Designation: D7249/D7249M – 12ε1

Standard Test Method for Facing Properties of Sandwich Constructions by Long Beam Flexure[1]

This standard is issued under the fixed designation D7249/D7249M; 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.

ε[1] NOTE—Figure 6 was corrected editorially in March 2014.

1. Scope

1.1 This test method covers determination of facing properties of flat sandwich constructions subjected to flexure in such a manner that the applied moments produce curvature of the sandwich facing planes and result in compressive and tensile forces in the facings. 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 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.*

NOTE 1—Alternate procedures for determining the compressive strength of unidirectional polymer matrix composites materials in a sandwich beam configuration may be found in Test Method D5467/D5467M.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C274 Terminology of Structural Sandwich Constructions

C393 Test Method for Flexural Properties of Sandwich Constructions

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

D5467/D5467M Test Method for Compressive Properties of Unidirectional Polymer Matrix Composite Materials Using a Sandwich Beam

D7250/D7250M Practice for Determining Sandwich Beam Flexural and Shear Stiffness

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

E251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gauges

E456 Terminology Relating to Quality and Statistics

E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases

E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases

3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology C274 defines terms relating to structural sandwich constructions. Terminology C393 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 *Symbols:*

b = specimen width
c = core thickness
CV = coefficient of variation statistic of a sample population for a given property (in percent)
d = sandwich total thickness

[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.

$D^{F,nom}$ = effective sandwich flexural stiffness
E^f = effective facing chord modulus
ε = measuring strain in facing
F^u = facing ultimate strength (tensile or compressive)
F_s = core shear allowable strength
F_c = core compression allowable strength
k = core shear strength factor to ensure facing failure
l = length of loading span
L = length of support span
l_{pad} = length of loading pad
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
σ = facing stress
t = facing thickness
x_1 = 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

4. Summary of Test Method

4.1 This test method consists of subjecting a long beam of sandwich construction to a bending moment normal to the plane of the sandwich, using a 4-point loading fixture. Deflection and strain versus force measurements are recorded.

4.2 The only acceptable failure modes for sandwich facesheet strength are those which are internal to one of the facesheets. Failure of the sandwich core or the core-to-facesheet bond preceding failure of one of the facesheets is not an acceptable failure mode. Careful post-test inspection of the specimen is required as facing failure occurring in proximity to the loading points can be caused by local through-thickness compression or shear failure of the core that precedes failure of the facing.

5. Significance and Use

5.1 Flexure tests on flat sandwich construction may be conducted to determine the sandwich flexural stiffness, the core shear strength, and shear modulus, or the facings' compressive and tensile strengths. Tests to evaluate core shear strength may also be used to evaluate core-to-facing bonds.

5.2 This test method is limited to obtaining the strength and stiffness of the sandwich panel facings, and to obtaining load-deflection data for use in calculating sandwich beam flexural and shear stiffness using Standard Practice D7250/D7250M. Due to the curvature of the flexural test specimen when loaded, facesheet compression strength from this test may not be equivalent to the facesheet compression strength of sandwich structures subjected to pure edgewise (in-plane) compression.

5.3 Core shear strength and shear modulus are best determined in accordance with Test Method C273 provided bare core material is available. Test Method C393 may also be used to determine core shear strength. Standard Practice D7250/D7250M may be used to calculate the flexural and shear stiffness of sandwich beams.

5.4 This test method can be used to produce facing strength data for structural design allowables, material specifications, and research and development applications; it may also be used as a quality control test for bonded sandwich panels.

5.5 Factors that influence the facing strength and shall therefore be reported include the following: facing material, core material, adhesive material, methods of material fabrication, facing stacking sequence and overall thickness, core geometry (cell size), core density, adhesive thickness, specimen geometry, specimen preparation, specimen conditioning, environment of testing, specimen alignment, loading procedure, speed of testing, facing void content, adhesive void content, and facing volume percent reinforcement. Further, facing strength may be different between precured/bonded and co-cured facesheets of the same material.

NOTE 2—Concentrated forces on beams with thin facings and low density cores can produce results that are difficult to interpret, especially close to the failure point. Wider loading blocks and rubber pressure pads may assist in distributing the forces.

NOTE 3—To ensure that simple sandwich beam theory is valid, a good rule of thumb for the four-point bending test is the span length divided by the sandwich thickness should be greater than 20 ($L/d > 20$) with the ratio of facing thickness to core thickness less than 0.1 ($t/c < 0.1$).

6. Interferences

6.1 *Material and Specimen Preparation*—Poor material fabrication practices and damage induced by improper specimen machining are known causes of high data scatter in composites and sandwich structures in general. A specific material factor that affects sandwich cores is variability in core density. Important aspects of sandwich core specimen preparation that contribute to data scatter include the existence of joints, voids or other core discontinuities, out-of-plane curvature, and surface roughness.

6.2 *Geometry*—Specific geometric factors that affect sandwich facing strength include facing thickness, core cell geometry, and facing surface flatness (toolside or bagside surface in compression).

6.3 *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. 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.

6.4 *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.

7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer having a flat anvil interface, or a caliper of suitable size, shall be used. The instrument(s) shall have an accuracy of ±25 µm [±0.001 in.] for thickness measurement, and an accuracy of ±250 µm [±0.010 in.] for length and width measurement.

NOTE 4—The accuracies given above are based on achieving measurements that are within 1 % of the sample length, width and thickness.

7.2 *Loading Fixtures*

7.2.1 *Standard Configuration*—The standard loading fixture shall consist of a 4-point loading configuration with two support bars that span the specimen width located below the specimen, and two loading bars that span the specimen width located on the top of the specimen (Fig. 1), The force shall be applied vertically through the loading bars, with the support bars fixed in place in the test machine. The standard loading fixture shall have the centerlines of the support bars separated by a distance of 560 mm [22.0 in.] and the centerlines of the loading bars separated by a distance of 100 mm [4.0 in.].

7.2.2 *Non-Standard Configurations*—All other loading fixture configurations (see Fig. 2) are considered non-standard and details of the fixture geometry shall be documented in the test report. Figs. 3-5 show typical test fixtures. Non-standard 3- and 4-point loading configurations have been retained within this standard a) for historical continuity with previous versions of Test Method C393, b) because some sandwich panel designs require the use of non-standard loading configurations to achieve facesheet failure modes, and c) load-deflection data from non-standard configurations may be used with Standard Practice D7250/D7250M to obtain sandwich beam flexural and shear stiffnesses.

7.2.3 *Support and Loading Bars*—The bars shall be designed to allow free rotation of the specimen at the loading and support points. The bars shall have sufficient stiffness to avoid significant deflection of the bars under load; any obvious bowing of the bars or any gaps occurring between the bars and the test specimen during loading shall be considered significant deflection. The recommended configuration has a 25 mm [1.0 in.] wide flat steel loading block to contact the specimen (through rubber pressure pads) and is loaded via either a cylindrical pivot (see Fig. 3) or a V-shaped bar riding in a V-groove in the top of the flat-bottomed steel loading pad. The tips of the V-shaped loading bars shall have a minimum radius of 3 mm [0.12 in.]. The V-groove in the loading pad shall have a radius larger than the loading bar tip and the angular opening of the groove shall be such that the sides of the loading bars do not contact the sides of the V-groove during the test. Loading bars consisting of 25 mm [1.0 in.] diameter steel cylinders may also be used, but there is a greater risk of local specimen crushing with cylindrical bars. Also, the load and support span lengths tend to increase as the specimen deflects when cylindrical loading bars without V-grooved loading pads are used (e.g., rolling supports).

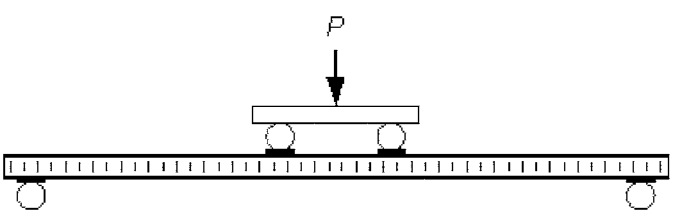
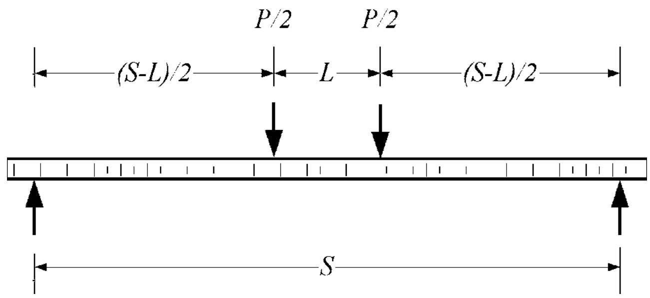


FIG. 1 Test Specimen and Fixture



Configuration		Support Span (*S*)	Load Span (*L*)
Standard	4-Point	560 mm [22.0 in.]	100 mm [4.0 in.]
Non-Standard	3-Point (Mid-span)	*S*	0.0
	4-Point (Quarter-Span)	*S*	*S/2*
	4-Point (Third-Span)	*S*	*S/3*

FIG. 2 Loading Configurations

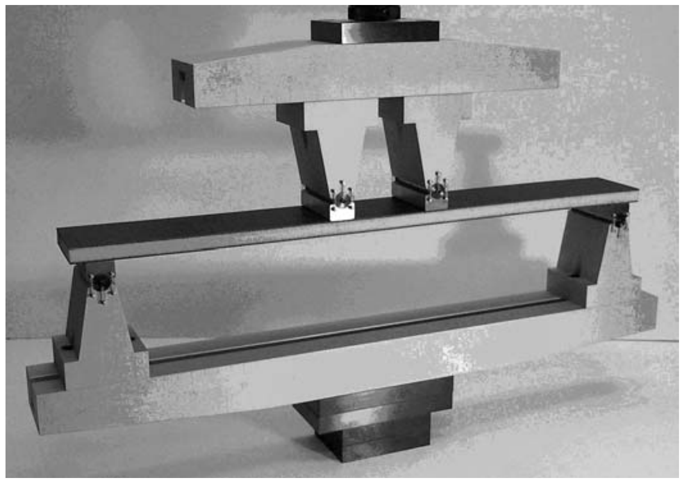


FIG. 3 Standard 4-Point Loading Configuration

7.2.4 *Pressure Pads*—Rubber pressure pads having a Shore A durometer of 60, a width of 25 mm [1.0 in.], a nominal thickness of 3 mm [0.125 in.] and spanning the full width of the specimen shall be used between the loading bars and specimen to prevent local damage to the facings.

7.3 *Testing Machine*—The testing machine shall be in accordance 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.

7.3.2 *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 in accordance with 11.4.

7.3.3 *Force Indicator*—The testing machine force-sensing device shall be capable of indicating the total force being

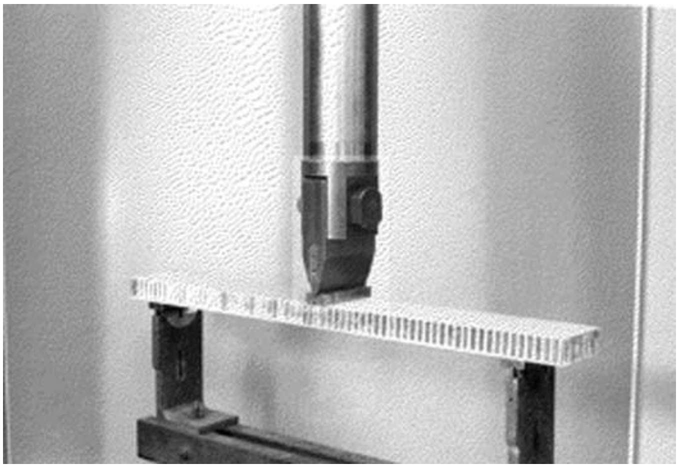


FIG. 4 3-Point Mid-Span Loading Configuration (Non-Standard)

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.

7.4 *Deflectometer (LVDT)*—The deflection of the specimen shall be measured in the center of the support span by a properly calibrated device having an accuracy of ±1 % or better.

NOTE 5—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.

7.5 *Strain-Indicating Device*—Strain data, when required, shall be determined by means of bonded resistance strain gages. One axial gage element shall be located on each face at the center of the specimen, with the gage aligned with the specimen length axis. Strain gages cannot be used on the non-standard 3-point loading configuration due to interference with the center loading bar.

7.5.1 *Bonded Resistance Strain Gage Selection*—Strain gage selection is based on the type of material to be tested. An active gage length of 1.5 mm [0.062 in.] is recommended for composite laminates fabricated from unidirectional layers. Larger strain gage sizes may be more suitable for some textile fabrics. Gage calibration certification shall comply with Test Method E251. Strain gages with a minimum normal strain range of approximately 3 % are recommended. When testing textile fabric laminates, gage selection should consider the use of an active gage length that is at least as great as the characteristic repeating unit of the fabric. Some guidelines on the use of strain gages on composite materials follow. A general reference on the subject is Tuttle and Brinson.[3]

7.5.1.1 Surface preparation of fiber-reinforced composites in accordance with Guide E1237 can penetrate the matrix material and cause damage to the reinforcing fibers, resulting in improper coupon failures. Reinforcing fibers should not be exposed or damaged during the surface preparation process. The strain gage manufacturer should be consulted regarding surface preparation guidelines and recommended bonding agents for composites, pending the development of a set of standard practices for strain gage installation surface preparation of fiber-reinforced composite materials.

7.5.1.2 Consideration should be given to the selection of gages having larger resistances to reduce heating effects on low conductivity materials. Resistances of 350 Ω or higher are preferred. Additional consideration should be given to the use of the minimum possible gage excitation voltage consistent with the desired accuracy (1 to 2 V is recommended) to reduce the power consumed by the gage. Heating of the coupon by the gage may affect the performance of the material directly or it may affect the indicated strain as a result of a difference between the gage temperature compensation factor and the coefficient of thermal expansion of the coupon material.

7.5.1.3 Consideration of some form of temperature compensation is recommended, even when testing at standard laboratory atmosphere. Temperature compensation may be required when testing in non-ambient temperature environments.

7.5.1.4 Consideration should be given to the transverse sensitivity of the selected strain gage. The strain gage manufacturer should be consulted for recommendations on transverse sensitivity corrections and effects on composites.

7.6 *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.

7.7 *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 gage section of the test specimen at the required test environment during the mechanical test.

8. Sampling and Test Specimen

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 *Geometry*—The standard specimen configuration should be used whenever the specimen design equations in section 8.2.3 indicate that the specimen will produce the desired facing failure mode. In cases where the standard specimen configuration will not produce a facing failure, a non-standard specimen shall be designed to produce a facing failure mode.

8.2.1 *Standard Configuration*—The standard test specimen shall be rectangular in cross section, with a width of 75 mm [3.0 in.] and a length of 600 mm [24.0 in.]. The depth of the specimen shall be equal to the thickness of the sandwich construction.

8.2.2 *Non-Standard Configurations*—For non-standard specimen geometries the width shall be not less than twice the

[3] Tuttle, M. E., and Brinson, H. F., "Resistance-Foil Strain-Gage Technology as Applied to Composite Materials," *Experimental Mechanics*, Vol 24, No. 1, March 1984, pp. 54–65; errata noted in Vol 26, No. 2, June 1986, pp. 153–154.

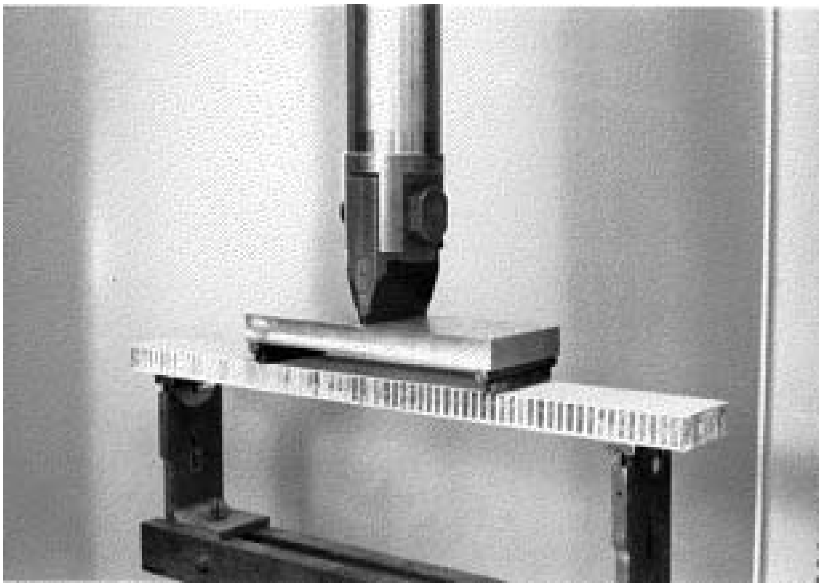


FIG. 5 4-Point Quarter-Point Loading Configuration (Non-Standard)

total thickness nor more than six times the total thickness, not less than three times the dimension of a core cell, nor greater than one quarter the span length. The specimen length shall be equal to the support span length plus 50 mm [2 in.] or plus one half the sandwich thickness, whichever is the greater. Limitations on the maximum specimen width are intended to allow for the use of simplified sandwich beam calculations; plate flexure effects must be considered for specimens that are wider than the restrictions specified above.

8.2.3 *Specimen Design*—Proper design of the sandwich flexure test specimen for determining compressive or tensile strength of the facings is required to avoid core crushing, core shear or core-to-facing failures. The facings must be sufficiently thin and the support span sufficiently long such that moments are produced at applied forces low enough so that the allowable core shear stress will not be exceeded. The core must be sufficiently thick to avoid excessive deflection. The following equations can be used to size the test specimen (these equations assume that both facings have the same thickness and modulus, and that the facing thickness is small relative to the core thickness [t/c £ ≤ ~0.10]):

$$\text{The support span length shall satisfy:} S \geq \frac{2\sigma t}{kF_s} + L \qquad (1)$$

$$\text{or, the core shear strength shall satisfy:} F_s \geq \frac{2\sigma t}{k\,(S-L)} \qquad (2)$$

$$\text{The core compression strength shall satisfy:} F_c \geq \frac{2(c+t)\sigma t}{(S-L)L_{pad}} \qquad (3)$$

where:

S = support span length, mm [in.],
L = loading span length, mm [in.] (L = 0 for 3-point loading),
σ = expected facing ultimate strength, MPa [psi],
t = facing thickness, mm [in.],
c = core thickness,
F_s = core shear allowable strength, MPa [psi],
k = core shear strength factor to ensure facing failure (recommend k = 0.75),
L_{pad} = dimension of loading pad in specimen lengthwise direction, mm [in.], and
F_c = core compression allowable strength, Mpa [psi].

8.3 *Facings*

8.3.1 *Compression Side Facing*—Unless otherwise specified by the test requestor, the bag-side facing of a co-cured composite sandwich panel shall be placed as the upper, compression loaded facing during test, as facing compression strength is more sensitive to imperfections typical of bag-side surfaces (e.g. intra-cell dimpling) than is facing tension strength.

NOTE 6—Tensile failures rarely occur unless the tensile facing is thinner or of different material than the compression facing. Failure in the compression facing may occur by actual crushing, yielding causing unduly large deflection, wrinkling of the facing into the core, the facing disbonding from the core, or the facing dimpling into the honeycomb core cells.

8.3.2 *Layup*—The apparent flexural strength, effective facing moduli, and flexural stiffness obtained from this method may be dependent upon the facing stacking sequence, albeit to a much lesser degree than is typical for laminate flexure. For the standard test configuration, facings consisting of a laminated composite material shall be balanced and symmetric about the sandwich beam mid-plane.

8.3.3 *Stiffness*—For the standard specimen, the facings shall be the same material, thickness and layup. The calculations assume constant and equal upper and lower facing stiffness properties. This assumption may not be applicable for certain facing materials (such as aramid fiber composites) which have significantly different tensile and compressive moduli or which exhibit significant non-linear stress-strain behavior.

8.3.4 *Facing Thickness*—Accurate measurement of facing thickness is difficult after bonding or co-curing of the facings and core. The test requestor is responsible for specifying the facing thicknesses to be used for the calculations in this test method. For metallic or precured composite facings which are secondarily bonded to the core, the facing 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 facings, the thicknesses are generally calculated using nominal per ply thickness values.

8.4 *Core*—For test specimens using a honeycomb core material, the core ribbon direction shall be oriented in the specimen lengthwise direction to aid in avoiding core shear failures. The core material shall be selected to provided sufficient local compression and shear strength under the loading points to avoid local core crushing or shear failures that precede and cause premature facing failure.

8.5 *Specimen Preparation and Machining*—Specimen preparation is extremely important for this test method. Take precautions when cutting specimens from large 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 coated machining tools has been found to be extremely effective for many material systems. Edges should be flat and parallel within the specified tolerances. Record and report the specimen cutting preparation method.

8.6 *Labeling*—Label the test specimens so that they will be distinct from each other and traceable back to the panel of origin, 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 specimen condition is effective moisture equilibrium at a specific relative humidity per Test Method D5229/D5229M; however, if the test requestor does not explicitly specify a pre-test conditioning environment, conditioning is not 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 7—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 Before Test:*

11.1.1 The specimen sampling method, specimen geometry, and conditioning travelers (if required).

11.1.2 The properties and data reporting format desired.

11.1.3 The environmental conditioning test parameters.

11.1.4 The nominal thicknesses of the facing materials.

NOTE 8—Determine specific material property, accuracy, and data reporting requirements prior to test for proper selection of instrumentation and data recording equipment. Estimate the specimen strength to aid in transducer selection, calibration of equipment, and determination of equipment settings.

11.2 *General Instructions:*

11.2.1 Report any deviations from this test method, whether intentional or inadvertent.

11.2.2 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.

11.2.3 Before testing, measure and record the specimen length, width, and thickness at three places in the test section. Measure the specimen length and width with an accuracy of ±250 µm [±0.010 in.]. Measure the specimen thickness with an accuracy of ±25 µm [±0.001 in.]. Record the dimensions to three significant figures in units of millimetres [inches].

11.2.4 If strain is to be measured, apply one longitudinal strain gage to each facing at the center of the specimen.

11.3 Measure and record the length of the support and loading spans.

11.4 *Speed of Testing*—Set the speed of testing so as to produce failure within 3 to 6 min. If the ultimate strength of the material cannot be reasonably estimated, initial trials should be conducted using standard speeds until the ultimate strength of the material and the compliance of the system are known, and speed of testing can be adjusted. The suggested standard speeds are:

11.4.1 *Strain-Controlled Tests*—A standard strain rate of 0.01 min^{-1}.

11.4.2 *Constant Head-Speed Tests*—A standard cross head displacement of 6 mm/min [0.25 in./min].

11.5 *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 testing machine 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 failure from withdrawal from the conditioning chamber. Record any modifications to the test environment.

11.6 *Fixture Installation*—Arrange the loading fixture as shown in Fig. 1 and Fig. 2 and place in the test machine.

11.7 *Specimen Insertion and Alignment*—Place the specimen into the test fixture. Align the fixture and specimen so that the longitudinal axis of the specimen is perpendicular (within 1°) to the longitudinal axes of the loading bars, and the bars are parallel (within 1°) to the plane of the specimen facings.

11.8 *Transducer Installation*—Attach the strain-recording instrumentation to the strain gages on the specimen. Attach the deflection transducer (LVDT) to the fixture and specimen, and connect to the recording instrumentation. Remove any remaining preload, zero the strain gages, and balance the LVDT.

11.9 *Loading*—Apply a compressive force to the specimen at the specified rate while recording data. Load the specimen until failure.

11.10 *Data Recording*—Record force versus head displacement, force versus strain, and force versus LVDT deflection data continuously, or at frequent regular intervals (on the order of 2-3 recordings per second, with a target minimum of 100 recorded data points per test). If any initial failures are noted, record the force, displacement, and mode of damage at such points. Potential initial (non-catastrophic) failures that should be reported include: facesheet delamination, core-to-facesheet disbond, partial core fracture, and local core crushing. Record the mode, area and location of each initial failure. Use the failure identification codes shown in Table 1. Record the method used to determine the initial failure (visual, acoustic emission, etc.). Record the maximum force, the failure force, measured strains, the head displacement, and the LVDT deflection at, or as near as possible to, the moment of ultimate failure.

11.11 *Ultimate Failure Modes*—Record the mode, area, and location of ultimate failure for each specimen. Use the failure identification codes shown in Table 1. Tensile or compressive failures of the sandwich facings are the only acceptable failure modes. Failure of the sandwich core or the core-to-facesheet bond preceding failure of one of the facesheets is not an acceptable failure mode.

11.11.1 *Acceptable Failure Area*—The acceptable failure area is between the loading (top) bars for a 4-point loading test, or within 12 mm [0.50 in.] of the loading bar for a 3-point loading test.

12. Validation

12.1 Values for ultimate properties shall not be calculated for any specimen that 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 A significant fraction of failures in a sample population occurring in the core or core-to-facing bond shall be cause to reexamine the loading and specimen geometry.

13. Calculation

13.1 *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.

13.2 *Facing Ultimate Stress*—Calculate the facing ultimate stress using Eq 4 and report the results to three significant figures. Eq 4 is valid for specimens with equal or unequal facing thicknesses, provided that the facing thicknesses are small relative to the core thickness [t/c £ ≤ ~0.10]). For specimens with unequal facing thicknesses, calculate and report a separate facing ultimate stress for each facing.

$$F_1^u = \frac{P_{max}}{2}\left(\frac{S-L}{2}\right)\left(\frac{1}{c+t_1/2+t_2/2}\right)\frac{1}{bt_1} = \frac{P_{max}(S-L)}{2(d+c)\,bt_1} = \frac{P_{max}\,S(1-L/S)}{4(d-t_1/2-t_2/2)bt_1}$$

$$F_2^u = \frac{P_{max}(S-L)}{2(d+c)\,bt_2} = \frac{P_{max}\,S(1-L/S)}{4(d-t_1/2-t_2/2)bt_2} \tag{4}$$

where:

$F_1{}^u$ = facing 1 ultimate stress, MPa [psi],
$F_2{}^u$ = facing 2 ultimate stress, MPa [psi],
P_{max} = maximum force prior to failure, N [lb],
t_1 = nominal facing 1 thickness, mm [in.],
t_2 = nominal facing 2 thickness, mm [in.],
d = measured sandwich total thickness, mm [in.],
c = calculated core thickness, mm [in.] (for specimens with equal facings, $c = d - 2t$, see Fig. 6; for specimens with unequal facings, $c = d - t_1 - t_2$),
b = specimen width, mm [in.],
S = support span length, mm [in.], and
L = loading span length, mm [in.] (L = 0 for 3-point loading).

TABLE 1 Sandwich Panel Facing Three Part Failure Identification Codes

First Character		Second Character		Third Character	
Failure Type	Code	Failure Area	Code	Failure Location	Code
skin to core Delamination	D	At load bar	A	Bottom facing	B
Filament fracture	F	Gage	G	Top facing	T
tHrough-thickness	H	Multiple areas	M	both Facings	F
Layer instability	L	Outside gage	O	Core	C
local Wrinkling	W	Various	V	core-facing bond	A
Multi-mode	M(xyz)	Unknown	U	Various	V
core Crushing	C			Unknown	U
longitudinal sPlitting	P				
teNsile	N				
transverse Shear	S				
eXplosive	X				
Other	O				

NOTE 9—Accurate measurement of facing thickness is difficult after bonding or co-curing of the facings and core. The test requestor is responsible for specifying the facing thicknesses to be used for the calculations in this test method. For precured composite facings which are secondarily bonded to the core, the facing 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 facings, the thicknesses are generally calculated using nominal per ply thickness values.

NOTE 10—The first order approximation to the shear stress distribution throgh the thickness of a thin facesheet sandwich panel uses a linear distribution of shear stress in the facesheets starting at zero at the free surface and increasing to the core shear stress value at the facesheet-core interface. Therefore, the effective area of transverse shear stress is the core thickness + ½ of each facesheet thickness which is equal to $c + t_1/2 + t_2/2 = (d + c)/2$.

13.3 *Effective Facing Chord Modulus*—Calculate the effective chord modulus of each facesheet using Eq 5 and report the results to three significant figures. Calculate a separate modulus value for each facing (compressive for the top facing, tensile for the bottom facing).

$$E_{f1} = (\sigma_{1\_3000} - \sigma_{1\_1000}) / [(\varepsilon_{1\_3000} - \varepsilon_{1\_1000})((c + t_1/2 + t_2/2)/(c + t_1 + t_2))] \tag{5}$$

$$E_{f2} = (\sigma_{2\_3000} - \sigma_{2\_1000}) / [(\varepsilon_{2\_3000} - \varepsilon_{2\_1000})((c + t_1/2 + t_2/2)/(c + t_1 + t_2))]$$

where:

E_{f1} = effective facing 1 chord modulus, Pa [psi],
E_{f2} = effective facing 2 chord modulus, Pa [psi],
σ_{1_3000} = facing 1 stress calculated using Eq 4 for applied force corresponding to ε_{1_3000}, N [lbf],
σ_{1_1000} = facing 1 stress calculated using Eq 4 for applied force corresponding to ε_{1_1000}, N [lbf],
σ_{2_3000} = facing 2 stress calculated using Eq 4 for applied force corresponding to ε_{2_3000}, N [lbf],
σ_{2_1000} = facing 2 stress calculated using Eq 4 for applied force corresponding to ε_{2_1000}, N [lbf],
ε_{1_3000} = recorded facing 1 strain value (magnitude) closest to 3000 micro-strain,
ε_{1_1000} = recorded facing 1 strain value (magnitude) closest to 1000 micro-strain,
ε_{2_3000} = recorded facing 2 strain value (magnitude) closest to 3000 micro-strain, and
ε_{2_1000} = recorded facing 2 strain value (magnitude) closest to 1000 micro-strain.

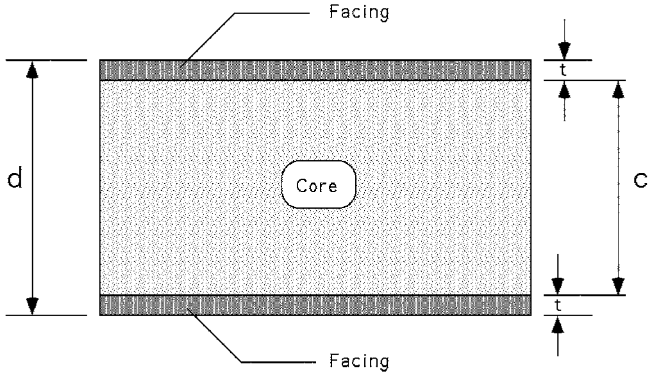


FIG. 6 Sandwich Panel Thickness Dimensions

13.4 *Sandwich Flexural Stiffness*—Calculate the effective sandwich flexural stiffness using Eq 6 and report the results to three significant figures.

$$D^{F,nom} = \frac{(S - L)\cdot d}{4}\cdot\left(\frac{P^{3000} - P^{1000}}{(\varepsilon_{1\_3000} - \varepsilon_{1\_1000}) + (\varepsilon_{2\_3000} - \varepsilon_{2\_1000})}\right) \tag{6}$$

where:

ε_{1_3000} = facing 1 (top surface) recorded strain value (magnitude) closest to 3000 micro-strain,
ε_{1_1000} = facing 1 (top surface) recorded strain value (magnitude) closest to 1000 micro-strain,
P^{3000} = applied force corresponding to facing 1 strain ε_{1_3000}, N [lbf],
P^{1000} = applied force corresponding to facing 1 strain ε_{1_1000}, N [lbf],
ε_{2_3000} = facing 2 (bottom surface) recorded strain value (magnitude) corresponding to P^{3000}, and
ε_{2_1000} = facing 2 (bottom surface) recorded strain value (magnitude) corresponding to P^{1000}.

NOTE 11—Eq 6 is strictly valid only for cases where the shear flexibility of the sandwich beam is negligible. For procedures and equations for calculating the sandwich flexural and through-thickness shear stiffnesses in cases where the shear flexibility cannot be neglected, see ASTM D7250/D7250M.

13.5 *Statistics*—For each series of tests calculate the average value, standard deviation, and coefficient of variation (in percent) for ultimate strength and modulus:

$$\bar{x} = \left(\sum_{i=L}^{n} X_i\right)/n \tag{7}$$

$$S_{n-1} = \sqrt{\left(\sum_{i=l}^{n} x_i^2 - n\,\bar{x}^2\right)/(n-1)} \tag{8}$$

$$CV = 100 \times S_{n-1}/\bar{x} \tag{9}$$

where:

$\bar{x}$ = sample mean (average),
S_{n-1} = sample standard deviation,
CV = sample coefficient of variation, %,
n = number of tested specimens, and
x_1 = measured or derived property.

14. Report

14.1 Report 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):

NOTE 12—Guides E1309 and E1434 contain data reporting recommendations for composite materials and composite materials mechanical testing.

14.1.1 The revision level or date of issue of this test method.

14.1.2 The name(s) of the test operator(s).

14.1.3 Any variations to this test method, anomalies noticed during testing, or equipment problems occurring during testing.

14.1.4 Identification of all the materials constituent to the sandwich panel specimen tested (including facing, adhesive and core materials), 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. Description of the core orientation.

14.1.5 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.

14.1.6 Method of preparing the test specimen, including specimen labeling scheme and method, specimen geometry, sampling method, and specimen cutting method.

14.1.7 Results of any nondestructive evaluation tests.

14.1.8 Calibration dates and methods for all measurements and test equipment.

14.1.9 Details of loading platens and apparatus, including loading configuration, loading and support span dimensions, loading bar details and material(s) used.

14.1.10 Type of test machine, alignment results, and data acquisition sampling rate and equipment type.

14.1.11 Type, range and sensitivity of LVDT, or any other instruments used to measure loading platen deflection.

14.1.12 Measured lengths, widths and thicknesses for each specimen.

14.1.13 Weight of specimen , if requested.

14.1.14 Conditioning parameters and results.

14.1.15 Relative humidity and temperature of the testing laboratory.

14.1.16 Environment of the test machine environmental chamber (if used) and soak time at environment.

14.1.17 Number of specimens tested.

14.1.18 Speed of testing.

14.1.19 Facing thicknesses used in the calculations.

14.1.20 Individual ultimate facing strengths and average value, standard deviation, and coefficient of variation (in percent) for the population.

14.1.21 Individual effective facing compressive and tensile modulus values and average value, standard deviation, and coefficient of variation (in percent) for the population.

14.1.22 Individual effective sandwich flexural stiffness values and average value, standard deviation, and coefficient of variation (in percent) for the population.

14.1.23 Force versus crosshead displacement data for each specimen.

14.1.24 Force versus LVDT deflection data for each specimen.

14.1.25 Force versus strain data for each strain gage on each specimen.

14.1.26 Failure mode and location of failure.

15. Precision and Bias

15.1 *Precision*—The data required for the development of a precision statement is not available for this test method.

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

16. Keywords

16.1 bending stress; facing modulus; facing stress; facing strength; flexural stiffness; sandwich construction; sandwich deflection