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Standard Guide for Testing Automotive/Industrial Polymer Matrix Composite Materials[1]

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INTRODUCTION

A new class of composite materials has been developed to meet the needs of automotive and industrial mass production applications. This new class of materials, referred to as automotive/industrial composites, is comprised of filled and unfilled polymers reinforced with chopped or continuous high modulus, or both (greater than 20.7 GPa (3×10^6 psi)) fibers.

Automotive/industrial composites possess some of the same advantages as high-performance aerospace composites. However, some aspects of performance are traded off for reduced cost, ease of manufacturing, and high quality appearance. Automotive/industrial composites are also different from materials classified as plastics. This difference arises from the use of high modulus fiber reinforcement to provide substantial improvements in structural properties of the base polymer system.

Currently, ASTM International standard test methods developed for high performance composites or plastics, or both, are used for testing of automotive/industrial composites. In many cases, these standards are quite adequate if proper attention is given to the special testing considerations for automotive/industrial composites covered in this guide. However, in some cases, current standards do not meet the needs for testing of the required properties. In this case, revised standards or new standards specifically for automotive/industrial composites may be desirable.

In addition to covering the special considerations required for automotive/industrial composites testing, this guide points out and compares existing ASTM International standards applicable to these materials. This is done only for some of the more commonly evaluated material properties.

[1] This guide is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.031 on Constituent/Precursor Properties. Editorial and Resource Standards.

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1. Scope

1.1 This guide covers summarizes the testing application of molded automotive/industrial ASTM standard test methods (and other supporting standards) to continuous-fiber reinforced polymer matrix composite materials. It is intended to increase the users awareness The most commonly used or most applicable ASTM standards are included, emphasizing use of the special considerations necessary for the testing standards of Committhtese D30 on Composite Materials. I

1.2 This guide does not cover all possible standards that could apply to polymer matrix composites and restricts discussion, to the user is provided with a comparison documented scope. Commonly used but non-standard industry extensions of tesot method scopes, such as application of the more commonly used ASTM International standard static test methods tho fatigue testing, are applicable for evaluating automotive/industrial composites.

1.2 Areas in which current ASTM International standard test methods do not discussed. A more complete summary of general composite testing standards, including non-ASTM test methods, is included in the Composite Materials Handbook (MIL-HDBK-17).[2] Additional specific recommendations for testing of automotive/industrial textile (fabric, braided) composites are indicated. This provides direction for future standardization work.

1.3 It is contained in Guide D 6856.

1.3 This guide does not specify a system of measurement; the intent systems specified within each of this guide to cover all test

Annual Book of ASTM Standards, Vol 08.04.

[2] Available from ASTM, and also from the U.S. DoD Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

methods which could possibly be used for automotive/industrial composites. Only the most commonly used and most applicable referenced standards shall apply as appropriate. Note that the referenced standards of ASTM Committee D30 are either SI-onely or combined-unit standards with SI units listed first.

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:* [3]

2.1.1 *Standards of Committee D30 on Composite Materials*

C 581 Practice 393 Test Method for Flexural Properties of Sandwich Constructions
C 480 Test Method for Flexure Creep of Sandwich Constructions
C 613/C 613M Test Method for Constituent Content of Composite Prepreg by Soxhlet Extraction
D 2344/D 2344M Test Method for Short Beam Strength of Composite Materials and Their Laminates
D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D 3171 Test Method for Constituent Content of Composite Materials
D 3410/D 3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading
D 3479/D 3479M Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials
D 3518/D 3518M Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45 Laminate
D 3529/D 3529M Test Method for Matrix Solids Content and Matrix Content of Composite Prepreg
D 3530/D 3530M Test Method for Volatiles Content of Composite Material Prepreg
D 3531 Test Method for Resin Flow of Carbon Fiber-Epoxy Prepreg
D 3532 Test Method for Gel Time of Carbon Fiber-Epoxy Prepreg
D 3544 Guide for Reporting Test Methods and Results on High Modulus Fibers[4]
D 3800 Test Method for Density of High-Modulus Fibers
D 3878 Terminology of Composite Materials
D 4018 Test Methods for Properties of Continuous Filament Carbon and Graphite Fiber Tows
D 4102 Test Method for Thermal Oxidative Resistance of Carbon Fibers
D 4255/D 4255M Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method
D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D 5379/D 5379M Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method
D 5448/D 5448M Test Method for In-Plane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders
D 5449/D 5449M Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders
D 5450/D 5450M Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders
D 5467/D 5467M Test Method for Compressive Properties of Unidirectional Polymer Matrix Composites Using a Sandwich Beam
D 5528 Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites
D 5687/D 5687M Guide for Preparation of Flat Composite Panels With Processing Guidelines for Specimen Preparation
D 5766/D 5766M Test Method for Open Hole Tensile Strength of Polymer Matrix Composite Laminates
D 5961/D 5961M Test Method for Bearing Response of Polymer Matrix Composite Laminates
D 6115 Test Method for Mode I Fatigue Delamination Growth Onset of Unidirectional Fiber-Reinforced Polymer-Matrix Composites
D 6264 Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force
D 6415 Test Method for Measuring the Curved Beam Strength of a Fiber-Reinforced Polymer-Matrix Composite
D 6416/D 6416M Test Method for Two-Dimensional Flexural Properties of Simply Supported Sandwich Composite Plates Subjected to a Distributed Load
D 6484/D 6484M Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D 6507 Practice for Fiber Reinforcement Orientation Codes for Composite Materials
D 6641/D 6641M Test Method for Determining the Compressive Properties of Polymer Matrix Composite Materials Using the

[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*, Vol 08.01. volume information, refer to the standard's Document Summary page on the ASTM website.
Annual Book of ASTM Standards, Vol 15.03.

[4] Withdrawn.

Combined Loading Compression (CLC) Test Fixture

D 6671 Test Method for Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites

D 6742/D 6742M Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates

D 6856 Guide for Testing Fabric Reinforced Textile Composite Materials

D 6873 Practice for Bearing Fatigue Testing of Polymer Matrix Composite Laminates

E 1309 Guide for the Identification of Fiber-Reinforced Polymer Matrix Composite Materials in Databases

E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases

E 1471 Guide for the Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases

2.1.2 *Standards of Committee D20 on Plastics*

C 581 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service

D 256 Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics

D 543 Practices 543 Test Method for Evaluating the Resistance of Plastics to Chemical Reagents

D 618 Practice for Conditioning Plastics for Testing

D 638 Test Method for Tensile Properties of Plastics

D 648 Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position

D 671 Test Method for Flexural Fatigue of Plastics by Constant-Amplitude-of- Force[4]

D 695 Test Method for Compressive Properties of Rigid Plastics

D 696 Test Method for Coefficient of Linear Thermal Expansion of Plastics Between— -30°C and 30°C With a Vitreous Silica Dilatometer

D 756 Practice 790 Test Methods for Determination Flexural Properties of Weight Unreinforced and Shape Changes of Reinforced Plastics Under Accelerated Service Conditions[3] and Electrical Insulating Materials

D 7902 Test Methods for Flexural Properties of Unreinforced Density and Reinforced Specific Gravity (Relative Density) of Plastics and Electrical Insulating Materials[3] by Displacement

D 79253 Test Methods for Density and Specific Gravity (Relative Density) Bearing Strength of Plastics by Displacement[3] Plastics

D 1822 Test 1505 Test Method for Tensile-Impact Energy to Break Density of Plastics and Electrical Insulating Materials[3] by the Density-Gradient Technique

D 182289 Test Method for Tensile Properties of Tensile-Impact Energy to Break Plastics at High Speeds[3] and Electrical Insulating Materials

D 234471 Test Method Short-Beam Strength of Polymer Matrix Composite Materials for Gel Time and Their Laminates Peak Exothermic Temperature of Reacting Thermosetting Resins

D 25843 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor

D 2584 Test Method for Ignition Loss of Cured Reinforced Resins

D 2734 Test Method for Void Content of Reinforced Plastics

D 2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

D 3039 Test 3418 Test Method for Tensile Properties Transition Temperatures of Polymer Matrix Composite Materials[4] Polymers by Differential Scanning Calorimetry

D 384106 Test Method for Compressive Properties of Composite Materials with Unsupported Gage Section by In-Plane Shear Loading[4] Strength of Reinforced Plastics

D 3418 Test Method 4065 Practice for Transition Temperatures Plastics: Dynamical Mechanical Properties: Determination and Report of Polymers by Thermal Analysis[5] Procedures

D 344793 Test Methods for Tension-Tension Fatigue of Polymer Matrix Composite Materials[4] Plastics: Dynamic Mechanical Properties: Cure Behavior

D 3846 Test 5083 Test Method for In-Plane Shear Strength Tensile Properties of Reinforced Thermosetting Plastics Using Straight-Sided Specimens

D 4065 Practice 6272 Test Method for Plastics: Mechanical Properties: Determination and Report of Procedures[5]

D 4255 Guide for Testing In-Plane Shear Flexural Properties of Composites Laminates[4] Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

2.1.3 *Standards of Other ASTM Committees*

E 228 Test Method for Linear Thermal Expansion of Solid Materials With a Vitreous Silica Dilatometer

E 289 Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry

E 1269 Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry

E 1461 Test Method for Thermal Diffusivity of Solids by the Flash Method

E 1922 Test Method for Translaminar Fracture Toughness of Laminated Polymer Matrix Composite Materials

3. Terminology

3.1 *Definitions:*

3.1.1 *automotive/industrial*

3.1 Definitions related to composite—any filled or unfilled polymer reinforced with chopped or continuous high modulus, or both, (greater than 20.7-GPa (3 × 10^6 psi)) fibers whose properties materials are dependent on the process parameters used defined in mass production manufacturing.

3.1.2 *Plaque*—a flate plate of molded material Terminology D 3878.

3.2 Symbology for evaluation specifying the orientation and stacking sequence of material properties.

3.1.3 *Part*—a component a composite laminate is defined in Practice D 6507.

3.3 For purposes of this document, "low modulus" composites are defined as being reinforced with fibers having a manufactured assembly.

3.2 *Abbreviations:Abbreviations:*

3.2.1 *A/I Composite*, automotive/industrial composite. modulus ≤20 GPa (≤3.0 × 10^6 psi), while "high-modulus" composites are reinforced with fiber having a modulus >20 GPa (>3.0 × 10^6 psi).

4. Significance and Use

4.1 This guide is intended to serve as a reference for aid in the testing selection of automotive/industrial standards for polymer matrix composite materials.

4.2 The use of this guide assures that proper consideration is given to materials. It specifically summarizes the unique characteristics application of these materials in testing. In addition, this guide also assists the user in selecting the best currently available standards from ASTM International test method for measurement of Committee D30 on Composite Materials that apply to continuous-fiber reinforced polymer matrix composite materials. For reference and comparison, many commonly evaluated material properties. used or applicable ASTM standards from other ASTM Committees are also included.

5. SummaryStandard Specimen Preparation

5.1 Preparation of Guide

5.1 Special testing considerations unique to automotive/industrial composites are identified and discussed. Recommendations for handling these considerations are provided. Special considerations covered are included polymer matrix composite test specimens is described in Section 7 on Material Definition, Section 8 on Sampling Techniques, Section 9 on Guide D 5687.

6. Standard Test Specimen Preparation, Section 10 on Test Specimen Conditioning, and Section 11 on Reporting of Results.

5.2 Current ASTM International standard Methods

6.1 ASTM test methods applicable to automotive/industrial for the evaluation of polymer matrix composites are compared for commonly evaluated material properties. Areas where revised or new standards are needed are identified. Test methods for commonly evaluated properties summarized in the following Tables 1-5. Advantages, disadvantages, and other comments for each test method groups are included where appropmpriate. Where possible, a single preferred: test method is identified.

	Test Methods	Sections	
	Mechanical Properties	12.4	
TEST METHOD CATEGORY	Mechanical Properties	12.4	TABLE
Fatigue Properties	12.5		
	Environmental ResistanceTable 1		
Lamina/Laminate Static Properties	Table 1		
Lamina/Laminate Dynamic Properties	12.6		
Lamina/Laminate Dynamic Properties	12.6	Table 2	
	CreepTable 3		
Laminate/Structural Response	Table 3		
Constituent/Precursor/Thermophysical Properties	12.7		
Constituent/Precursor/Thermophysical Properties	12.7	Table 4	
	Thermal Properties	12.8	
Environmental Conditioning/Resistance	Thermal Properties	12.8	
	Physical Properties	12.9	
	Impact Properties	12.10	
	Impact Properties	12.10	Table 5

6. Procedure for Use

6.1 Review Sections 7-11 to become familiar with the special testing considerations for automotive/industrial composites.

6.2 Locate the table for the property that you would like to determine in Section 12. Use the table to help in selecting the best ASTM International standard test method for determining that property.

6.3 Follow the selected ASTM International standard, but refer back to the guide for recommendations on material definition, sampling procedures, test specimen preparation, test specimen conditioning, and reporting of results.

7. Material Definition Standard Data Reporting

7.1 *Constituent Definition*—Variations in Material Description— Data reporting of the type and content description of fiber, filler, and resin can have a significant influence on composite material property test results. Each constituent material should be carefully defined and constituents is documented before testing to avoid misinterpretation of test results.

TABLE 1 Lamina/Laminate Static Test Methods

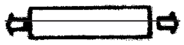
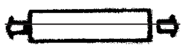
Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
		In-Plane Tensile Test Methods			
D 3039		Tensile Strength	Straight sided specimen. Suitable for both random, discontinuous and continuous-fiber composites. Tabbed and untabbed configurations available.	Tabbed configurations require careful adhesive selection and special specimen preparation. Certain laminate layups prone to edge delamination which can affect tensile strength results.	Preferred for most uses. Provides additional configurations, requirements, and guidance that are not found in D 5083. Limited to laminates that are balanced and symmetric with respect to the test direction.
		Tensile Modulus, Poisson's Ratio, Stress-Strain Response	Requires use of strain or displacement transducers. Modulus measurements do not require use of tabs.		Modulus measurements typically robust.
D 638		Tensile Strength, Tensile Modulus	"Dumbbell" shaped specimen. Ease of test specimen preparation.	Stress concentration at the radii. Unsuitable for highly oriented fiber composites.	Not recommended for high-modulus composites. Technically equivalent to ISO 527-1.
D 5083		Tensile Strength, Tensile Modulus	Straight-sided, untabbed specimen only.	Suitable for plastics and low-modulus composites.	A straight-sided alternative to D 638. Technically equivalent to ISO 527-4 except as noted below: (*a*) This test method does not include testing of the Type I dog-bone shaped specimen described in ISO 527-4. Testing of this type of specimen, primarily used for reinforced and unreinforced thermoplastic materials, is described in D 638. (*b*) The thickness of test specimens in this test method includes the 2 mm to 10 mm thickness range of ISO 527-4, but expands the allowable test thickness to 14 mm.
D 5450		Transverse (90°) Tensile Strength	Hoop wound cylinder with all 90° (hoop) plies loaded in axial tension. Develops data for specialized process/form.	Limited to hoop-wound cylinders. Limited to transverse tensile properties. Must bond specimen to fixture.	Must ensure adequate bonding to fixture.
		In-Plane Compression Test Methods			
D 6641		Compressive Strength	Untabbed, straight-sided specimen loaded via a combination of shear and end-loading. Smaller lighter, less expensive fixture than that of D 3410. Better also at non-ambient environments. Suitable for continuous fiber composites.	May be necessary to tab highly oriented fiber composites or laminates with 0° plies on the surface. Not recommended for determining compressive strength of unidirectional (0° ply orientation) tape or tow laminates.	Preferred method. Thickness must be sufficient to prevent column buckling. Limited to laminates that are balanced and symmetric and contain at least one 0° ply. For strength determination, the laminate is limited to a maximum of 50 % 0° plies, or equivalent.
		Compressive Modulus, Poisson's Ratio, Stress-Strain Response	Requires use of strain or displacement transducers.		Unidirectional tape or tow composites can be tested to determine unidirectional modulus and Poisson's ratio.

TABLE 1 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
D 695		Compressive Strength, Compressive Modulus	"Dogbone" shaped specimen with loading applied at the ends via a platen. Tabs are optional.	Failure mode is often end-crushing. Stress concentrations at radii. Specimen must be dog boned and ends must be accurately machined. No assessment of alignment.	Not recommended for highly oriented or continuous fiber composites. Modified version of D 695 released as SACMA SRM 1 test method is widely used in aerospace industry, but ASTM D30 and MIL-HDBK-17 prefer use of D 6641 method.
D 3410		Compressive Strength	Straight sided specimen with load applied by shear via fixture grips. Suitable for random, discontinuous and continuous fiber composites. Tabbed and untabbed configurations available.	Strain gages required to verify alignment. Poor for non-ambient testing due to massive fixture.	Expensive and heavy/bulky fixturing. Thickness must be sufficient to prevent column buckling.
		Compressive Modulus, Poisson's Ratio, Stress-Strain Response	Requires use of strain or displacement transducers.		
D 5467		Compressive Strength, Compressive Modulus, Stress-Strain Response	Sandwich beam specimen loaded in 4-point bending. Intended result is a compression failure mode of the facesheet. Data is especially applicable to sandwich structures. Fixturing is simple compared to other compression tests.	An expensive specimen that is not recommended unless the structure warrants its use. Strain gages required to obtain modulus and strain-to-failure data. Narrow (1 in. wide) specimen may not be suitable for materials with coarse features, such as fabrics with large filament count tows (12K or more) or certain braided materials.	Must take care to avoid core failure modes. Limited to high-modulus composites. Due to the nature of the specimen construction and applied flexural loading these results may not be equivalent to a similar laminate tested by other compression methods such as D 3410 or D 6641.
D 5449		Transverse (90°) Compressive Strength	Hoop-wound cylinder with all 90° (hoop) plies loaded in compression. Develops data for specialized process/form.	Limited to hoop-wound cylinders. Limited to transverse compressive properties. Must bond specimen to fixture.	Must ensure adequate bonding to fixture.
In-Plane Shear Test Methods					
D 3518		Shear Strength, Shear Modulus, Stress-Strain Response	Tensile test of [+45/-45]ns layup. Simple test specimen and test method.	Poor specimen for measuring ultimate shear strength due to large non-linear response. Limited to material forms/processes that can be made in flat ±45° form. Biaxial transducers required to obtain modulus and strain-to-failure data.	Widely used due to its low cost and relationship to actual structural laminates.

~~7.1.1 Fiber, filler, and resin content should be measured and recorded at least one location in each part or plaque from which test specimens are machined. In 12.9, techniques for measuring these values are covered.~~

~~7.1.2 The following items should be documented each time a material is tested: fiber type, dimensions, and surface treatment; filler type, dimensions, and surface treatment; and resin type and component breakdown.~~ Guide E 1471.

7.2 ~~*Process Definition*—Processing techniques can affect fiber orientation, void content, and state~~Composite Material Description— Data reporting of ~~polymerization. These factors can in turn influence material property test results significantly. Each~~ the description of ~~these items should be defined and documented before testing to avoid misinterpretation of test results.~~

~~7.2.1 Fiber orientation should be quantitatively measured and documented for each part or plaque from which test specimens are machined. Both overall and local variations in fiber orientation should be documented. Unfortunately, a practical test method for measuring and quantifying local fiber orientation has not yet been developed and standardized.~~

TABLE 1 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
D 5379		Shear Strength, Shear Modulus, Stress-Strain Response	V-notched specimen loaded in special bending fixture. Provides the best shear response of the standardized methods. Provides shear modulus and strength. Can be used to test most composite types. Produces a relatively pure and uniform shear stress state.	May be necessary to tab the specimen. Specimen can be difficult to machine. Biaxial strain gages required to obtain modulus and strain-to-failure data. Requires good strain-gage installation technique. In-plane tests not suitable for materials with coarse features, such as fabrics with large filament count tows (12K or more) or certain braided materials. Unacceptable failure modes, especially with high-strength laminates, can occur due to localized failure of the specimen at the loading points.	Recommended for quantitative data, or where shear modulus or stress/strain data are required. Enables correlation with out-of-plane properties. Must monitor strain data for specimen buckling. Limited to the following forms: (*a*) unidirectional tape or tow laminates with fibers parallel or perpendicular to loading axis. (*b*) woven fabric laminates with the warp direction parallel or perpendicular to loading axis. (*c*) laminates with equal numbers of 0° and 90° plies with the 0° plies parallel or perpendicular to loading axis. (*d*) short-fiber composites with majority of the fibers randomly distributed. The most accurate modulus measurements obtained from laminates of the [0/90] family.
D 4255		Shear Strength, Shear Modulus, Stress-Strain Response	Rail shear methods. Suitable for both random and continuous fiber composites.	Difficult test to run. Historically has had poor reproducibility. Stress concentrations at gripping areas. Strain gages required to obtain modulus and strain-to-failure data.	Expensive specimen. Best reserved for testing of laminates.
D 5448		Shear Strength, Shear Modulus, Stress-Strain Response	Hoop-wound cylinder with all 90° (hoop) plies loaded in torsion. Develops data for specialized process/form.	Limited to hoop-wound cylinders. Limited to in-plane shear properties. Must bond specimen to fixture.	Must ensure adequate bonding to fixture.
		Out-of-Plane Tensile Test Methods			
D 6415		Curved Laminate Strength	Right-angle curved laminate specimen loaded in 4-point bending. Suitable for continuous fiber composites.	A complex stress state is generated in the specimen that may cause an unintended complex failure mode. There is typically a large amount of scatter in the curved beam strength data. While the failure mode is largely out-of-plane, the result is generally considered a structural test of a curved beam rather than a material property.	Limited to composites with defined layers (no through-the-thickness reinforcement). For structural comparison, the same manufacturing process should be used for both the test specimen and the structure. Non-standard versions of the curved-beam test yield a different stress state that may affect the strength and failure mode.
		Interlaminar Tensile Strength	See above.	See above.	Tests for interlaminar tensile strength limited to unidirectional materials with fibers oriented continuously along the legs and around the bend.

TABLE 1 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
			Out-of-Plane Shear Test Methods		
D 2344		Short Beam Strength	Short rectangular beam specimen loaded in 3-point bending. Short Beam Strength is a good indicator of resin-dominated properties. Simple, inexpensive specimen and test configuration.	Short Beam Strength may be related to interlaminar shear strength, but the stress state is quite mixed, and so results are not recommended as an assessment of shear strength due to stress concentrations and high secondary stresses at loading points. Shear modulus cannot be measured.	Intended primarily for quality control, comparative data, and assessment of environmental effects.
D 5379		Interlaminar Shear Strength, Interlaminar Shear Modulus	V-notched specimen loaded in special bending fixture. Provides the best shear response of the standardized methods. Provides shear modulus and strength. Can be used to test most composites. Produces a relatively pure and uniform shear stress state.	May be necessary to tab the specimen. Specimen can be difficult to machine. Strain gages required to obtain modulus and strain-to-failure data. Requires good strain-gage installation technique. Requires a very thick laminate, 20 mm (0.75 in.) for out-of-plane properties.	Recommended for quantitative data, or where shear modulus or stress/strain data are required. Enables correlation with in-plane properties. Must monitor strain data for specimen buckling.
D 3846		Shear Strength	Specimen with two machined notches loaded in compression. Suitable for randomly dispersed and continuous fiber reinforced materials. May be preferable to D 2344 for materials with randomly dispersed fiber orientations.	Failures may be sensitive to accuracy of notch machining. Stress concentrations at notches. Failure may be influenced by the applied compression stress. Requires post-failure measurement of shear area. Shear modulus cannot be measured.	Specimen loaded in compression utilizing the D 695 loading/stabilizing jig. Shear loading occurs in a plane between two machined notches. Often a problematic test. Note that this is an out-of-plane shear test (using recognized terminology), despite the title that indicates in-plane shear loading.
			Sandwich Flexural Test Methods		
C 393		Core Shear Strength, Core Shear Modulus, Sandwich Flexural Stiffness, Facesheet Compressive Strength, Facesheet Tensile Strength	Sandwich beam specimen for sandwich constructions. Ease of specimen construction and testing. Includes both 3-point and 4-point techniques, for different test objectives.	Method limited to 1D bending. Failures are often dominated by stress concentrations and secondary stresses at loading points, especially with specimens having low-density cores and thin face sheets. Care must be exercised when testing for core shear modulus to insure that the beam geometry is such that simple sandwich beam theory is valid. Specimen must be carefully designed to obtain the desired failure mode.	Since this method was developed for characterizing sandwich composite structures, results apply to a beam that could be made up of both composite and non-composite components. Therefore the failure may initiate in a non-composite element (core, adhesive) of the structure. Span-to-depth ratio >20:1 is recommended when testing for shear modulus. The ratio of face sheet thickness to core thickness (t/c) should be <0.10.

7.2.2 Void content should be measured for each material tested in at least three different parts or plaques from which test specimens are taken. Methods for measuring void content are reviewed in 12.9.

7.2.3 State of polymerization should be measured quantitatively and documented for at least three different parts or plaques from which test specimens are machined. Although a specific test composite materials is not standardized for measuring state of

TABLE 1 *Continued*

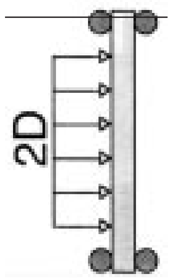
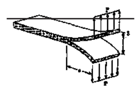
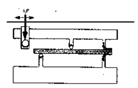
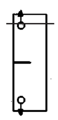
Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
D 5467		Facesheet Compressive Strength, Compressive Modulus, Stress-Strain Response	Sandwich beam specimen loaded in 4-point bending. Intended result is a compression failure mode of the facesheet. Data is especially applicable to sandwich structures. Fixturing is simple compared to other compression tests.	Limited to high-modulus composites. An expensive specimen that is not recommended unless the structure warrants its use. Strain gages required to obtain modulus and strain-to-failure data.	Must take care to avoid core failure modes. Narrow (1 in. wide) specimen may not be suitable for materials with coarse features, such as fabrics with large filament count tows (12K or more) or certain braided materials.
D 6416		Pressure-Deflection Response, Pressure-Strain Response, Sandwich Bending and Shear Stiffness	Two-dimensional plate flexure induced by a well-defined distributed load. Apparatus, instrumentation ensure applied pressure distribution is known. Failures typically initiate away from edges. Specimens are relatively large, facilitating study of manufacturing defects and process variables.	For studies of failure mechanics and other quantitative sandwich analyses, only small panel deflections are allowed. The test fixture is necessarily more elaborate, and some calibration is required to verify simply-supported boundary conditions. Results highly dependent upon panel edge boundary conditions and pressure distribution. Relatively large specimen and support fixture geometry.	The same caveats applying to C 393 (above) could apply to D 6416. However, this method is not limited to sandwich composites; D 6416 can be used to evaluate the 2-dimensional flexural properties of any square plate. Distributed load is provided using a water-filled bladder. Ratio of support span to average sandwich specimen thickness should be between 10 to 30.
Laminate Flexural Test Methods					
D 790		Flexural Strength, Flexural Modulus, Flexural Stress-Strain Response	Flat rectangular specimen loaded in 3-point bending. Suitable for randomly dispersed and continuous fiber reinforced materials. Ease of test specimen preparation and testing.	Stress concentrations and secondary stresses at loading points. Results sensitive to specimen and loading geometry, strain rate.	Failure mode may be tension, compression, shear, or combination.
D 6272		Flexural Strength, Flexural Modulus, Flexural Stress-Strain Response	Flat rectangular specimen loaded in 4-point bending. Suitable for randomly dispersed and continuous fiber reinforced materials. Ease of test specimen preparation and testing. Choice of two procedures enable adjustable tension/compression/shear load distribution.	Center-point deflection requires secondary instrumentation. Results sensitive to specimen and loading geometry, strain rate. Span-to-depth ratio must increase for laminates with high tensile strength with respect to in-plane shear strength.	The quarter-span version is recommended for high-modulus composites. Failure mode may be tension, compression, shear, or combination.
D 6416		Pressure-Deflection Response, Pressure-Strain Response, Plate Bending and Shear Stiffness	Two-dimensional plate flexure induced by a well-defined distributed load. Apparatus, instrumentation ensure applied pressure distribution is known. Failures typically initiate away from edges. Specimens are relatively large, facilitating study of manufacturing defects and process variables.	For studies of failure mechanics and other quantitative sandwich analyses, only small panel deflections are allowed. The test fixture is necessarily more elaborate, and some calibration is required to verify simply-supported boundary conditions. Results highly dependent upon panel edge boundary conditions and pressure distribution. Relatively large specimen and support fixture geometry.	The same caveats applying to C 393 (above) could apply to D 6416. However, this method is not limited to sandwich composites; D 6416 can be used to evaluate the 2-dimensional flexural properties of any square plate. Distributed load is provided using a water-filled bladder. Ratio of support span to average sandwich specimen thickness should be between 10 to 30.

TABLE 1 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
		Fracture Toughness Test Methods			
D 5528		Mode I Interlaminar Fracture Toughness, G_{Ic}	Flat rectangular specimen with delamination insert loaded in tension. Suitable for unidirectional tape or tow laminates. Relatively stable delamination growth.	Specimens must be hinged at the loading points. Crack growth not always well behaved.	Calculations assume linear elastic behavior. Crack growth should be observed from both sides of the specimen.
D 6671		Mixed Mode I/II Interlaminar Fracture Toughness, G_c	Flat rectangular specimen with delamination insert loaded in bending. Suitable for unidirectional tape or tow laminates. Tests at most mode mixtures. Constant mode mixtures with crack growth. Can obtain initiation and propagation toughness values.	Specimens must be hinged at the loading points. Crack growth not always well behaved. Complicated loading apparatus.	Good alignment is critical. Calculations assume linear elastic behavior.
E 1922		Translaminar Fracture Toughness, K_{TL}	Flat rectangular specimen containing an edge notch loaded in tension. Simple test to perform.	Results are only valid for the particular laminate tested. Laminates producing large damage zones do not give valid values.	

polymerization, other auxilliary tests are often used. One such measurement is determination of glass transition temperature by Test Method D 3418.

7.2.4 As a minimum, the following process conditions should be documented for each material tested: compound preparation, charge preparation, molding technique, molding temperature, molding pressure, molding time, and part or plaque dimensions. in Guide E 1309.

7.3 *History Definition*—Load and environmental history after molding and before testing can have a significant influence on A/I composite materials property test results. These history factors should be fully defined before testing to avoid misinterpretation-Composite Material Test Data—Data reporting of mechanical test results.

7.3.1 Load history, if any, should be documented data results for each test specimen. Information on the loading mode, magnitude, rate, and number of times that the load was applied should be included.

7.3.2 Environmental history should be composite materials is documented for each test specimen. Time, temperature, and humidity conditions from molding to testing should be fully documented. in Guide E 1434.

8. Sampling Techniques

8.1 *Test Plaques and Parts*—Either parts or test plaques may be used as a source of test specimens. Flat plaques tend to produce optimum and more uniform material property results than complex parts if the plaques are molded under carefully controlled conditions. If complex parts are used, the effects of local flow and molding conditions are much more likely to affect test results. The objectives of the testing to be done dictate the choice of parts or flat plaques for sampling.

8.1.1 A complete description of the part or plaque dimensions, molding source, and molding date should be documented.

8.2 *Mix of Parts*—Sampling from several parts (or plaques) produces average test results which are less influenced by part-to-part material or process variation. In addition, part-to-part variation may be evaluated when several parts are used.

8.2.1 A minimum of three parts should be used for sampling for each material property evaluated. An equal number of test specimens should be taken from each part.

8.2.2 Each test specimen should be labeled so that the part from which it was cut can be identified.

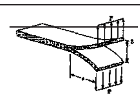
8.3 *Test Specimen Orientation*—Overall and local fiber orientation effects can have a significant influence on material property test results.

8.3.1 Test specimen orientation should be mixed to determine average properties of a nominally planar isotropic material. A minimum of two perpendicular directions should be selected for test specimens within each part (or plaque). These orientations should be selected to produce the maximum and minimum material property test results if possible.

8.3.2 Maximum and minimum properties should be measured independently for materials with oriented fiber reinforcement. Test results for minimum and maximum properties should not be averaged.

8.3.3 Each test specimen should be marked so that its orientation within the original part can be identified.

TABLE 2 Lamina/Laminate Dynamic Test Methods

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
In-Plane Tension/Tension Fatigue Test Methods					
D 3479		Tension-Tension Stress-Cycles (S-N) Data	Uses D 3039 tensile test specimen, with axial tension-tension cyclic loading. Suitable for both random and continuous-fiber composites.	Stress concentrations at the end tabs. End tab machining and bonding required.	Careful specimen preparation is critical. Appropriate specimen geometry may vary from material to material. User should be prepared to do preliminary fatigue tests to optimize tab configurations and materials.
In-Plane Flexural Fatigue Test Methods					
D 671		Flexural Stress-Cycles (S-N) Data	Constant-force cantilever specimen. Inexpensive high cycle fatigue (HCF) method.	Stress concentrations at notches. Results sensitive to specimen thickness. Not suitable for continuous-fiber composites.	This test method should not be used for continuous-fiber composites. Flexural tests are typically considered structural tests, not material property tests.
Fatigue Crack-Growth/Toughness Test Methods					
D 6115		Mode I Fatigue Delamination Initiation; Toughness-Cycles (G-N) Data	Uses D 5528 DCB specimen, with cyclic loading. Produces threshold fatigue data (G_{Imax} versus N).	Does not produce da/dN data. The limitations and comments for D 5528 also apply.	
Tensile Creep Test Methods					
D 2990		Tensile Strain versus Time	Uses D 638 tensile specimen, with long-duration loading. Ease of test specimen preparation.	Stress concentrations at specimen radii.	Not suitable for continuous fiber composites; instead use D 3039 type specimen.
Flexural Creep Test Methods					
D 2990		Flexural Deflection versus Time	Uses D 790 flexure specimen, with long-duration loading. Includes both 3 and 4-point bending test setups. Simple to set up and run.	Continuous-fiber flexural material response is complex, making results hard to interpret or generalize. Results sensitive to specimen and loading geometry. Failure mode may vary.	Not widely used in advanced composites industry.
C 480		Flexural Deflection versus Time	Sandwich beam specimen for sandwich construction loaded in 3-point bending.	Limited to sandwich panels.	
Tensile Impact Test Methods					
D 1822		Tensile Impact Energy of Rupture	Relatively inexpensive test machine.	Stress concentrations at the radii. Very small test specimens. Not instrumented.	Not suitable for continuous fiber composites.
Flexural Impact Test Methods					
D 256		Impact Energy of Rupture.	Notched specimen. Flexibility in testing methods.	Not instrumented. Varying failure modes. Sensitive to test specimen geometry variations.	This test provides a structural impact property, not a material impact property.

~~8.4 *Test Specimen Location*—The location of test specimens within a part (or plaque) can influence material property test results.~~

~~8.4.1 Areas near the edges of parts should be avoided for test specimen location unless the properties in these areas are specifically desired.~~

~~8.4.2 Areas near or over local geometric conditions such as ribs, bosses, molded holes, corners, and flanges should be avoided for routine material property testing. Test specimens may be taken from these areas when properties are needed for the analysis of these specific geometric conditions.~~

~~8.4.3 Test specimen location within each part should be documented with a drawing or photograph. Each test specimen should be identified so that its location within the original part can be traced. Special identification should be used for test specimens taken from part edges or from an area near or over any local geometric variation.~~

~~8.5 *Number of Test Specimens*—The more test specimens that are used to determine each material property, the less local and~~

TABLE 3 Laminate/Structural Test Methods

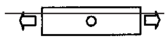
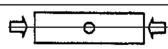
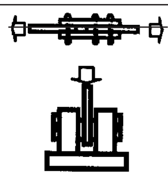
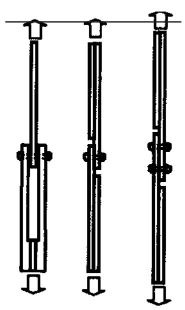
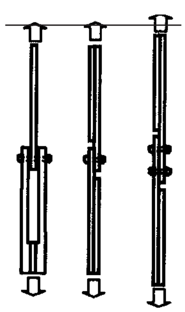
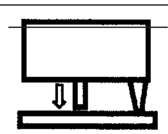
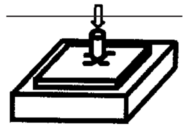
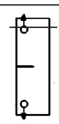
Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
			Notched Laminate Tension Test Methods		
D 5766		Open Hole Tensile Strength	Straight-sided, untabbed, open hole configuration. Procedure nearly equivalent to D 3039.	Limited to multi-directional laminates with balanced and symmetric stacking sequences.	Provides requirements and guidance on specimen configuration and failure modes.
D 6742		Filled Hole Tensile Strength	Straight-sided, untabbed, filled hole configuration. Procedure and specimen nearly equivalent to D 3039, D 5766.	Same as D 5766.	Same as D 5766. Also provides guidance on hole tolerances, fastener torque/preload.
			Notched Laminate Compression Test Methods		
D 6484		Open Hole Compressive Strength	Straight-sided, untabbed, open hole configuration. Fixture can be loaded using either hydraulic grips or end platens.	Limited to multi-directional laminates with balanced and symmetric stacking sequences.	Provides requirements and guidance on specimen configuration and failure modes.
D 6742		Filled Hole Compressive Strength	Straight-sided, untabbed, filled hole configuration. Procedure, specimen and apparatus nearly equivalent to D 6484.	Same as D 6484.	Same as D 6484. Also provides guidance on hole tolerances, fastener torque/preload.
			Bolted Joint Test Methods		
D 953		Static Pin Bearing Strength	One fastener, double shear pin bearing specimen. Two methods available: tensile and compressive pin bearing. Monitors global load versus deformation behavior.	Focus is plastics. Does not account for various fastener geometries, torque/preload levels. Deformation local to hole is not measured.	Some specimen geometric properties (for example, width/diameter ratio) vary from D 5961 guidelines. Not recommended for continuous fiber composites.
D 5961		Static Bearing Strength	One and two fastener double and single shear bearing specimens loaded in tension. Multiple specimen configurations provided to assess a variety of structural joint configurations. Procedures provided to monitor inelastic deformation behavior at hole.	Limited to multi-directional laminates with balanced and symmetric stacking sequences. Response highly dependent upon specimen configuration and fastener torque/preload. Limited to bearing failure modes only. Some details of specimen configurations are not suitable for determining bypass failure strengths.	Provides requirements and guidance on specimen configuration, type of loading, hole tolerances, fastener torque/preload and failure modes.
D 6873		Bearing Stress-Cycles (S-N) Data	Specimen and apparatus equivalent to D 5961, with cyclic loading procedures provided to monitor hole elongation for a variety of joint configurations and fatigue loading conditions.	Same as D 5961. Certain tests may require fastener removal or a variant quasi-static loading ratio to monitor hole elongation.	Same as D 5961. Also provides guidance on fatigue loading ratio effects.
			Static Indentation Test Methods		
D 2583		Indentation Hardness	Provides a relative measure of hardness based upon load versus indentation depth response. Barcol impressor is portable, and load is applied by hand.	Focus is plastics and low-modulus composites. Does not record force versus indentation depth response. Does not evaluate resulting damage state.	Uses flat-tipped indenter.

TABLE 3 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
D 6264		Force-Indenter Displacement Response, Dent Depth, Damage Characteristics	Flat rectangular laminated subject to a static point loading. Permits damage resistance testing of simply-supported and rigidly backed plate specimens. Uses a conventional testing machine. Contact force and indenter displacement data are obtained.	Limited to continuous fiber composites without through-the-thickness reinforcement. Test method does not address dynamic indentation effects. Narrow range of permissible specimen thicknesses.	Uses 12.7 mm (0.50 in.) diameter hemispherical indenter. Often used to approximate the damage state caused by a dynamic impact. Multi-directional fiber laminates with balanced and symmetric stacking sequences are usually used. The damage response is a function of the indentor geometry, support conditions and specimen configuration.
Trans-laminar Fracture Test Methods					
E 1922		Translaminar Fracture Toughness, K_{TL}	Flat rectangular specimen containing an edge notch loaded in tension. Simple test to perform	Results only valid for the particular laminate tested; laminates producing large damage zones do not give valid values	

part to part variations in properties will affect average test results.

8.5.1 A minimum of six test specimens for each material property to be measured is suggested for a nominally planar isotropic material. These six should be from three separate parts with two from each part. Each two should be perpendicularly oriented so that fiber orientation effects are averaged in each part. More test specimens may be required depending on the variability of test data and the desired confidence level in the value of the property being measured.

8.5.2 When testing oriented fiber reinforced materials, at least six test specimens should be used for evaluating both minimum and maximum property values. These six should be from three separate parts with two specimens from each part. More specimens may be necessary for measurement of materials properties to specific statistical levels of confidence.

9. Test Specimen Preparation

9.1 *Test Specimen Machining*—Improper machining of test specimens can cause damage to the material to be evaluated, resulting in inaccurate test results.

9.1.1 The machining technique selected to rough cut and finish cut test specimens should result in smooth cut edges with no delaminations or fiber pull out. Each test specimen should be carefully inspected after machining to assure that the machined edges are smooth and undamaged.

9.1.2 The machining technique selected to rough cut and finish cut test specimens should not overheat the material to be tested. Water cooling may be used to reduce overheating when necessary. However, specimens should be thoroughly wiped dry immediately after machining if water coolant is used. Prolonged exposure to water will lead to moisture absorbtion with a resultant effect on properties of the specimen.

9.1.3 The method of test specimen machining should be documented.

9.1.4 *Health and Safety*—When fabricating composite specimens by machining operations, a fine dust consisting of particles of fibers or the matrix material, or both, may be formed. These fine dusts can be a serious health or safety hazard, or both. Adequate protection should be afforded operating personnel and equipment. This may require adequate ventilation or dust, or both, collecting facilities at a minimum.

9.2 *Test Specimen Handling*—Careless handling of parts and test specimens can cause damage on stresses in the material which are high enough to influence test results.

9.2.1 Parts (or plaques) from which test specimens are to be machined should be handled carefully from molding to test specimen machining. Part shipping, if necessary, should be done in sturdy containers with each part fully supported and separated from other parts.

9.2.2 Test specimens should be carefully handled and stored in containers which will protect them from being damaged.

9.2.3 Parts or test specimens which have been exposed to severe handling should be marked, and the nature of the severe handling conditions should be documented. Test specimens should be discarded if damage as a result of excessive handling can be detected by careful visual examination.

9.3 Test specimens may be molded to the required geometry, eliminating the need for machining. Molded specimens do not give the same results as machined specimens because of surface effects.

TABLE 4 Constituent/Precursor/Thermophysical Test Methods

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
			Reinforcement Property Test Methods		
D 3800		Fiber Density	Test method for density of high-modulus continuous and discontinuous fibers.		
D 4018		Carbon Fiber Tow Properties: -Tensile Modulus -Tensile Strength -Density -Mass per Unit Length -Sizing Content -Moisture Absorption	Provides test methods for continuous filament carbon and graphite yarns, rovings and tows. Tensile properties are determined using resin-impregnated fiber.	Tensile testing requires careful specimen preparation. The resin used to impregnate the fibers can affect the tensile test results.	
D 4102		Fiber Weight Loss	Test method for determining weight loss of carbon fibers exposed to hot ambient air. Exposure conditions are: -24 h at 375°C (707°F). -500 h at 315°C (600°F).		Determines oxidative resistance of carbon fibers for use in high-temperature applications.
			Matrix (Resin) Physical Property Test Methods		
D 792		Density	Test method for density of plastics using immersion methods. Ease of test specimen preparation and testing.	Some specimens may be affected by water; alternate immersion liquids are optional.	
D 1505		Density	Test method for density of plastics using density gradient method.		Typically used for film and sheeting materials
D 2471		Gel Time	Test method for determining gel time and peak exothermic temperature of reacting thermosetting resins		Used for testing neat resins. For composite prepregs, see D 3532 below.
D 4473		Cure Behavior	Test method for cure behavior of plastics by measuring dynamic mechanical properties.		
			Extent of Cure Test Methods		
D 3531		Resin Flow	Test method for resin flow of prepreg tape or sheet using square 2-ply specimen heated in a platen press.	Limited to carbon fiber-epoxy prepreg materials.	
D 3532		Gel Time	Test method for gel time of prepreg tape or sheet	Limited to carbon fiber-epoxy prepreg materials.	
			Constituent Content Test Methods		
C 613		Constituent Content	Test method for Soxhlet extraction procedure to determine the matrix content, reinforcement content, and filler content of composite material prepreg.	Limited to prepreg materials.	Not suitable for cured composites.
D 3171		Fiber, Resin, Void Content	Test method for fiber, resin, and void content of resin-matrix composites by either digestion of the matrix or by thickness of a material of known fiber areal weight (void content not determined). Includes methods for metal matrix composites as well.		The resin digestion methods are primarily intended for cured thermoset matrices but may also be suitable for some thermoplastics as well as prepreg resin content for materials that do not respond well to other methods.

TABLE 4 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
D 3529		Resin Content	Test method for matrix solids content and matrix content using extraction by organic solvent.	Limited to prepreg materials. Resins that have started to cross-link (for example, B-staged resins) may be difficult to extract; D 3171 methods are recommended for these materials. Does not determine or require reporting of reinforcement content.	Not suitable for cured composites.
D 3530		Volatiles Content	Test method for volatiles content of epoxy-matrix prepreg tape and sheet	Limited to prepreg materials. Limited to reinforcement material types which are substantially unaffected by the temperature selected for use in removing volatiles from the matrix material.	Not suitable for cured composites.
D 2734		Void Content	Test methods for void content of reinforced plastics. Ease of test specimen preparation and testing.	Limited to composites for which the effects of ignition on the materials are known. May not be suitable for reinforcements consisting of metals, organic materials, or inorganic materials that may gain or lose weight. The presence of filler in some composites is not accounted for.	D 3171 is preferred for advanced composites. Void content of less than 1 % is difficult to measure accurately.
D 2584		Resin Content	Test method for ignition loss of cured reinforced resins. Ease of test specimen preparation and testing.	The presence of filler in some composites is not accounted for.	D 3171 is preferred for advanced composites. Result may be used as resin content under specified limitations.
Thermo-Physical Test Methods					
D 696		Thermal Expansion versus Temperature Curves, Coefficients of Thermal Expansion	Test method for linear thermal expansion of plastic materials having coefficients of expansion greater than 1×10^{-6}/°C by use of a vitreous silica dilatometer. Ease of test specimen preparation and testing. Suitable for random and continuous fiber composites.	Limited to temperature range of -30°C to 30°C. Use E 228 for other temperatures.	This test method cannot be used for very low thermal expansion coefficient materials, such as unidirectional graphite fiber composites.
E 228		Thermal Expansion versus Temperature Curves, Coefficients of Thermal Expansion	Test method for linear thermal expansion over the temperature range of -180 to 900°C using vitreous silica push rod or tube dilatometers. Suitable for discontinuous or continuous fiber composites of defined orientation state.		Good for low values of thermal expansion. Precision greater than for D 696. Precision significantly lower than for E 289.
E 289		Thermal Expansion versus Temperature Curves, Coefficients of Thermal Expansion	Test method for linear thermal expansion of rigid solids using either a Michelson or Fizeau interferometer. Suitable for composites with very low values of thermal expansion.		Precision is listed as better than +40 nm/m/K.

TABLE 4 *Continued*

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
E 1461		Thermal Diffusivity	Uses laser flash technique.		With specific heat measurement, can be used to calculate thermal conductivity indirectly.
E 1269		Specific Heat	Uses Differential Scanning Calorimetry.		
Transition Temperature Test Methods					
D 648		Heat Deflection Temperature	Test method for determining temperature at which an arbitrary deformation occurs when specimen is subjected to an arbitrary set of testing conditions. Ease of test specimen preparation and testing.	Deflection temperature is dependent on specimen thickness and fiber reinforcement variables.	Test data used for material screening. Test data is not intended for design purposes.
D 3418		Glass Transition Temperature (Tg)	Test method for determination of transition temperatures of polymers by differential thermal analysis or differential scanning calorimetry (DSC). Ease of test specimen preparation and testing.	Not suitable for composites with low resin content.	The correlation between thermally measured transition temperatures and mechanical property transitions has not been suitably established.
D 4065		Transition Temperatures, Elastic Moduli, Loss Moduli	Practice for determining the transition temperatures, elastic, and loss moduli of plastics over a range of temperatures, frequencies, or time, by free vibration and resonant or nonresonant forced vibration techniques. Can use variety of test specimen geometries and loading methods.	Requires specialized equipment.	For best results, tests should be run on unreinforced resin.

10. Test Specimen Conditioning

10.1 *Pretest Conditioning*—Proper pretest conditioning of test specimens assures more uniform and consistent moisture content.

10.1.1 Test specimens should be conditioned in a room or enclosed space maintained at 23 ± 1°C (73.5 ± 1.8°F) and 50 ± 10 % relative humidity for such time as necessary to attain prescribed equilibrium temperature and moisture conditions before testing in accordance with Procedure A of Practice D 618. Conditioning for other conditions of temperature and moisture are carried out similarly. Moisture diffusion constants are small and most materials take weeks or months to approach moisture equilibrium with uniform moisture content through the thickness.

NOTE 1—A useful condition for determining a prescribed moisture concentration is defined by a relation:

$$\%M = (W_f - W_i)/W_i \times 100$$

where:

W_f = final or present weight of the sample,
W_i = initial weight of the sample, and
M = moisture content.

This condition defines moisture content in terms of percent moisture content by weight. When M is constant on successive measurements, the sample is defined as being in equilibrium. Under this condition of equilibrium, the moisture profile through the thickness may not be uniform. For tests that are sensitive to the moisture variation in the sample, a more stringent equilibrium condition must be defined.

10.1.2 Pretest conditioning should be documented for each test specimen.

10.2 *Test Temperature Conditioning*— Test specimens should be exposed to their test temperatures just long enough to assure a uniform temperature throughout the thickness of the specimen.

10.2.1 The thickness of the test specimens will affect the time required to condition the specimens. A nominal conditioning time of 15 ± 5 min is sufficient for specimens under 7 mm (0.25 in.) thick.

TABLE 5 Environmental Conditioning/Resistance Test Methods

Test Method	Specimen	Measured Property	Description and Advantages	Disadvantages	Comments
Equilibrium Moisture Content/Conditioning Test Methods					
D 5229		Through-Thickness Moisture Diffusivity, Equilibrium Moisture Content, Equilibrium Conditioning	Rigorous determination of moisture equilibrium for various exposure levels (including dry) as well as moisture absorption constants. Used for conditioning test coupons prior to use in other test methods	Requires long-conditioning times for many materials. Assumes 1-D Fickian behavior for material absorption constant determination.	A faster two-specimen approach documented in MIL-HDBK-17 has not yet been included in this standard.
Non-Equilibrium Conditioning Test Methods					
D 618		None.	Test method for conditioning plastics prior to test.	No standard mechanical tests are specified. Weight gain is not monitored.	Not recommended for conditioning composites.
Chemical Resistance Test Methods					
C 581		Changes to: Hardness, Weight, Thickness, Specimen Appearance Appearance of Immersion Media, Flexural Strength, Flexural Modulus.	Test method for chemical resistance of thermosetting resins. Ease of test specimen preparation and testing. Flexible exposure conditions.	The only mechanical tests specified are flexural. Weight gain is not monitored. No standard exposure times or temperatures are specified.	Exposure chemicals, times, temperatures are left to the user's discretion.
D 543		Changes to: Weight, Thickness, Specimen Appearance Tensile Strength, Tensile Modulus.	Practices for evaluating the resistance of plastics to chemical reagents. Standard exposure time and temperature set as a starting point.	The only mechanical loading type specified is tensile; others are optional	Longer exposure times may be desirable. Other mechanical loading types may be specified.

10.2.2 Time at test temperature before testing should be documented for each test specimen.

11. Report of Results

11.1 *Standard Reporting*—All of the normal reporting requirements of the standard used for testing should be followed.

11.2 *A/I Composites Reporting*—Sections 7-10 covered the special considerations for testing of A/I 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 dimensions.

11.2.1.3 Fiber surface treatment.

11.2.1.4 Fiber content.

11.2.1.5 Fiber orientation state.

11.2.1.6 Filler type.

11.2.1.7 Filler dimensions.

11.2.1.8 Filler surface treatment.

11.2.1.9 Filler content.

11.2.1.10 Resin type.

11.2.1.11 Resin components.

11.2.1.12 Resin content.

11.2.1.13 Resin state of cure.

11.2.1.14 Void content.

11.2.2 *Process Documentation*:

11.2.2.1 Compound preparation.

11.2.2.2 Charge preparation.

11.2.2.3 Molding technique.

11.2.2.4 Molding temperature.

11.2.2.5 Molding pressure.

11.2.2.6 Molding time.

11.2.3 *Part or Plaque Documentation* :

11.2.3.1 Part or plaque dimensions.

11.2.3.2 Part or plaque source.

11.2.4 *History Documentation*:

11.2.4.1 Molding date.

11.2.4.2 Machining date.

11.2.4.3 Testing date.

11.2.4.4 Load history.

11.2.4.5 Environmental history.

11.2.5 *Sampling Documentation*:

11.2.5.1 Number of parts.

11.2.5.2 Location of specimens.

11.2.5.3 Orientation of specimens.

11.2.5.4 Number of specimens.

11.2.6 *Test Specimen Documentation* :

11.2.6.1 Machining technique.

11.2.6.2 Machined edge condition.

11.2.7 *Pretest Conditioning Documentation* :

11.2.7.1 Time at 23 ± 1°C (73.4 ± 1.8°F) before testing.

11.2.7.2 Time at test temperature.

12. Test Method Comparison

12.1 Applicable test methods for frequently evaluated properties of automotive/industrial composites are compared in this section. The comparison are summaries and are in tabular form. Listed advantages, disadvantages, and comments are limited to the three most important for each test method.

12.2 It is not the intent of this comparison to cover all the test methods that could possibly be used for automotive/industrial composites. Only the most applicable ASTM International standard test methods for the most commonly evaluated properties are included. Additional details on the included test methods can be found in the *Annual Book of ASTM Standards*.

12.3 *Health and Safety*—When testing composite materials, it is possible to store enough energy in the test specimen to produce dangerous levels of force on rupture. This can create small high velocity particles and a dust consisting of fractured fibers and matrix materials. The particles and fine dust can create a serious health or safety hazard, or both. Adequate protection should be afforded operating personnel, bystanders and the equipment. This may require shielding or dust collection facilities, or both, at a minimum.

12.4 *Test Methods for Mechanical Properties*

TABLE 1 Tensile Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 638	Ease of test specimen preparation.	Stress concentration at the radii. Unsuitable for highly oriented fiber composites.	Should not be used for oriented fiber composites.
D 3039	Suitable for both random and oriented fiber composites.	Stress concentrations at the end tabs. End tab machining and bonding required.	...

TABLE 2 Compression Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 695	Strain gages not required for modulus. Test specimen width may be varied.	Failure mode may be end crushing. Stress concentrations at radii. Specimen ends must be accurately machined.	Should not be used for highly oriented fiber composites.

D 3410	Accurate alignment assured by test fixture. Suitable for random and oriented fiber composites.	End tab machining and bonding required. Strain gages required for modulus. Constant test specimen width required.	The addition of the IITRI compression test method to this standard eliminates the constant test specimen width requirement.

TABLE 3 In-Plane Shear Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 4255	Suitable for both random and oriented fiber composites.	Difficult test to run. Poor reproducibility. Stress concentrations at gripping areas.	This is a standard guide and not a standard test method.

TABLE 4 Through-The-Thickness Shear Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 3846	Suitable for random and oriented fiber composites.	Stress concentrations at notches.hear modulus cannot be measured.	...
D 2344	Ease of test specimen preparation. Ease of testing.	Stress concentrations and high secondary stresses. Suitable only for unidirectional and fabric fiber composites.Shear modulus cannot be measured.	This test method should only be used for unidirectional fiber composites. This test should not be used to generate design numbers.

TABLE 5 Flexural Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 790	Ease of test specimen preparation. Ease of testing.	Stress concentrations and secondary stresses at loading points. Results sensitive to specimen and loading geometry. Varying failure modes.	Flexural tests are structural tests, not material property. Failure mode may be tension, compression, shear, or combination.

12.5 *Test Methods for Fatigue Properties*

TABLE 6 Tensile Fatigue Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 638 specimen in fatigue	Ease of test specimen preparation.	Stress concentrations at the radii. Unsuitable for highly oriented fiber composites. Not an ASTM International standard test method.	...
D 3479	Suitable for both random and oriented fiber composites.	Stress concentrations at the end tabs. End tab machining and bonding required.	...

TABLE 7 Compression Fatigue Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 695 specimen in fatigue	Strain gages not required for modules.	Stress concentrations at radii. Failure mode may be crushing. Not an ASTM International standard test method.	This test specimen should not be used for highly oriented fiber composites.
D 3410 specimen in fatigue	Accurate alignment is assured by test fixture. Suitable for random and oriented fiber composites.	Stress concentrations at the end tabs. End tab machining and bonding required. Not an ASTM International standard test method.	...

12.6 *Test Methods for Environmental Resistance Properties*

TABLE 8 Flexural Fatigue Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 671	...	Stress concentrations at notches. Results sensitive to specimen thickness. Not suitable for oriented fiber composites.	This test method should not be used for oriented fiber composites. Flexural tests are structural tests, not material property tests.

D 790 specimen in fatigue	Ease of test specimen preparation. Ease of testing. Suitable for random and oriented fiber composites.	Secondary stresses at load introduction points. Results sensitive to specimen and loading geometry. Not an ASTM International standard test method.	Flexural tests are structural tests, not material property tests.

TABLE 9 Moisture Resistance Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 618	...	No standard mechanical tests are specified. Weight gain is not monitored.	...
D 756	...	No standard mechanical tests are specified. Exposure times are short.	...

TABLE 10 Chemical Resistance Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
C 581	Ease of test specimen preparation and testing. Flexible exposure conditions.	The only mechanical tests specified are flexural and weight gain is not monitored. No standard exposure times or temperatures are specified.	Exposure chemicals, times, temperatures are left to the user's discretion.
D 543	Standard exposure time and temperature set as a starting point.	The only mechanical test specified is tensile, others are optional. No automotive fluids are specified.	Longer exposure times may be desirable. Other mechanical ests may be specified.

12.7 *Test Methods for Creep Properties*

TABLE 11 Tensile Creep Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 2990	Ease of test specimen preparation.	Stress concentrations at specimen radii. Unsuitable for highly oriented fiber composites.	The test specimens specified in this standard should not be used for highly oriented fiber composites.

TABLE 12 Flexural Creep Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 2990	Ease of test specimen preparation. Ease of testing.	Stress concentrations and secondary stresses at loading points. Results sensitive to specimen and loading geometry. Failure mode may vary.	Flexural tests are structural tests, not material property tests.

12.8 *Test Methods for Thermal Properties*

TABLE 13 Thermal Expansion Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 696	Ease of test specimen preparation and testing. Suitable for random and oriented fiber composites.	...	This test method cannot be used for very low thermal expansion coefficient materials, such as unidirectional graphite fiber composites.
E 228	Suitable for discontinuous or continuous fiber composites of defined orientation state.	...	Good for low values of thermal expansion.

TABLE 14 Transition Temperature Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 648	Ease of test specimen preparation and testing.	Deflection temperature is dependent on specimen thickness and fiber reinforcement variables.	Test data is not intended for design purposes.
D 3418	Ease of test specimen preparation and testing.	Not suitable for composites with low resin content.	The correlation between thermally measured transition temperatures and mechanical property transitions has not been suitably established.
D 4065	Can use variety of test specimen geometries and loading methods.	Required specialized equipment.	For best results, tests should be run on the unreinforced resin.

12.9 *Test Methods for Physical Properties*

TABLE 15 Specific Gravity Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 792	Ease of test specimen preparation and testing.	Some specimens may be affected by water.	...

TABLE 16 Fiber/Filler/Resin Content Test Method Comparison

Test Method	Advantages	Disadvantages	Comments

D 2584	Ease of test specimen preparation and testing.	The presence of filler in some composites is not accounted for.	...

TABLE 17 Void Content Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 2734	Ease of test specimen preparation and testing.	The presence of filler in some composites is not accounted for.	Void content of less than 1 % is difficult to measure accurately.

12.10 *Test Methods for Impact Properties*

TABLE 18 Tensile Impact Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 1822	Relatively inexpensive test machine.	Stress concentrations at the radii. Very small test specimens. Not instrumented.	This test method should not be used or highly oriented fiber composites.
D 2289	Instrumented.	Stress concentrations at radii. Not suitable for highly oriented fiber composites.	This test method should not be used for highly oriented fiber composites.

TABLE 19 Flexural Impact Test Method Comparison

Test Method	Advantages	Disadvantages	Comments
D 256	Flexibility in methods.	Not instrumented. Varying failure modes. Sensitive to test specimen geometry variations.	This test provides a structural impact property, not a material impact property.

13. Keywords

13.1 automotive/industrial;

8.1 bearing strength; coefficient of thermal expansion; composite materials; composites; compression; compressive strength; constituent content; crack-growth testing; creep; creep strength; CTE; curved-beam strength; damage; data recording; data records; delamination; density; elastic modulus; fatigue; fiber; fiber volume; filament; filled-hole compression strength; filled-hole tensile strength; flatwise tensile strength; flexural modulus; flexure; fracture; fracture toughness; gel time; glass transition temperature; hoop-wound; impact; impact strength; lamina; laminate; matrix content; mixed mode; mode I; mode II; mode III; modulus of elasticity; moisture content; moisture diffusivity; Poisson's ratio; OHC; OHT; open-hole compressive strength; open-hole tensile strength; out-of-plane compressive strength; out-of-plane shear strength; out-of-plane tensile strength; panel; plate; polymer matrix composites; prepreg; reinforcement; reinforcement content; reinforcement volume; resin; resin content; shear; shear modulus; shear strength; short-beam strength; specific heat; strain energy release rate; strength; structure; tensile strength; tension; thermal conductivity; thermal diffusivity; thermal expansion coefficient; tow; V-notched beam strength; void content; winding; yarn