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Standard Test Method for Shear Fatigue of Sandwich Core Materials[1]

This standard is issued under the fixed designation C394/C394M; 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 effect of repeated shear forces on core material used in sandwich panels. 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 This test method is limited to test specimens subjected to constant amplitude uniaxial loading, where the machine is controlled so that the test specimen is subjected to repetitive constant amplitude force (stress) cycles. Either shear stress or applied force may be used as a constant amplitude fatigue variable.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C271/C271M Test Method for Density of Sandwich Core Materials
C273/C273M Test Method for Shear Properties of Sandwich Core Materials
D883 Terminology Relating to Plastics
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
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
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (***S-N***) and Strain-Life (ε-***N***) Fatigue Data
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

2.2 *ISO Standards*[3]

ISO 13003:2003(E) Fibre-reinforced plastics: Determination of fatigue properties under cyclic loading conditions

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology D3878 defines terms relating to high-modulus fibers and their composites, as well as terms relating to sandwich constructions. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E456 and Practice E177 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other terminologies.

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 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 *Definitions:*

[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.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

3.2.1 *constant amplitude loading, n—in fatigue*, a loading in which all of the peak values of force (stress) are equal and all of the valley values of force (stress) are equal.

3.2.2 *fatigue loading transition, n—in the beginning of fatigue loading*, the number of cycles before the force (stress) reaches the desired peak and valley values.

3.2.3 *force (stress) ratio, R [nd], n—in fatigue loading*, the ratio of the minimum applied force (stress) to the maximum applied force (stress), where positive force (stress) corresponds to the tension mode of loading.

3.2.4 *frequency, f [T^{-1}], n—in fatigue loading*, the number of force (stress) cycles completed in 1 s (Hz).

3.2.5 *peak, n—in fatigue loading*, the occurrence where the first derivative of the force (stress) versus time changes from positive to negative sign; the point of maximum force (stress) in constant amplitude loading.

3.2.6 *residual strength, [$ML^{-1}T^{-2}$], n*—the value of force (stress) required to cause failure of a specimen under quasi-static loading conditions after the specimen is subjected to fatigue loading.

3.2.7 *run-out, n—in fatigue*, an upper limit on the number of force cycles to be applied.

3.2.8 *spectrum loading, n—in fatigue*, a loading in which the peak values of force (stress) are not equal or the valley values of force (stress) are not equal (also known as variable amplitude loading or irregular loading).

3.2.9 *valley, n—in fatigue loading*, the occurrence where the first derivative of the force (stress) versus time changes from negative to positive sign; the point of minimum force (stress) in constant amplitude loading.

3.2.10 *wave form, n*—the shape of the peak-to-peak variation of the force (stress) as a function of time.

3.3 *Symbols*—b = width of specimen, mm [in]

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

L = length of specimen, mm [in]

N = number of constant amplitude cycles

P = force on specimen, positive for tension mode of loading, N [lb]

R = fatigue force (stress) ratio, minimum-to-maximum cyclic force (stress)

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

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

τ = core shear stress, MPa [psi]

4. Summary of Test Method

4.1 This test method consists of subjecting a sandwich core to cyclic shear force parallel to the plane of its faces. The force is transmitted to the core through loading plates which are bonded directly to the core (unlike the static core shear test, Test Method C273/C273M, bonding of loading plates to facesheets bonded to the core is not permitted). The number of force (stress) cycles at which failure occurs for a specimen subjected to a specific force (stress) ratio and force (stress) magnitude is determined.

NOTE 2—This test method may be used as a guide to conduct shear fatigue testing of sandwich panels consisting of facesheets and core with the Test Method C273/C273M loading plates bonded to the facesheets.

4.2 The only acceptable failure modes for shear fatigue of sandwich core materials are those which are internal to the sandwich core. Failure of the loading plate-to-core bond is not an acceptable failure mode.

5. Significance and Use

5.1 Often the most critical stress to which a sandwich panel core is subjected is shear. The effect of repeated shear stresses on the core material can be very important, particularly in terms of durability under various environmental conditions.

5.2 This test method provides a standard method of obtaining the sandwich core shear fatigue response. Uses include screening candidate core materials for a specific application, developing a design-specific core shear cyclic stress limit, and core material research and development.

NOTE 3—This test method may be used as a guide to conduct spectrum loading. This information can be useful in the understanding of fatigue behavior of core under spectrum loading conditions, but is not covered in this standard.

5.3 Factors that influence core fatigue response and shall therefore be reported include the following: core material, core geometry (density, cell size, orientation, etc.), specimen geometry and associated measurement accuracy, specimen preparation, specimen conditioning, environment of testing, specimen alignment, loading procedure, loading frequency, force (stress) ratio and speed of testing (for residual strength tests).

NOTE 4—If a sandwich panel is tested using the guidance of this standard, the following may also influence the fatigue response and should be reported: facing material, adhesive material, methods of material fabrication, adhesive thickness and adhesive void content. Further, core-to-facing strength may be different between precured/bonded and co-cured facings in sandwich panels with the same core and facing materials.

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 in general. Specific material factors that affect sandwich core include variability in core density and degree of cure of core bonding adhesive. For this particular core shear test, thickness of the adhesive bond to honeycomb core (adhesive-filled depth into the honeycomb core cells), core misalignment/distortion/damage, or bonding surface roughness may affect the core shear strength and fatigue life.

6.2 *System Alignment*—Unintended loading eccentricities will cause premature failure. Every effort should be made to eliminate undesirable eccentricities from the test system. Such eccentricities may occur as a result of misaligned grips, poor specimen preparation, or poor alignment of the bonded loading plates and loading fixture. If there is any doubt as to the alignment inherent in a given test machine, then the alignment should be checked following the general philosophical approach described in Test Method E1012.

6.3 *Geometry*—Specific geometric factors that affect core shear fatigue response include core cell geometry (shape, density, orientation), core thickness, specimen shape (L/b ratio), and adhesive thickness.

6.4 *Environment*—Results are affected by the environmental conditions under which the tests are conducted. Specimens tested in various environments can exhibit significant differences in both fatigue life and failure mode. Critical environments must be assessed independently for each adhesive and core material tested. 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.

6.5 *Loading Frequency*—Results may be affected by specimen heating if the test is run at too high a cyclic loading rate. High cyclic rates may induce heating due to material damping, and may cause variations in specimen temperature and properties of the core. Varying the cyclic frequency during the test is generally not recommended, as the response may be sensitive to the frequency utilized and the resultant thermal history.

6.6 *Force (Stress) Ratio*—Results may be affected by the force (stress) ratio under which the tests are conducted.

6.7 *Loading Mode*—Results may be affected by the mode of loading (tension versus compression).

6.8 *Failure Mode*—In some sandwich applications the effective shear strength of the core may be limited by the strength of the core-to-facing interface. In these cases it may be appropriate to test a sandwich panel representative of the intended application.

7. Apparatus

7.1 *Micrometers*—The micrometer(s) shall use a flat anvil interface on machined edges or very smooth-tooled surfaces. The accuracy of the instrument(s) shall be suitable for reading to within 1 % of the sample length, width and thickness. For typical specimen geometries, an instrument with an accuracy of ±25 µm [±0.001 in.] is desirable for thickness, length and width measurement.

7.2 *Test Fixtures*—Use either the tension or compression tension loading fixture described in Test Method C273/C273M depending on the specified mode of loading.

7.3 *Testing Machine*—The testing machine shall be in accordance with Practice E467 and shall satisfy the following requirements:

7.3.1 *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 11.7.

7.3.2 *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 to within ±1 % of the indicated value.

7.3.3 *Counter*—The testing machine shall be capable of counting cycles of applied load.

7.4 *Conditioning Chamber*—When conditioning materials in 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 gage section of the test specimen at the required test environment during the mechanical test.

7.6 *Thermocouple and Temperature Recording Devices,* capable of reading specimen temperature to ±0.5°C [±1.0°F].

8. Sampling and Test Specimens

8.1 *Sampling*—For statistically significant data, the procedures outlined in Practice E122 should be consulted. A statistically significant distribution of data should be obtained for a given core material, environment and loading condition from the number of tests selected.

8.1.1 *Sample Size for S-N Curve*—The recommended minimum number of specimens in the development of S-N data is three specimens per load level and a minimum of three load levels. For additional procedures consult Practice E739. Report the method of sampling.

8.2 *Geometry*—The test specimens shall be as described in Test Method C273/C273M, and the core material shall be bonded directly to the fixture plates (the optional Test Method C273/C273M configuration that includes facesheets is not covered by this standard). The dimensions of the specimen shall be such that the line of load action passes through the diagonally opposite corners of the core material.

8.3 *Specimen Preparation and Machining*—Specimen preparation is extremely important for this test method. Select an appropriate adhesive, given the desired environmental and cyclic loading conditions, and follow all adhesive supplier-recommended bonding processes. Take precautions when cutting specimens from large blocks to avoid notches, undercuts, rough or uneven surfaces, or delaminations due to inappropriate machining methods. Obtain final dimensions by water-lubricated precision sawing. The use of diamond tooling 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.

8.3.1 *Labeling*—Label the test specimens so that they will be distinct from each other and traceable back to the panel of origin, and located where they 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 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, including specified environmental exposure levels and resulting moisture content, shall be reported with the test data.

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

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

11. Procedure

11.1 *Parameters to be Specified 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.

NOTE 6—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 and life to aid in transducer selection, calibration of equipment, and determination of equipment settings.

11.1.3 The pre-test environmental conditioning parameters.

11.1.4 The fatigue test environment conditions.

11.1.5 The mode of loading (tension or compression).

11.1.6 The fatigue test cyclic applied force levels (maximum and minimum) and cyclic load frequency.

11.1.7 The cycle intervals for force-displacement recording.

11.1.8 The estimated life (number of cycles).

11.1.9 The data collection schema.

11.2 *General Instructions:*

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

11.2.2 If core density is to be reported, then obtain these samples from the same sheet of core being tested. Density may be evaluated in accordance with Test Method C271/C271M.

11.2.3 Following final specimen machining, but before conditioning and testing, measure the specimen length and width, taking care not to deform the unsupported core. The accuracy of these measurements shall be within 0.5 % of the dimension. Measure the specimen thickness; the accuracy of this measurement shall be within ±25 µm [±0.001 in.]. Record the dimensions to three significant figures in units of millimetres [inches]. Weigh the specimen to the nearest 0.1 g and calculate the specimen density per Test Method C271/C271M.

11.3 *Bonding*—Bond the specimen to the loading plates, in accordance with the requirements of 8.3.

11.4 *Pre-Test Conditioning*—Condition the bonded specimens as required. Store the specimens in the conditioned environment until test time, if the test environment is different than the conditioning environment.

11.4.1 *As-Conditioned Dimensions*—Following final specimen conditioning, but before testing, re-measure the specimen length and width as in 11.2.3.

11.5 *Static Control Testing*—Before the fatigue tests, test a minimum of five control specimens statically in a standard test machine in accordance with Test Method C273/C273M. Test in the same loading mode (tension or compression) as the planned fatigue testing. Use the average of the five specimens as the 100 % level for the fatigue tests.

NOTE 7—The static strength of some non-metallic core materials is sensitive to the loading rate. For fitting a curve to S-N data including data at N=1, it is recommended to perform additional ultimate static strength measurements at the fatigue load rate as described in ISO 13003:2003(E) for example.

11.6 *Specimen Installation*—Install the specimen/bonding plate assembly into the test machine test fixture, and environmental chamber if required, as shown in Fig. 1.

11.7 *Cyclic Loading:*

11.7.1 *Force (Stress) Ratio*—Use a force (stress) ratio, R, of minimum to maximum force of 0.10 for tension mode of loading, or 10 for compression mode of loading, unless a

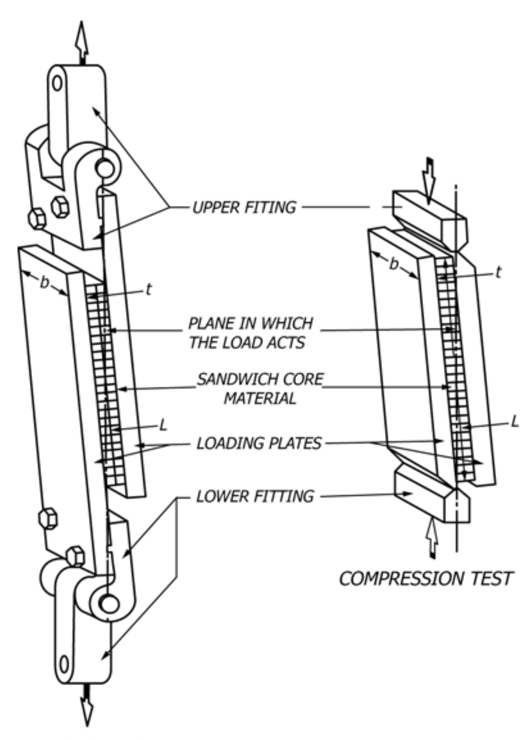

FIG. 1 Plate Shear Specimens, Force of Line Action

different ratio has been specified. For example, in tension mode of loading, using a maximum force of +4000N with a minimum force of +400N would provide R=400/4000=0.1, whereas in compression mode of loading, using a minimum force of -4000N with a maximum force of -400N would provide R = -4000/-400 = 10.

11.7.2 *Loading Shape*—Unless otherwise specified, the applied loading mode shape shall be sinusoidal and of constant amplitude.

11.7.3 *Fatigue Force Application:*

11.7.3.1 *Method A (Amplitude Loading)*—This approach of transitioning force to the specimen consists of quasi-statically increasing the force until reaching the desired mean force (stress), in other words the set point, and slowly increasing the force (stress) amplitude, in other words the span, until the desired peak and valley values are obtained. In this approach, a fatigue loading transition occurs before the desired peak and valley values are reached. The number of loading cycles corresponding to this transition shall be reported.

11.7.3.2 *Method B (Direct Loading)*—This approach of transitioning force to the specimen consists of quasi-statically increasing the force to either the maximum or minimum force (stress) followed by immediate cycling between maximum and minimum force using a haversine wave form (for which the valley values will not decrease below the minimum force). This approach eliminates the fatigue loading transition associated with amplitude loading and is only possible with modern signal generators and controllers.

11.7.3.3 *Monitoring Force*—Following the fatigue force transition, the peak and valley force values should be monitored periodically. If required, the settings of the force controller should be adjusted to achieve the desired loading. Peak and valley force values commonly drift during fatigue loading due to changes in compliance of the specimen. Report instances in which the loading was not within 2 % of the desired peak and valley values.

11.7.4 *Temperature Monitoring*—Attach the temperature recording device in a manner not to influence the dynamic response of the specimen. The temperature of the specimen shall be monitored, and the frequency should be kept low enough to avoid heating the specimen more than 3°C [5°F].

11.7.5 *Data Recording*—Record force versus head displacement and resulting hysteresis loops at the specified intervals.

11.7.6 *Life Measurement*—Record the maximum fatigue cycle force and number of cycles to failure or test run-out.

11.8 *Residual Strength*—If a specimen does not fail in fatigue, the static residual strength may be measured by testing to failure per Test Method C273/C273M.

11.9 *Failure Modes*—Adhesive failures that occur at the bond to the loading blocks are not acceptable failure modes and the data shall be noted as invalid. Core shear failure is the only acceptable failure mode.

12. Validation

12.1 Results shall not be calculated for any specimen that does not exhibit an acceptable failure mode. Retests shall be performed for any specimen on which results are not calculated.

12.2 A significant fraction of failures in a sample population occurring at the bond(s) to the loading blocks shall be cause to reexamine the means of force introduction into the material. Factors considered should include the fixture alignment, adhesive material, specimen surface characteristics, and uneven machining of specimen ends.

13. Calculation

13.1 Calculate the core shear stress in accordance with Test Method C273/C273M with the following exception: in Test Method C273/C273M the force *P* is taken as positive regardless of the mode of loading, whereas in the current method the sign of *P* reflects the sense of the applied force (positive for tension).

$$\tau = \frac{P}{Lb} \tag{1}$$

where:

τ = core shear stress, MPa [psi];
P = load on specimen, N [lb];
L = length of specimen, mm [in.]; and
b = width of specimen, mm [(in.].

13.2 *Fatigue Life Distribution:*

13.2.1 *Log-Normal Distribution*—The use of a log-normal distribution is presented in Practice E739 for the representation of constant amplitude fatigue life data.

13.2.2 *Weibull Distribution*—The two parameter Weibull distribution is commonly used to represent constant amplitude fatigue life data. A two parameter Weibull distribution density function for fatigue life may be expressed as:

$$f(N) = \frac{\beta}{\alpha}\left(\frac{N}{\alpha}\right)_{\beta-1} \exp-\left[\left(\frac{N}{\alpha}\right)_{\beta}\right] \tag{2}$$

The distribution cumulative function for fatigue life may be given as:

$$F(N) = 1 - \exp\left[-\left(\frac{N}{\alpha}\right)_{\beta}\right] \tag{3}$$

One method of determining the Weibull scale and shape parameters, α and β, is the maximum likelihood technique.[4]

13.3 *S-N Curve*—As described in Practice E739.

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).

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 the core material tested, including:

[4] Talreja, R., "Estimation of Weibull Parameters for Composite Material Strength and Fatigue Life Data," Fatigue of Fibrous Composite Materials, ASTM STP 723, American Society for Testing and Materials, Philadelphia, PA, 1981, pp. 291-311.

14.1.4.1 Material specification,
14.1.4.2 Material type,
14.1.4.3 Manufacturer's material designation,
14.1.4.4 Manufacturer's batch or lot number,
14.1.4.5 Source (if not from manufacturer),
14.1.4.6 Date of certification, and
14.1.4.7 Expiration of certification;
14.1.5 Results of any nondestructive evaluation tests,
14.1.6 Method of preparing the test specimen, including:
14.1.6.1 Specimen labeling scheme and method,
14.1.6.2 Specimen geometry,
14.1.6.3 Sampling method, and
14.1.6.4 Specimen cutting method;
14.1.7 Calibration dates and methods for all measurements and test equipment,
14.1.8 Details of test fixtures and apparatus, including dimensions and material used,
14.1.9 Type of test machine, alignment results, and data acquisition sampling rate and equipment type,
14.1.10 Measured length, width, and thickness for each specimen (prior to and after conditioning, if appropriate),
14.1.11 Weight of specimen,
14.1.12 Method of bonding specimens to loading plates; adhesive, cure cycle, and pressure,
14.1.13 Conditioning parameters and results,
14.1.14 Relative humidity and temperature of the testing laboratory,
14.1.15 Environment of the test machine environmental chamber (if used) and soak time at environment,
14.1.16 Number of specimens tested,
14.1.17 Speed of testing, including loading rate on static control specimen and testing speed (number of cycles per second) on fatigue test specimens and mode of testing (tensile or compressive),
14.1.18 Ultimate force and ultimate shear stress obtained from static control test, and a description of the type of failure,
14.1.19 Shear stress levels, and stress ratio, and mode of loading (tension or compression) for each specimen used in fatigue tests, and
14.1.20 Number of cycles to failure for each specimen. If test is stopped at a specified number of cycles without failure occurring, it shall be so noted.
14.1.21 Force-displacement hysteresis loops and a curve of maximum shear stress versus number of cycles to failure (S-N curve) shall be plotted.
14.1.22 If static residual strength testing of unfailed fatigue coupons is required, report static strength per Test Method C273/C273M.

15. Precision and Bias

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

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

16. Keywords

16.1 fatigue; sandwich core; shear strength; shear stress