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Standard Guide for Testing Fabric-Reinforced "Textile" Composite Materials[1]

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INTRODUCTION

A variety of fabric-reinforced composite materials have been developed for use in aerospace, automotive, and other applications. These composite materials are reinforced with continuous fiber yarns that are formed into two-dimensional or three-dimensional fabrics. Various fabric constructions, such as woven, braided, stitched, and so forth, can be used to form the fabric reinforcement. Due to the nature of the reinforcement, these materials are often referred to as "textile" composites.

Textile composites can be fabricated from 2-dimensional (2-D) or 3-dimensional (3-D) fabrics. Stitched preforms and 3-D fabrics contain through-thickness yarns, which can lead to greater delamination resistance. Textile composites are also amenable to automated fabrication. However, the microstructure (or fiber architecture) of a textile composite, which consists of interlacing yarns, can lead to increased inhomogeneity of the local displacement fields in the laminate. Depending upon the size of the yarns and the pattern of the weave or braid, the inhomogeneity within a textile composite can be large compared to traditional tape laminates.

Thus, special care should be exercised in the use of the current ASTM standards developed for high performance composites. In many cases, the current ASTM standards are quite adequate if proper attention is given to the special testing considerations for textile composites covered in this guide. However, in some cases, current standards do not meet the needs for testing of the required properties. This guide is intended to increase the user's awareness of the special considerations necessary for the testing of these materials. It also provides the user with recommended ASTM standards that are applicable for evaluating textile composites. The specific properties for which current ASTM standards might not apply are also highlighted in this guide.

1. Scope

1.1 This guide is applicable to the testing of textile composites fabricated using fabric preforms, such as weaves, braids, stitched preforms, and so forth, as the reinforcement. The purpose of this guide is to:

1.1.1 Ensure that proper consideration is given to the unique characteristics of these materials in testing.

1.1.2 Assist the user in selecting the best currently available ASTM test method for the measurement of commonly evaluated material properties for this class of materials.

1.2 Areas where current ASTM test methods do not meet the needs for testing of textile composites are indicated.

1.3 It is not the intent of this guide to cover all test methods which could possibly be used for textile composites. Only the most commonly used and most applicable standards are included.

1.4 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

[1] This guide is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

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system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 *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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D883 Terminology Relating to Plastics

D2344/D2344M Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates

D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials

D3171 Test Methods for Constituent Content of Composite Materials

D3410/D3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading

D3479/D3479M Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials

D3518/D3518M Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate

D3846 Test Method for In-Plane Shear Strength of Reinforced Plastics

D3878 Terminology for Composite Materials

D4255/D4255M Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method

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

D5379/D5379M Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method

D5528 Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites

D5766/D5766M Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates

D5961/D5961M Test Method for Bearing Response of Polymer Matrix Composite Laminates

D6115 Test Method for Mode I Fatigue Delamination Growth Onset of Unidirectional Fiber-Reinforced Polymer Matrix Composites

D6415 Test Method for Measuring the Curved Beam Strength of a Fiber-Reinforced Polymer-Matrix Composite

D6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

D6484/D6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates

D6641/D6641M Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture

D6671/D6671M Test Method for Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites

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

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*—Definitions used in this guide are defined by various ASTM methods. 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 defines terms relating to statistics. In the event of a conflict between definitions of terms, Terminology D3878 shall have precedence over the other standards. Terms relating specifically to textile composites are defined by Ref (**1**).[3]

3.2 *textile unit cell*—In theory, textile composites have a repeating geometrical pattern based on manufacturing parameters. This repeating pattern is often referred to as the materials "unit cell." It is defined as the smallest section of architecture required to repeat the textile pattern (see Figs. 1-4). Handling and processing can distort the "theoretical" unit cell. Parameters such as yarn size, yarn spacing, fabric construction, and fiber angle may be used to calculate theoretical unit cell dimensions. However, several different "unit cells" may be defined for a given textile architecture. For example, Fig. 2 shows two different unit cells for the braided architectures. Thus, unit cell definition can be somewhat subjective based on varying interpretations of the textile architecture. The user is referred to Refs (**1, 2**) for further guidance. In this guide, to be consistent, the term "unit cell" is used to refer to the smallest unit cell for a given textile architecture. This smallest unit cell is defined as the smallest section of the textile architecture required to replicate the textile pattern by using only in-plane translations (and no rotations) of the unit cell. Examples of the smallest unit cells for some of the commonly used textile composites are shown in Figs. 1-4. For the 3-D weaves in Figs. 3 and 4, the smallest unit cell length (as indicated) is defined by the undulating pattern of the warp yarns. The smallest unit cell

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

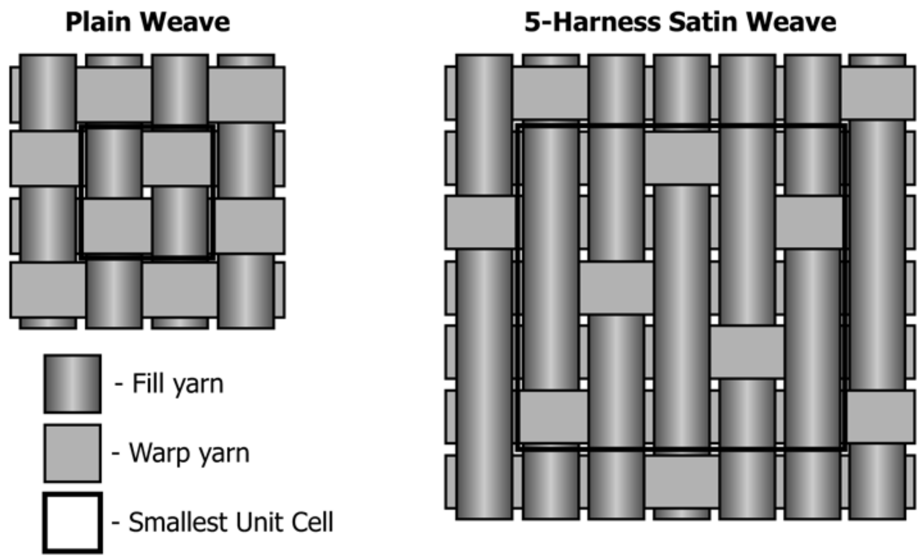

FIG. 1 Smallest Unit Cells for Plain Weave and 5-Harness Satin Weave Architectures

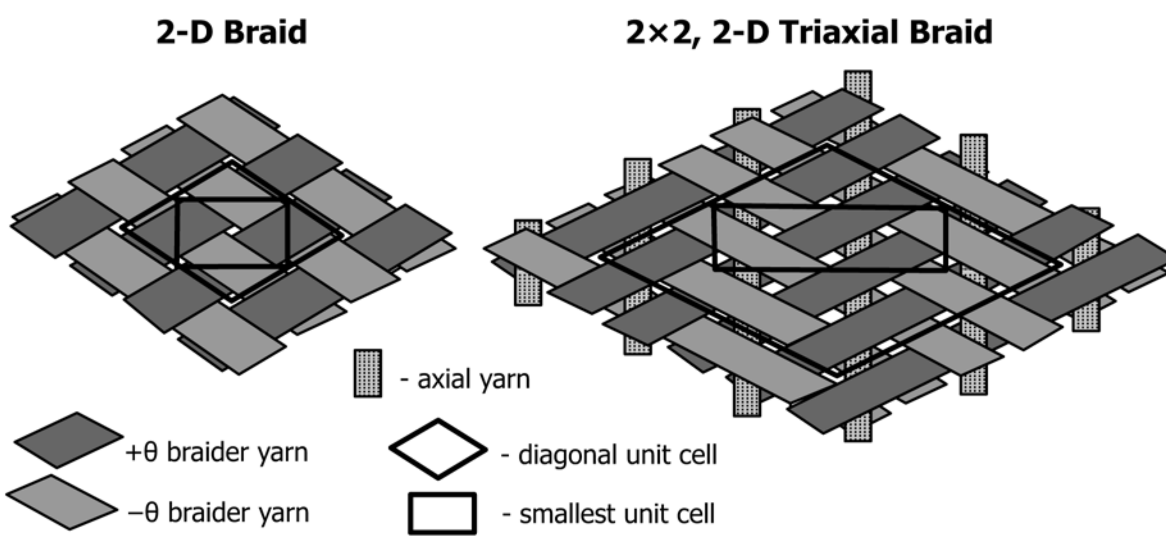

FIG. 2 Smallest Unit Cells for a 2-D Braid and a 2×2, 2-D Triaxial Braid

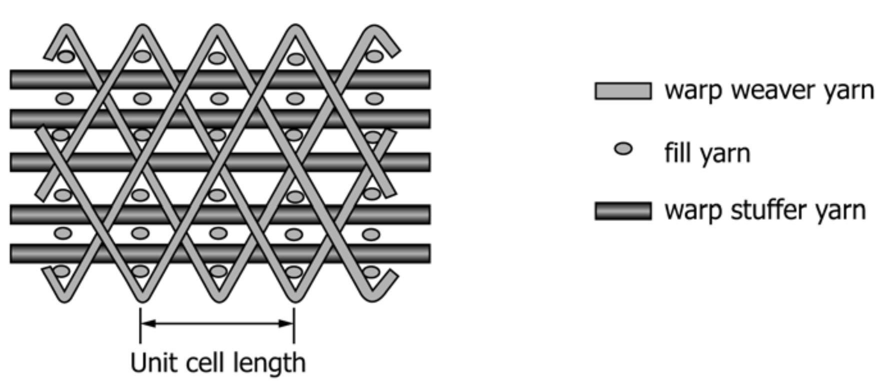

FIG. 3 Smallest Unit Cell Length for Through-Thickness Angle-Interlock Weave

width is the distance between two adjacent warp stuffer yarn columns (in the fill yarn direction) and the smallest unit cell height is the consolidated woven composite thickness.

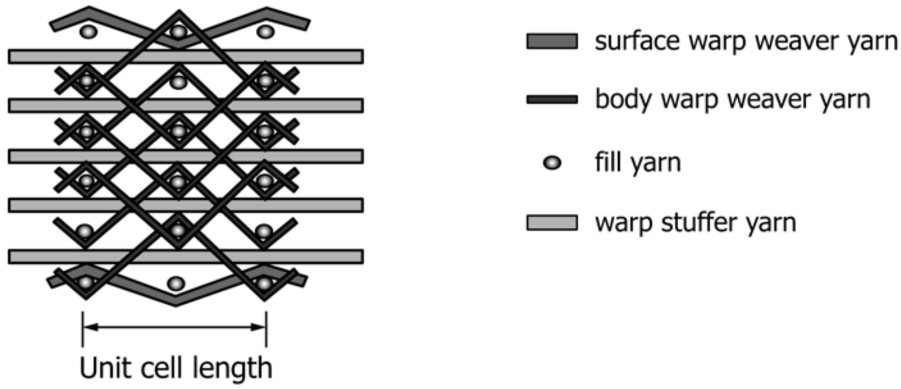

FIG. 4 Smallest Unit Cell Length for Layer-to-Layer Angle-Interlock Weave

4. Significance and Use

4.1 This guide is intended to serve as a reference for the testing of textile composite materials.

4.2 The use of this guide ensures that proper consideration is given to the unique characteristics of these materials in testing. In addition, this guide also assists the user in selecting the best currently available ASTM test method for measurement of commonly evaluated material properties.

5. Summary of Guide

5.1 Special testing considerations unique to textile composites are identified and discussed. Recommendations for handling these considerations are provided. Special considerations covered are included in Section 7 on Material Definition; Section 8 on Gage Selection; Section 9 on Sampling and Test Specimens; Section 10 on Test Specimen Conditioning; Section 11 on Report of Results; and Section 12 on Recommended Test Methods.

5.2 Recommended ASTM test methods applicable to textile composites and any special considerations are provided in Section 12 for mechanical and physical properties. Section 13 identifies areas where revised or new standards are needed for textile composites.

6. Procedure for Use

6.1 Review Sections 7 – 12 to become familiar with the special testing considerations for textile composites.

6.2 Follow the recommended ASTM test method identified in Section 12 for determining a required property but refer back to this guide for recommendations on test specimen geometry, strain measurement, and reporting of results.

7. Material Definition

7.1 *Constituent Definition*—Variations in type and amount of sizing on the fibers can significantly influence fabric quality and subsequently material property test results. Each constituent, that is, the fiber, fiber sizing type and amount, and resin should be carefully documented prior to testing to avoid misinterpretation of test results.

7.1.1 Fiber and resin content should be measured and recorded using at least one unit cell of the material from at least one location in each panel from which test specimens are machined. Section 12 covers methods for measuring these values.

7.1.2 The following items should be documented each time a material is tested: fiber type, fiber diameter, fiber surface treatment or sizing type and amount, and resin type.

7.2 *Fabric Definition*—Due to the limitless possibilities involved in placing yarns during the weaving and braiding operations, it is important to carefully document the yarn counts (or yarn sizes), yarn spacings, yarn orientations, yarn contents, weave or braid pattern identification, and yarn interlocking through the preform thickness. Such documentation is required to properly define the textile unit cell and also to properly identify the textile material that was tested and to avoid any possible misinterpretations of the test results.

7.3 *Process Definition*—Processing techniques can affect fiber orientation, void content, and state of polymerization. These factors can in turn influence material property test results significantly. Each of these items should be defined and documented prior to testing to avoid misinterpretation of the test results.

7.3.1 The amount of debulking of the preform during processing can affect the fiber volume and also the fiber orientation through the thickness. In-plane fiber orientation can be adversely affected during the placement of the preform in the mold. Both overall and local variations in fiber orientation should be documented.

7.3.2 As a minimum the following process conditions should be documented for each material tested: preform thickness, preform tackifier (or resin compatible binder) used, molding technique, molding temperature, molding pressure, molding time, and panel dimensions.

8. Strain Gage Selection

8.1 The surface preparation, gage installation, lead wire connection, and verification check procedures described in Test Methods E251 and Guide E1237 are applicable to textile composites and should be used in the application of bonded resistance strain gages.

8.2 The strain gage size selected for each particular textile composite should take into consideration the size of the unit cell for the particular textile composite architecture. Each different textile architecture has an independent unit cell size, which defines the extent of inhomogeniety in the displacement fields. The size of the gage should be large enough relative to the textile unit cell to provide a reliable measurement of the average strain magnitude. It is recommended for most textile architectures that the gage length and width should, at a minimum, equal the length and width of the smallest unit cell. This applies to specimens loaded in the axial fiber direction (longitudinal direction) and to specimens loaded perpendicular to the axial fibers (transverse direction). For stitched composites, it is recommended that the gage length and width should, at a minimum, equal the stitch spacing and stitch pitch, respectively. The user is also referred to Ref (**3**) for further guidance.

9. Sampling and Test Specimens

9.1 *Sampling*—It is recommended that at least five specimens be tested per series unless valid results can be obtained using less specimens, such as by using a designed experiment. For statistically significant data, the procedure outlined in Practice E122 should be used and the method of sampling should be reported.

9.2 *Specimen Geometry*—The test specimen geometry shall be in accordance with the corresponding ASTM test method and the specimen geometry recommended in Section 12 for each measured property. The recommended ratio of specimen width to unit cell width for a textile composite is 2:1. The larger of (*1*) the specimen width dictated by this recommended ratio and (*2*) the specimen width recommended in the corresponding ASTM standard for the measured property, should be used to ensure that at least two unit cells are included within the specimen gage section.

9.3 *Specimen Fabrication*—The specimens may be molded individually without cut edges or machined from a plate after bonding on tab material. If cut from a plate, precautions must be taken to avoid notches, undercuts, or rough edges. When machined, each specimen should be saw cut oversized and ground to the final dimensions.

10. Test Specimen Conditioning

10.1 Unless a different environment is required, the test specimens shall be conditioned in accordance with Procedure C of Test Method D5229/D5229M. The specimens should be stored and tested at standard laboratory conditions of 23 ± 1°C [73.4 ± 1.8°F] and 50 ± 10 % relative humidity.

11. Report

11.1 *Standard Reporting*—All of the normal reporting requirements of the ASTM standard recommended for use for the particular property should be followed.

11.2 *Textile Composite Reporting*—Sections 7 – 10 covered the special considerations for testing of textile composite materials. A recommended list of the items which should be documented in test reports as a consequence of these considerations follows. Neglecting to document any of these items could result in misinterpretation of test results.

11.2.1 *Material Documentation:*

11.2.1.1 Fiber type,

11.2.1.2 Fiber diameter,

11.2.1.3 Fiber surface treatment type and amount,

11.2.1.4 Fiber content,

11.2.1.5 Preform fabric type (weave, braid, and so forth),

11.2.1.6 Fabric construction (plain weave, 2×2 triaxial braid, angle-interlock weave, and so forth),

11.2.1.7 Yarn filament count or yarn size for each different set of yarns used in the fabric (for example, warp, weft/fill, stuffer, braider, and so forth),

11.2.1.8 Yarn spacings for each different set of yarns (for example, warp, weft/fill, stuffer, braider, and so forth),

11.2.1.9 Yarn orientations for each different set of yarns,

11.2.1.10 Yarn content (%) for each different set of yarns in the fabric,

11.2.1.11 Yarn interlocking length (or number of fill columns interlocked) along weave warp direction (for angle-interlock weaves),

11.2.1.12 Yarn interlocking depth (or number of layers interlocked) through the thickness (for angle-interlock weaves),

11.2.1.13 Stitch type (modified lock stitch, loop stitch, and so forth),

11.2.1.14 Stitching yarn type and filament count (or yarn size),

11.2.1.15 Stitch spacing and stitch pitch (for stitched preforms),

11.2.1.16 Dry preform thickness,

11.2.1.17 Preform surface treatment,

11.2.1.18 Resin type,

11.2.1.19 Resin content,

11.2.1.20 Void content, and

11.2.1.21 Specific gravity.

11.2.2 *Process Documentation:*

11.2.2.1 Molding technique (resin transfer molding (RTM), resin film infusion (RFI), and so forth),

11.2.2.2 Tackifier (or resin compatible binder) used for better preform handling,

11.2.2.3 Mold release material identification and mold release technique,

11.2.2.4 Molding temperature,

11.2.2.5 Molding pressure,

11.2.2.6 Molding time, and

11.2.2.7 Panel dimensions.

11.2.3 *History Documentation:*

11.2.3.1 Molding date,

11.2.3.2 Machining date,

11.2.3.3 Testing date,

11.2.3.4 Load history, and

11.2.3.5 Environmental history.

11.2.4 *Sampling Documentation:*

11.2.4.1 Number of panels,

11.2.4.2 Location of specimens,

11.2.4.3 Orientation of specimens, and

11.2.4.4 Number of specimens.

11.2.5 *Test Specimen Documentation:*

11.2.5.1 Machining technique, and

11.2.5.2 Machined edge condition.

11.2.6 *Pre-Test Conditioning Documentation:*

11.2.6.1 Temperature, humidity, pressure, load, and time at which specimens were pre-conditioned prior to testing, and

11.2.6.2 Time at test temperature prior to testing.

12. Recommended Test Methods

12.1 *Unnotched Tension Testing of Textile Composites:*

12.1.1 Uniaxial tension tests should be performed using Test Method D3039/D3039M. Further guidance specific to textile composites is available in Ref (**4**).

12.1.2 Strain measurements should be made using an extensometer or strain gages of sufficient size relative to the textile unit cell as recommended in Section 8.

12.1.3 Test specimen width should be based on the minimum width recommended in 9.2 and a minimum gage length of 127 ± 2.0 mm [5.00 ± 0.1 in.].

12.1.4 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.1.5 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.2 *Unnotched Compression Testing of Textile Composites:*

12.2.1 Uniaxial compression tests should be performed using either Test Method D6641/D6641M or D3410/D3410M (Procedure B only). Test Method D6641/D6641M is not recommended for uniwoven fabrics and can be used only for textile composites with a maximum of 50 % warp (0-degree) yarns (in the loading direction). Further guidance specific to textile composites is available in Ref (**5**).

12.2.2 Strain measurements should be made using an extensometer or strain gages of sufficient size relative to the textile unit cell as recommended in Section 8.

12.2.3 Test specimen width should be based on the minimum width recommended in 9.2.

12.2.4 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.2.5 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.3 *In-plane Shear Testing of Textile Composites:*

12.3.1 In-plane shear tests should be performed using either Test Method D5379/D5379M or D4255/D4255M. Test Method D3518/D3518M can be used only for woven or orthogonally braided (braid angle = ±45°) composites with equal yarn sizes and spacings in the warp and fill (or ±45° braiding) directions or for laminated uniweave constructions that have a ±45° layup. Further guidance specific to textile composite testing using Test Method D5379/D5379M is available in Ref (**6**).

12.3.2 Strain measurements should be made using strain gages of sufficient size relative to the textile unit cell as recommended in Section 8.

12.3.3 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.3.4 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.4 *Through-Thickness Shear Testing of Textile Composites:*

12.4.1 Through-thickness shear testing of textile composites with no through-thickness interlocking yarns, such as, plain weave, satin weaves, 2-D braids, etc., should be performed using either Test Method D5379/D5379M or D3846. Test Method D3846 can be used only when the distance between the notches is at least equal to the length of two textile unit cells. Test Method D2344/D2344M cannot be used for most textile composites (except uniweave constructions) due to specimen geometry limitations which do not provide sufficient space to accommodate at least two textile unit cells along the width (see 9.2) or in the test section between the loading and the support points.

12.4.2 Textile composites with through-thickness yarns have a high through-thickness shear strength relative to their in-plane compression strength. Test Method D5379/D5379M or D3846 cannot be used to achieve adequate through-thickness shear failures in these composites.

12.4.3 For 2-D weaves and 2-D braids, test specimen width should be based on the minimum width recommended in 9.2.

12.4.4 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.4.5 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.5 *Flexural Testing of Textile Composites:*

12.5.1 Flexural tests should be performed using Test Methods D6272 or D790. Test Method D6272 is the preferred method.

12.5.2 Test specimen width should be based on the minimum width recommended in 9.2.

12.5.3 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.5.4 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.6 *Open Hole Tension Testing of Textile Composites:*

12.6.1 Open hole tension tests should be performed using Test Method D5766/D5766M. Further guidance specific to textile composites is available in Ref (**7**).

12.6.2 Recommended specimen dimensions for textile composites are as follows: width—36.0 ± 0.1 mm [1.500 ± 0.005 in.]; length—200 to 300 mm [8.0 to 12.0 in.]; and centrally located hole—6.00 ± 0.06 mm [0.250 ± 0.003 in.] diameter.

12.6.3 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10 respectively.

12.6.4 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.7 *Open Hole Compression Testing of Textile Composites:*

12.7.1 Open hole compression tests should be performed using Test Method D6484/D6484M.

12.7.2 Recommended specimen dimensions for textile composites are as follows: width—36.0 ± 0.25 mm [1.50 ± 0.01 in.]; length—300 ± 0.25 mm [12.0 ± 0.01 in.]; and centrally located hole—6.00 ± 0.06 mm [0.250 ± 0.003 in.] diameter.

12.7.3 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.7.4 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.8 *Bearing Response Testing of Textile Composites:*

12.8.1 Bearing response tests should be performed using Test Method D5961/D5961M.

12.8.2 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.8.3 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.9 *Tension Fatigue Testing of Textile Composites:*

12.9.1 Tension fatigue tests should be performed using Test Method D3479/D3479M.

12.9.2 Strain measurements should be made using an extensometer of sufficient size relative to the textile unit cell as recommended in Section 8.

12.9.3 Test specimen width should be based on the minimum width recommended in 9.2 and a minimum gage length of 127 ± 2.0 mm [5.00 ± 0.1 in.].

12.9.4 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.9.5 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.10 *Flexural Fatigue Testing of Textile Composites:*

12.10.1 Flexural fatigue tests should be performed using the test specimen recommended in either Test Methods D6272 or D790. An ASTM test method does not exist at this time for flexural fatigue testing.

12.10.2 Test specimen width should be based on the minimum width recommended in 9.2.

12.10.3 Test specimen fabrication and conditioning should be performed according to 9.3 and Section 10, respectively.

12.10.4 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.11 *Density and Specific Gravity of Textile Composites:*

12.11.1 Density and specific gravity measurements for textile composites should be performed using Test Methods D792.

12.11.2 Test specimen length and width should be selected based on the size of the textile unit cell. At a minimum, the length and width of the specimen should be equal to the length and width of the unit cell for the particular textile architecture.

12.11.3 The special reporting requirements described in Section 11 should be used for all textile composite materials.

12.12 *Fiber Content of Textile Composites:*

12.12.1 Fiber content measurements for textile composites should be performed using Test Method D3171.

12.12.2 Test specimen length and width should be selected based on the size of the textile unit cell. At a minimum, the length and width of the specimen should be equal to the length and width of the unit cell for the particular textile architecture.

12.12.3 The special reporting requirements described in Section 11 should be used for all textile composite materials.

13. Standard Test Methods Needed for Textile Composites

13.1 *Through-Thickness Shear Testing*—As mentioned in Section 12, the current Test Methods D5379/D5379M or D3846 for through-thickness shear might not be adequate for textile composites with large amounts of through-thickness yarns. A modified test specimen needs to be developed which will lead to through-thickness shear failures in the 3-D textile composite materials.

13.2 *Out-of-Plane Tension Testing*—Currently there does not exist an adequate test method for measuring out-of-plane tension strength and modulus of textile composites. Test Method D6415 which uses a curved beam for out-of-plane tension strength can be used only for uniweave textile composites. This test method is not recommended for bi-directional composites such as 2-D weaves and 2-D braids since the test results are often influenced by transverse yarn cracking which usually precedes interlaminar tension failure. Further work needs to be undertaken to develop an adequate standard test method for out-of-plane stiffness and strength properties of 3-D woven and 3-D braided composites.

13.3 *Interlaminar Fracture Testing*—Currently adequate test methods for measuring interlaminar fracture toughness (mode I, mode II and mixed mode) of textile composites do not exist. There is a need to examine the applicability of the Test Methods D5528, D6115, and D6671/D6671M to textile composites.

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