INTERNATIONAL

Designation: D8510/D8510M − 23

Standard Test Method for Local Buckling and Crippling under Axial Compressive Loading[1]

This standard is issued under the fixed designation D8510/D8510M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the local buckling and crippling stresses for one-edge-free and no-edge-free cross section configurations using solid laminate composite material construction. Design of test specimens is covered in Guide D8511/D8511M. A number of test parameters may be varied within the scope of the standard, provided that the parameters are fully documented in the test report. The composite material forms are limited to continuous-fiber or discontinuous-fiber (tape, fabric, braids or hybrids of these forms) reinforced composites.

1.2 This test method requires careful specimen design, instrumentation, data measurement and data analysis. The use of this test method requires close coordination between the test requestor and the test lab personnel. Test requestors need to be familiar with Guide D8511/D8511M and CMH-17 Volume 3 Chapter 9[2](**1**).

1.3 *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.

1.3.1 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D2734 Test Methods for Void Content of Reinforced Plastics
D3171 Test Methods for Constituent Content of Composite Materials
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D7137/D7137M Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates
D8511/D8511M
E4 Practices for Force Calibration and Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E83 Practice for Verification and Classification of Extensometer Systems
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 Gages
E456 Terminology Relating to Quality and Statistics
E1237 Guide for Installing Bonded Resistance Strain Gages

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

Current edition approved Sept. 1, 2023. Published September 2023. DOI: 10.1520/D8510_D8510M-23.

[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[3] 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.

3.1.1 Terminology D3878 defines terms relating to high-modulus fibers and their composites. 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 documents.

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 of Terms Specific to This Standard:*

3.2.1 *crippling force, P^{cc} [MLT^{-2}], n*—the applied compressive force at or above the local buckling force at which specimen failure occurs.

3.2.2 *crippling stress, F^{cc} [$ML^{-1}T^{-2}$], n*—the average stress in the test specimen cross-section at failure (maximum force).

3.2.3 *local buckling force, P^{lcr} [MLT^{-2}], n*—the applied compressive force at which buckling of a compression element within the cross-section initiates.

3.2.4 *local buckling stress, F^{lcr} [$ML^{-1}T^{-2}$], n*—the average stress in the test specimen cross-section at which buckling of a compression element within the cross-section initiates.

3.2.5 *width to thickness ratio, b/t [nd], n*—the ratio of the width of the buckling critical section of the specimen cross-section to the specimen thickness.

3.2.5.1 *Discussion*—The width to thickness ratio may be either a nominal value determined from nominal thickness or an actual value determined from measured thickness.

3.3 *Symbols:*

3.3.1 *A*—cross-sectional area, mm^2 [in.^{2}].

3.3.2 *b*—width of buckling critical segment of specimen cross-section, relative to laminate centerline, mm [in.].

3.3.3 F^{lcr}—local buckling stress, MPa [psi].

3.3.4 F^{cc}—crippling stress, MPa [psi].

3.3.5 *L1*—specimen length between end potting or fixture inner surfaces, mm [in.].

3.3.6 *L2*—total specimen length, mm [in.].

3.3.7 *n*—number of tested specimens.

3.3.8 *P*—total compressive force applied to specimen, N [lbf].

3.3.9 P^{lcr}—applied compressive force at which buckling initiates, N [lbf].

3.3.10 P^{cc}—maximum applied compressive force, N [lbf].

3.3.11 *t*—specimen thickness (nominal or actual, as specified), mm [in.].

3.3.12 *w*—overall width of buckling critical segment of specimen cross-section, mm [in.].

3.3.13 $\bar{X}$—sample mean (average).

3.3.14 S_{n-1}—sample standard deviation.

3.3.15 *CV*—sample coefficient of variation, %.

3.3.16 x_i—measured or derived property.

4. Summary of Test Method

4.1 This test standard establishes the procedure for determining the local instability (buckling) force in one or more cross-section segments and the post-buckled force sustained by a composite specimen. The test involves applying an axial compressive force to an unsupported specimen until local buckling and subsequent catastrophic failure ("crippling") occurs. The test frame head travel, force and cross-sectional strains are recorded during the test. Still or video images, or both, of the specimen deformations under force are recorded and reported.

4.1.1 This test standard does not provide an explicit specimen geometry or data reduction methodology. The specimen geometry is to be provided by the test requestor. Refer to Guide D8511/D8511M for specimen design and analysis information. The three test procedures in Fig. 1 are covered in this standard.

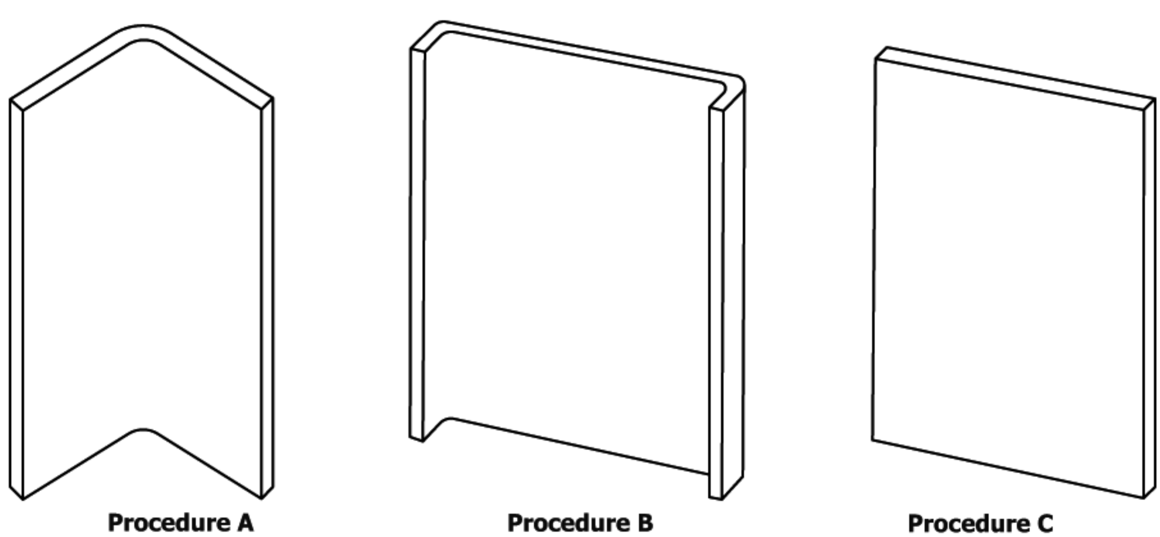

FIG. 1 Specimen Types

Other non-standard test specimen configurations may be tested using this method.

4.2 *Procedure A – One Edge Free (OEF):*

4.2.1 The test specimen consists of a constant cross-section, symmetric L-section with potted ends. Both segments of the L-section are intended to buckle at the same applied force. This specimen configuration often exhibits a flexural-torsional buckling mode which produces lower bound OEF results. This is further discussed in Guide D8511/D8511M.

4.3 *Procedure B – No Edge Free (NEF):*

4.3.1 The test specimen consists of a constant cross-section, symmetric C-section with potted ends. The center "web" segment of the C-channel is intended to buckle while the edge segments are intended to remain unbuckled up to the specimen failure force.

4.4 *Procedure C – No Edge Free (NEF):*

4.4.1 The test specimen consists of a laminated plate specimen that is supported on the unloaded edges by V-groove fixture restraints and loaded with a clamping fixture on each end.

5. Significance and Use

5.1 This test method is designed to produce composite stiffener cross-section local buckling and crippling data for research and development, and for structural design and analysis. The standard generic configurations for this procedure provide data for two types of cross-section segments: one-edge-free and no-edge-free. This type of data is used in classical stiffener analysis methods. Compressive loading of composite column type specimens may exhibit one of four modes: *(1)* a compression material strength failure, *(2)* an overall column flexural, torsional, and or flexural-torsional instability, *(3)* a local instability followed by a continued post-buckled force carrying capability which eventually results in a material strength failure, or *(4)* a combination of local and overall instability followed by post-buckling failure. The first two modes are outside the scope of this test method. The latter two modes are categorized as crippling failure and is the purpose of this test method.

5.1.1 The desired failure mode is characterized by an initial linear elastic structural deformation. Continued loading eventually renders one of the cross-sectional segments unstable. Additional loading beyond this point of initial buckling exhibits a pattern of local lateral deflections or buckles. These deflections will grow, and possibly change modes, until catastrophic column failure occurs. This failure is considered the ultimate crippling stress for the buckled segments.

5.2 General factors that influence the mechanical response of composite laminates and should therefore be reported include the following: material, methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, time held at test temperature, void content, and volume percent reinforcement.

6. Interferences

6.1 Refer to Guide D8511/D8511M for discussion of interferences with specimens used in this test method.

7. Apparatus

7.1 *Micrometers*—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, a course peel ply surface which is neither smooth nor flat). A micrometer or caliper with a flat anvil interface shall be used for measuring length, width, and other machined surface dimensions. The use of alternative measurement devices is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory. The accuracy of the instrument(s) shall be suitable for reading to within 1 % of the specimen dimensions. For typical specimen geometries, an instrument with an accuracy of ±0.0025 mm [±0.0001 in.] is adequate for thickness measurements, while an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for measurement of length, width, other machined surface dimensions.

7.2 *Compression Loading Platens*—The force shall be applied to the specimen by a compression platen such that the mismatch between the specimen ends and the loading surfaces does not exceed 0.025 mm [0.001 in.] over the contact area of the end of the specimen. Self-aligning (spherical seat) or screw adjustable (tripod) compression platens may be used to meet this requirement. The loading platen surfaces shall be, as a minimum, as wide as the specimen and flat to within 0.10 mm [0.004 in.].

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.

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 as specified in 11.3.10.

7.3.3 *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.

7.4 *Displacement*—Displacement transducers such as LVDTs or DCDTs shall satisfy, at a minimum, Practice E83, Class B2 requirements for the displacement range of interest, and shall be calibrated over that range in accordance with Practice E83. The transducers shall be essentially free of inertia-lag at the specified speed of testing.

7.5 *Strain-Indicating Device*—Strain data, when required, shall be determined by means of bonded resistance strain gauges.

7.5.1 *Bonded Resistance Strain Gauge Selection*—Strain gauge selection is based on the type of material to be tested. A minimum active gauge length of 3 mm [0.125 in.] is recommended for composite laminates fabricated from unidirectional layers. Larger strain gauge sizes may be more suitable for some textile fabrics or braids. Gauge calibration certification shall comply with Test Method E251. Strain gauges with a minimum normal strain range of approximately 3 % are recommended. When testing textile fabric laminates, gauge selection should consider the use of an active gauge length that is at least as great as the characteristic repeating unit of the fabric. Some guidelines on the use of strain gauges on composite materials follow.

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 gauge 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 gauge 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 gauge excitation voltage consistent with the desired accuracy (1 V to 2 V is recommended) to reduce the power consumed by the gauge. Heating of the coupon by the gauge may affect the performance of the material directly or it may affect the indicated strain as a result of a difference between the gauge 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 gauge. The strain gauge manufacturer should be consulted for recommendations on transverse sensitivity corrections and effects on composites.

7.6 *Buckle Shape Measurement*—When required by the test requestor, moiré fringe image methods or Digital Image Correlation (DIC) may be used to provide images of the specimen initial buckle shapes and changes with increasing applied force. An applied force readout visible in the recorded images or video is required.

7.7 *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.

7.8 *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. The relative humidity level controlled within the test chamber shall be specified by the test requestor.

7.9 *Procedure C Support Fixture*—A support fixture per the general type shown in Fig. 2 shall be used. The fixture shall accommodate the specimen size(s) defined by the test requestor. The specimen unloaded edges shall be supported by a straight V-groove of sufficient size to accommodate the specimen thickness, which allows a simple support along these

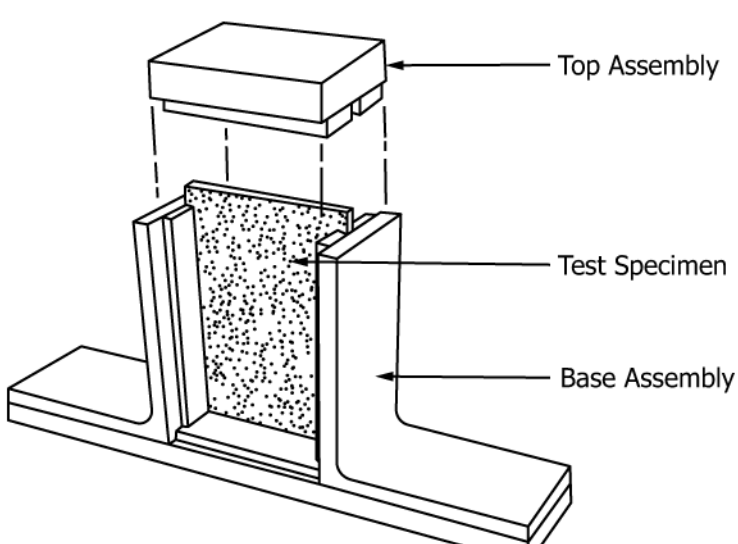

FIG. 2 Procedure C No-Edge-Free Support Fixture

edges. The specimen ends shall be clamped in the fixture to prevent end brooming failure modes. Details of a similar fixture are provided in Test Method D7137/D7137M.

8. Sampling and Test Specimens

8.1 *Sampling*—The number of test replicates for each specimen configuration shall be specified by the test requestor.

NOTE 2—If specimens are to undergo environmental conditioning to equilibrium, and the end potting is installed prior to conditioning (recommended), then use a traveler specimen of the same nominal thickness and appropriate size (but without potting) to determine when equilibrium has been reached for the specimens being conditioned.

8.2 *Geometry:*

8.2.1 *Stacking Sequence*—The standard laminate shall have balanced and symmetric stacking sequences. Fabric laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise specified and noted in the report. Non-symmetric and non-balanced layups have extensional-bending stiffness coupling which leads to complicated buckling patterns and non-linear post-buckling response.

8.2.2 *Configuration*—The generic geometry of the specimens are shown in Fig. 3 and Fig. 4 (Procedure A), Fig. 5 and Fig. 6 (Procedure B), and Fig. 7 and Fig. 8 (Procedure C). The corner radii for Procedure A and B specimens should be representative of intended part design configurations for which the crippling data will be used for stress analysis. A standard

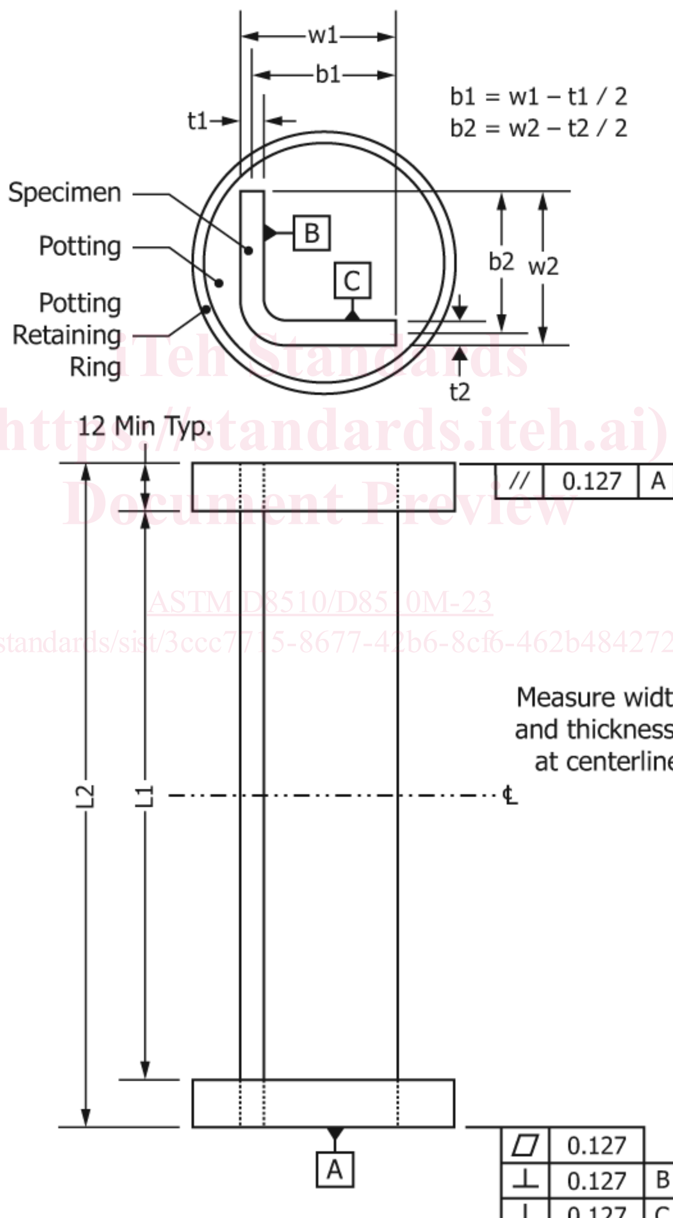

FIG. 3 Procedure A Specimen Dimensions (SI Units)

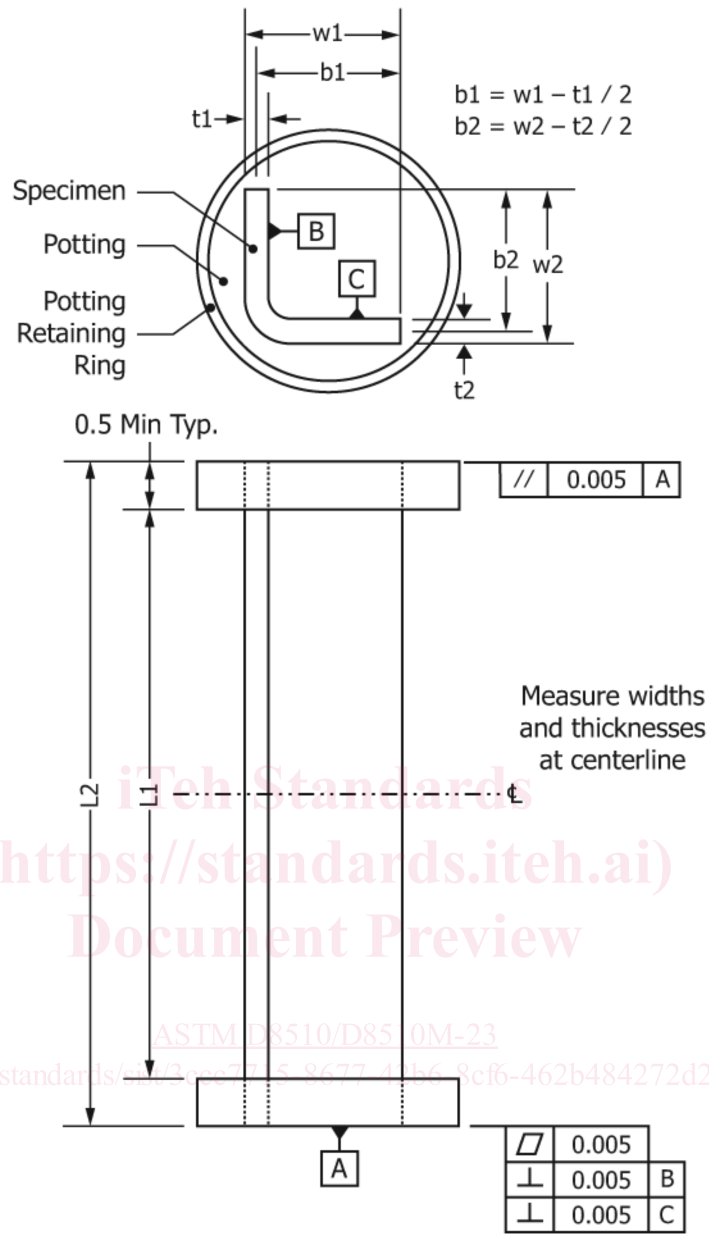

FIG. 4 Procedure A Specimen Dimensions (Inch-Pound Units)

specimen configuration is not provided; refer to Guide D8511/D8511M for the design of these test specimens. The potting retaining rings should be selected from standard tube sizes and shall be sufficient size to fit the specimen.

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

8.3.1 *Specimen Fabrication*—Control of fiber alignment is critical. Improper fiber alignment will influence the measured properties. The specimen(s) cross section segments must be flat and of uniform thickness, and the overall specimen must be straight to ensure even loading and avoid column bending.

8.3.2 *Machining Methods*—Specimen preparation is extremely important for this specimen. Take precautions when cutting specimens from plates 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 tooling has been found to be extremely effective for many material systems. Edges should be flat and parallel within the specified tolerances.

8.3.3 *End Potting*—The ends of Procedure A and B specimens shall be potted to prevent end brooming failure. The effective length of the column should be considered as the length between the end potting inner surfaces. The following procedure is recommended for potting the specimen ends:

8.3.3.1 Machine the specimens prior to end potting.

8.3.3.2 On each end use a retaining ring consisting of aluminum or stainless steel tubing. Recommended tube wall thickness range is 0.9 mm to 3.2 mm [0.035 in. to 0.125 in.].

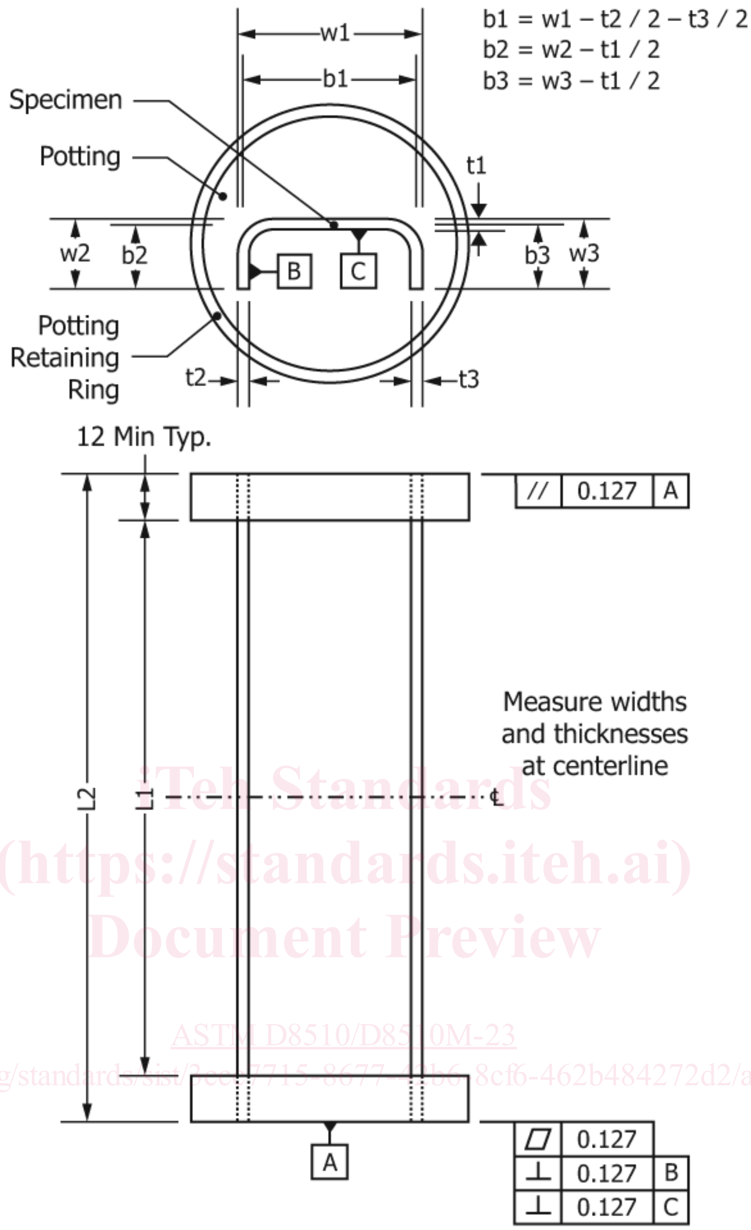

FIG. 5 Procedure B Specimen Dimensions (SI Units)

8.3.3.3 Use a room temperature curing epoxy potting compound.

8.3.3.4 Place a retaining ring on a flat surface. Stand and support a specimen end inside the ring per below. Pour in potting and allow to cure. Repeat for the other specimen end.

8.3.3.5 Locate the centroid of the specimen within 6 mm [0.25 in.] of the center of the retaining ring – this will aid the alignment of the specimen with the test frame force axis.

8.3.3.6 Potting and rings should be flush with specimen ends within 0.8 mm [0.030 in.] prior to machining.

8.3.3.7 Machine specimen ends in accordance to meet the flatness and parallelism tolerances in Fig. 6 or Fig. 7. A complete cross-section/footprint of the specimen end must visible on each end (not covered with potting). This requires precision machining.

8.3.3.8 The final height of the end potting shall be a minimum of 12 mm [0.5 in.].

8.3.3.9 The specimen length between potting inner surfaces shall meet the test requestor requirements. Alternate procedures achieving sufficient end support for the specimens are acceptable.

8.3.4 If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from the same specimen sections being tested. Specific gravity and density may be evaluated by means of Test Method D792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D3171 or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D2584. The void