcu}—facesheet ultimate open-hole (notched) compressive strength

L—length of specimen

n—number of specimens

P—applied force

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

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

t—nominal facesheet thickness

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

w—width of specimen across hole

Δ—percent difference

σ—facesheet compressive stress

ε—indicated strain from gage

4. Summary of Test Method

4.1 This test method consists of subjecting a sandwich panel, with a centrally located through-hole, to a uniaxial compressive force parallel to the plane of its faces. The 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. Ultimate strength is calculated based on the nominal cross-sectional area of the two facesheets, disregarding the presence of the hole. While the hole causes a stress concentration and reduced net section, it is common aerospace practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (flaws, damage, and so forth) not explicitly modeled in the stress analysis.

4.2 The only acceptable failure modes for ultimate open-hole sandwich compressive strength are ones which pass through the hole in the test specimen.

5. Significance and Use

5.1 This test method provides a standard method of determining the open-hole (notched) strength of the sandwich panel for structural design allowables, material specifications, and research and development.

5.2 The reporting section requires items that tend to influence notched sandwich 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 (including hole diameter, diameter-to-thickness ratio, and width-to-diameter ratio), specimen preparation (especially of the hole), specimen conditioning, environment of testing, type, specimen/fixture alignment, time at temperature, and speed of testing. Further, notched sandwich compressive strength may be different between precured/bonded and co-cured facesheets of the same material.

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

6. Interferences

6.1 *Hole Preparation*—Because of the dominating presence of the notch, and the lack of need to measure the material response, results from this test method are relatively insensitive

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to parameters that would be of concern in an unnotched compressive property test. However, since the notch has a dominant effect on the strength, consistent preparation of the hole, without damage to the sandwich specimen, is important to meaningful results. Damage caused by hole preparation will affect strength results. Some types of damage, such as longitudinal splitting and delamination, can blunt the stress concentration caused by the hole, increasing the force-carrying capacity of the specimen and the calculated strength. Other types of damage can reduce the calculated strength.

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 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 *Geometry*—Results are affected by the ratio of specimen width to hole diameter (w/*D*); a ratio of 6 is recommended if the notch sensitivity is unknown. Results may also be affected by the ratio of hole diameter to facesheet thickness (*D*/*t*). Results may also be affected by facesheet thickness. Further, due to the hole size effect, notched strength from this test may not be equivalent to results obtained from Test Method D6484.

6.4 *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 both strength behavior and failure mode. Experience has demonstrated that elevated temperature, humid environments are generally critical for notched compressive strength. However, critical environments must be assessed independently for each specific combination of core material, facesheet material, facesheet stacking sequence, and core-to-facesheet interfacial adhesive (if used) that is tested.

6.5 *Material Orthotropy*—The degree of facesheet orthotropy strongly affects the failure mode and measured notched strength. Valid notched strength results should only be reported when appropriate failure modes are observed, in accordance with 11.13.

6.6 *Facesheet Thickness Scaling*—Thick facesheet sandwich structures do not necessarily fail at the same strengths as thin facesheet sandwich structures with the same facesheet orientation (that is, strength does not always scale linearly with facesheet thickness). Thus, data gathered using this test method may not translate directly into equivalent thick-structure properties.

6.7 *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.

6.8 *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.

6.9 *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, due to one facesheet having more dimpling due to cocuring (bagside versus toolside effects), then accurate calculation of the facesheet stress in the facesheets 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 the Practice D8453/D8453M test method may be more useful and appropriate.

6.10 *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, bag-side of a facesheet laminate). 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 hole diameter. 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 hole diameter.

7.2 *Support Fixture*—The compressive test fixture, shown in Fig. 1 and Fig. 2, utilizes adjustable retention plates to support

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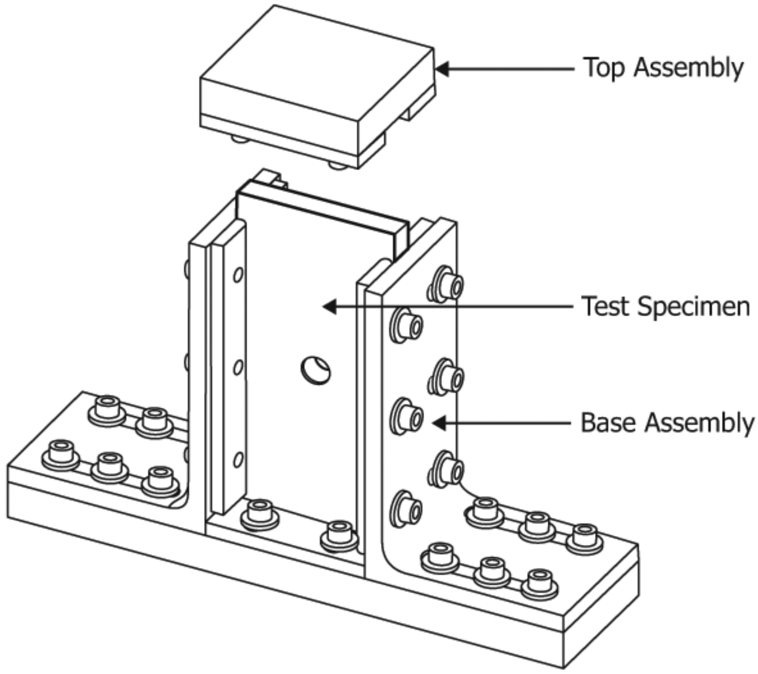

FIG. 1 Schematic of Support Fixture with Specimen in Place

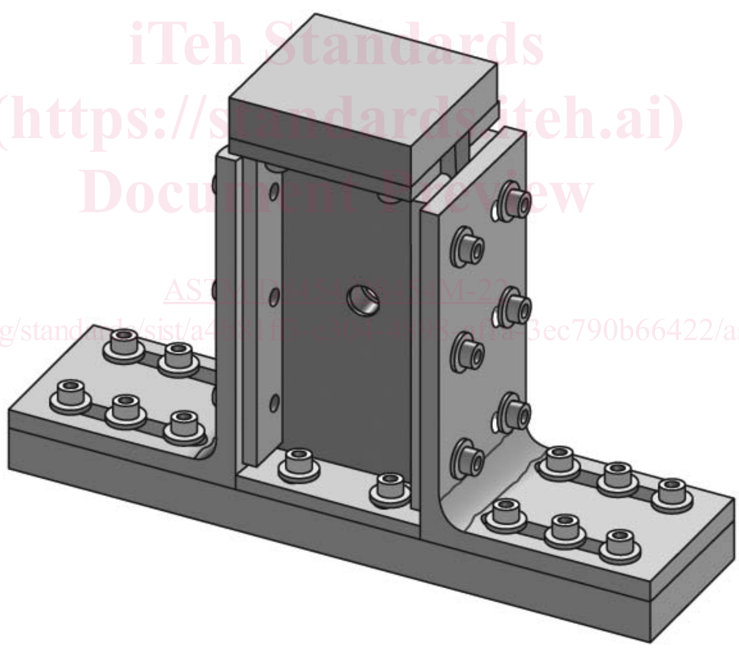

FIG. 2 Assembled Support Fixture

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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. 1-3, but other designs that perform the necessary functions are acceptable. The fixture shall be constructed of sufficient stiffness and precision as to satisfy the

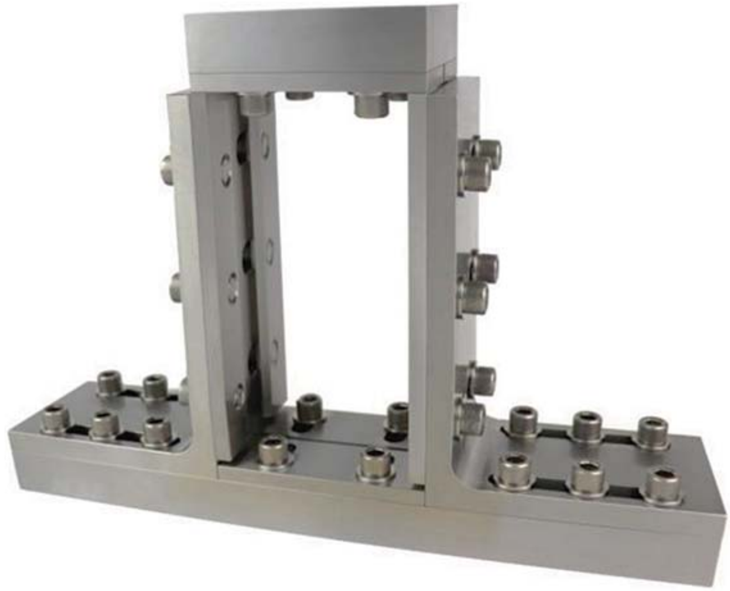

FIG. 3 Support Fixture Base Assembly and Top Assembly

loading uniformity requirements of this test method. The following general notes apply to these figures:

NOTE 2—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 3—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 Practices 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 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 72 mm [3 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 4—While the use of a 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 5—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 11.4.

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.

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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. 4 and Fig. 5) 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 bottom 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 prescribed test environment. Attachment of the strain-indicating device to the specimen shall not cause damage to the specimen surface.

NOTE 6—Although the compression test may be performed without the use of strain-indicating devices, lack of instrumentation for the notched specimens makes the detection of poor alignment, undesirable specimen instability, or both, much more difficult. For this reason, strain measurement of the specimens during compressive loading is required.

NOTE 7—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 polytetrafluoroethylene (PTFE) 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 the intended use. The standard width is 72 mm [3.0 in.], length of 144 mm [6 in.], and a hole diameter of 12 mm [0.50 in.]. The hole shall be machined through both facesheets and the core. The geometry of the specimen is shown in Fig. 4 and Fig. 5.

8.3 *Non-Standard Specimen Configuration*—For non-standard specimen geometries, the length and width must be sufficient so that strain gages can be placed in the far field strain field. The width-to-diameter (w/*D*) ratio should be large enough to produce a statistically significant reduction in strength from the unnotched configuration, and small enough to minimize finite width effects. A ratio of 6 is recommended if the notch sensitivity is unknown. The specimen length should be at least 12 times the hole diameter to minimize finite length effects.

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[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.

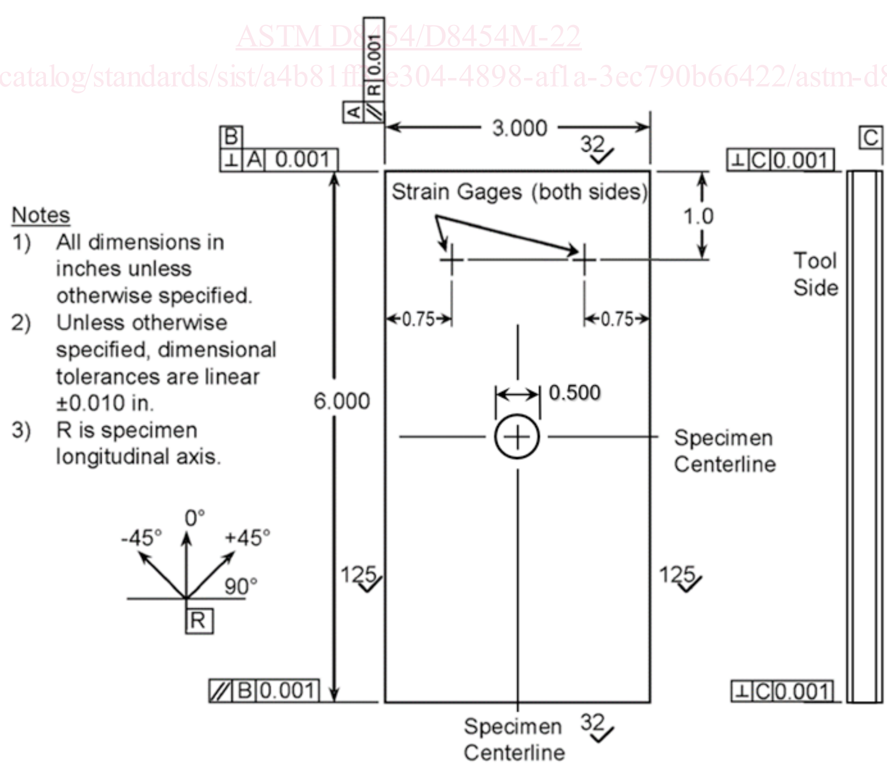

FIG. 4 Open-Hole Compressive Strength Specimen (Inch-Pound Version)

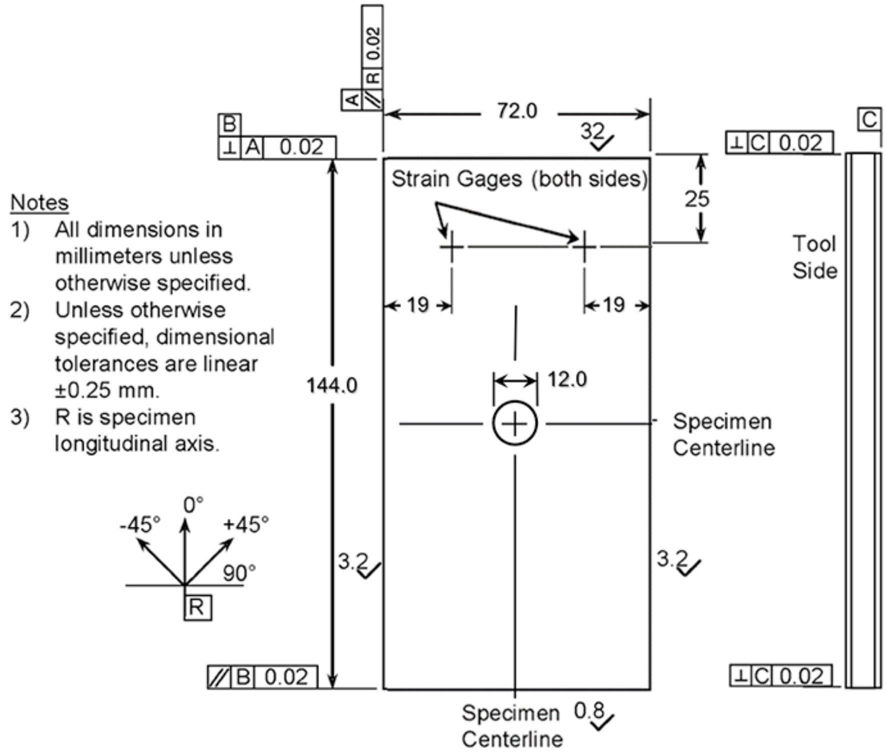

FIG. 5 Open-Hole Compressive Strength Specimen (SI Version)

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

8.4.1 *Facesheets:*

8.4.1.1 *Fabrication*—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 be flat and of uniform thickness to assure even loading. Erratic fiber alignment and facesheet dimpling will also increase the coefficient of variation. 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.

NOTE 8—If the composite sandwich configuration has facesheets of insufficient thickness to prevent end brooming prior to specimen failure at or through the hole, the core material within 12.0 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.

8.4.1.2 *Layup*—The apparent notched facesheet strength obtained from this method may be dependent upon the facesheet stacking sequence. For the standard test configuration, facesheets consisting of a laminated composite material shall be balanced and symmetric about the sandwich beam mid-plane. The standard tape and fabric facesheets shall have multidirectional fiber orientations (fibers shall be oriented in a minimum of two directions).

8.4.1.3 *Thickness*—Accurate measurement of facesheet thickness is difficult after bonding or co-curing of the facesheets and core. The test requestor is responsible for specifying the facesheet thicknesses to be used for the calculations in this test method. For metallic or precured composite facesheets which are secondarily bonded to the core, the facesheet thickness should be measured prior to bonding. In these cases, the test requestor may specify that either or both measured and nominal thicknesses be used in the calculations. For co-cured composite facesheets, the thicknesses are generally calculated using nominal per ply thickness values.

8.4.2 *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.

8.4.3 *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 %.

8.4.4 *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,