DEVELOPMENT OF STANDARD TEST METHODS FOR SANDWICH COMPOSITES UNDER ASTM COMMITTEE D30

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SUMMARY

Sandwich composite standard test methods developed by ASTM D30 Committee on Composite Materials are discussed. Technical attributes of new and revised D30 sandwich standards are detailed to aid the international composites community in the selection and utilization of sandwich test methods. Ongoing sandwich test method development activities are described.

Keywords: sandwich, composites, test methods, ASTM

INTRODUCTION

ASTM D30 Committee on Composite Materials has developed 20 internationally recognized standards for the assessment of physical and mechanical properties of sandwich composites. Within the past decade, the D30 subcommittee responsible for sandwich standards (D30.09) has revised the majority of its documents, and has developed six new test methods for sandwich composites. The purpose of this paper is to discuss the technical attributes of D30 sandwich standards, to aid the international composites community in the selection and utilization of sandwich test methods.

ASTM D30 COMMITTEE OVERVIEW

D30 is one of over 130 technical committees which comprise ASTM International, a worldwide volunteer organization that develops full-consensus standards for materials, products, systems and services. Formed in 1898, ASTM International is composed of more than 32,000 members from 125 countries, and administers, publishes and distributes over 12,000 standards.

Committee D30 was formed in 1964 (with heritage from Committee D20 on Plastics), and is comprised of approximately 230 members representing composite structure developers/OEMs, testing laboratories, composite material suppliers, component fabricators, academic and research institutions, government and certification agencies. D30 has significant and active participation from the aerospace, marine and civil infrastructure industries. The committee develops standard test methods, practices, terminology and guides (but does not develop standard specifications).

D30 is organized into eight subcommittees, six of which develop and maintain standards. D30.09 Subcommittee on Sandwich Construction is responsible for those standards used to assess properties of sandwich structure constituent materials, as well as the characteristics of integrated sandwich constructions.

D30.09 SANDWICH STANDARDS

Currently, D30.09 has 20 standards published as shown in Table 1; these can be divided into two groups: core material standards and sandwich structure standards. Thirteen of these standards (those with the "C" designation) originated in historical Committee C19 on Structural Sandwich Constructions; the earliest of these (C 271) was first published in 1951. Subsequently, these standards were transferred for a period into Committee F7 on Aerospace Industry Methods which developed F 1645, then were transferred into the jurisdiction of D30 in 2000.

Table 1: ASTM D30.09 Core Material and Sandwich Structure Standards

Designation	Publication Date	Focus Area/ Property Assessed
Core Material Standards		
C 271/C 271M	2005	Core Density
C 272	2007	Core Water Absorption
C 273/C 273M	2007	Core Shear Properties
C 363	2000	Honeycomb Core Node Tensile Strength
C 365/C 365M	2005	Core Flatwise Compressive Properties
C 366/C 366M	2005	Core Thickness Measurement
C 393/C 393M	2006	Core Shear Properties by Beam Flexure
C 394	2008	Core Shear Fatigue
D 6772	2007	Core Dimensional Stability
D 6790	2007	Honeycomb Core Poisson's Ratio
D 7336/D 7336M	2007	Honeycomb Core Static Energy Absorption
F 1645/F 1645M	2007	Honeycomb Core Water Migration
Sandwich Structure Standards		
C 274/C 274M	2007	Sandwich Terminology
C 297/C 297M	2004	Sandwich Flatwise Tensile Strength
C 364/C 364M	2007	Sandwich Edgewise Compressive Strength
C 480	2008	Sandwich Flexural Creep
C 481	2005	Sandwich Laboratory Aging
D 6416/D 6416M	2007	Sandwich 2D Plate Flexural Properties
D 7249/D 7249M	2006	Sandwich Facing Properties by Beam Flexure
D 7250/D 7250M	2006	Practice for Sandwich Beam Flexural & Shear Stiffness

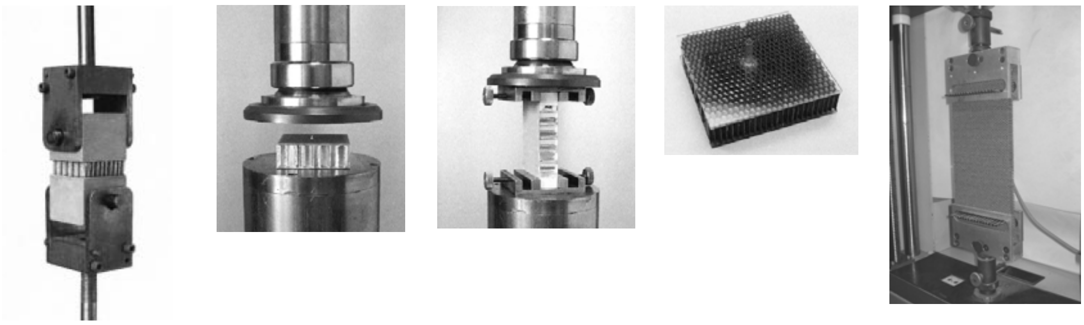
A concise overview for each of these sandwich test methods is provided in the D 4762 Standard Guide to Testing Polymer Matrix Composite Materials. This document summarizes the scope, advantages, and disadvantages of related D30 standards, as well as other commonly referenced related standards from other ASTM committees. The latest revision to D 4762 was published in 2008, so the guide contains up-to-date guidance on the selection and use of sandwich test methods.

RECENT REVISIONS TO HISTORICAL STANDARDS

ASTM standards are “living documents” in that organizational regulations require review and re-approval of standards over time. Standards are continually revised to meet stakeholder needs and to incorporate technological advancements. Accordingly, D30.09 has revised its historical sandwich standards to be consistent in format and content with heritage D30 composite standards. Within the past five years, eight standards (C 271, C 273, C 297, C 364, C 365, C 366, C 393 and F 1645) underwent substantial revision and reformatting, with key changes including:

- conversion into dual unit (SI and inch-pound) standards
- revision of scope to define applicable core material forms
- addition of sections on terminology, interferences, sampling, calibration, validation and reporting
- addition of reference sampling rates and minimum number of data points for digital data recording, when appropriate
- revision of preconditioning requirements to provide the test requester with greater flexibility to define requirements for his/her test

Along with these common changes, individual standards have incorporated significant technical revisions. Photographs exhibiting revised test methods are shown in Figure 1.



Flatwise Tension | Flatwise Compression | Edgewise Compression | Water Migration | Honeycomb Node Tensile Strength

Figure 1: Recently revised D30.09 sandwich test methods.

Sandwich Flatwise Tension

The 2004 publication of C 297/C 297M incorporated two major technical changes compared to the 1999 version. First, requirements for the minimum facing area of the specimen were clarified to differentiate between cores with continuous bonding surfaces (e.g. foams, balsa wood) and discontinuous bonding surfaces (e.g. honeycomb). For cores with discontinuous bonding surfaces, the minimum facing area is defined so that a minimum number of cells are included in the test specimen. Second, a figure was added to define permissible geometric tolerances of the bonded test assembly.

While addition of assembly tolerances has succeeded in reducing test variation over the past five years, feedback from industry has indicated that the specified core edge tolerance (relative to the bonding blocks) of ± 0.025 mm is too stringent for honeycomb core materials. In 2009, D30.09 will initiate a work item to revise C 297/C 297M to provide a relaxed edge tolerance for honeycomb cores. The current tolerance will be maintained for other core types (such as foam) which exhibit greater sensitivity to edge effects.

Core Flatwise Compression

Technical modifications to C 365/C 365M for core flatwise compression published in 2005 were primarily associated with procedures for calculating flatwise compressive core modulus. These included guidance on the use of stabilized and unstabilized specimens, along with recommendations for permissible displacement-monitoring devices (test machine, LVDT or compressometer). To avoid having "toe" regions in the force vs. displacement response influence modulus calculations, recommendations were added to keep the core thickness variation within ±0.05% of the nominal core thickness when testing for compressive modulus.

Sandwich Edgewise Compression

The 2007 revision of C 364/C 364M for sandwich edgewise compression included improved definition of specimen geometry and tolerances to promote desirable failure modes, along with enhanced guidance on the characterization of commonly observed failure modes.

Honeycomb Core Water Migration

Test method F 1645/F 1645M is used to determine the rate of water migration within honeycomb core materials. A single cell in a core sample is filled with water, and is subjected to a constant hydrostatic pressure by maintaining a specified water column height. The amount of water transferred into the honeycomb core (primarily due to diffusion through the cell walls) within a 24-hour period is determined.

In 2007, a revision was published, which tightened requirements for maintaining the head of water throughout the test (within ±0.5%) to keep the water pressure consistent in the primary core cell. To enable this, requirements for the accuracy of equipment used to measure the mass, volume and column height of water during the test were clarified. Guidelines for reporting the number of cells that become filled with water were also improved.

Honeycomb Core Node Tensile Strength

Committee D30 recently approved an extensive revision to C 363 in March 2009. Previously entitled as "Delamination Strength of Honeycomb Core Materials," the title of the standard was changed to better reflect the failure mode that the test is designed to assess ("delamination strength" might imply that the facing-to-core bond interface is assessed). Enhanced guidance and requirements for test apparatus, measurement equipment, specimen geometric tolerances, speed of testing, and data reporting were added to the standard.

NEW SANDWICH STANDARDS

In addition to maintaining and revising existing standards, the membership of D30.09 is active in developing new standards based upon the needs expressed by the international composites community. Since 2001, six new standards have been published, which cover core properties and structural sandwich properties not previously addressed. Associated with these new standards was a major revision to one of the most commonly used D30.09 standards, C 393 for long beam flexure.

Sandwich Beam Flexure

C 393 for sandwich beam flexure was originally published in 1957, and has a long history of use throughout the composites industry. Through 2005, the test method scope included the determination of sandwich flexural stiffness, sandwich shear stiffness, core shear strength and facing strength. Multiple loading conditions (e.g. 3-point and 4-point bending) were permitted, and little guidance was provided on the selection of a specimen design and test configuration to attain specific property data or achieve a failure mode of interest. These conditions led to difficulties throughout the industry in comparing data generated using this “standard” test method.

Under the leadership of Stephen Ward (SW Composites), a significant effort was undertaken in 2004 to improve the procedures and data reduction associated with the sandwich flexure test method. The result of this effort was a major revision to C 393, and the development of two new standards.

The 2006 edition of C 393/C 393M limited the scope of the standard to cover the determination of the core shear strength and stiffness properties only. The standard loading fixture was established as a 3-point configuration (“short” beam) of defined support span (150 mm). Data reduction procedures for additional 4-point configurations are provided, but these configurations are considered as non-standard (these were retained for historical purposes). Recommended loading pad/bar geometries and materials were added to the standard, as were guidelines for specimen design to promote core shear or core-to-facing bond failure (and to avoid facing failures).

A complimentary standard, D 7249/D 7249M, was also published in 2006. The scope is limited to the determination of facing stiffness and strength properties. The standard loading fixture was established as a 4-point configuration (“long” beam) of defined specimen length (600 mm), width (75 mm), support span (560 mm) and load span (100 mm), as shown in Figure 2. Data reduction procedures for additional 3-point and 4-point configurations are provided for historical purposes. Apparatus and procedures are analogous to those in C 393/C 393M. Guidelines on specimen design are included to promote facing failures (and to avoid core shear and core-to-facing bond failures).

Concurrently, a new standard practice (D 7250/D 7250M) was published to aid the determination of sandwich stiffness properties using flexural test data. If the facing modulus is known, the sandwich transverse (through-thickness) shear rigidity and core shear modulus can be calculated using deflection data from a single C 393/C 393M flexure test. Alternatively, sandwich flexural stiffness, shear rigidity and core shear modulus can be calculated using deflection and/or strain data obtained from two or more tests conducted using different loading configurations (either C 393/C 393M and/or D 7249/D 7249 can be utilized). Standard data reduction methods are provided for multiple loading configurations.

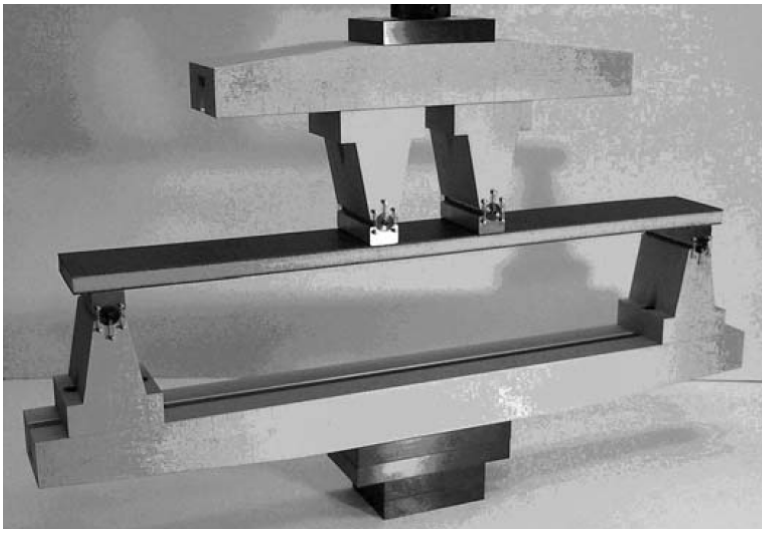


Figure 2: ASTM D 7249 test setup for sandwich facing properties generation.

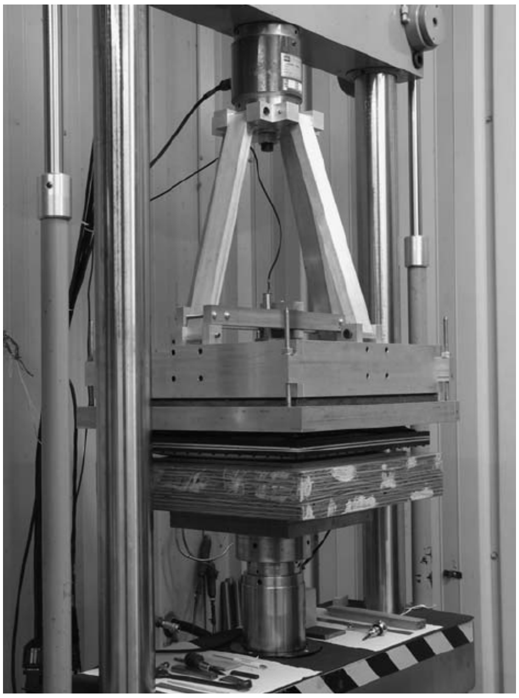
Sandwich Plate Flexure

Based upon an emerging need for a standard test method to simulate the hydrostatic loading of marine sandwich composite hulls, D30 published a new test method under the leadership of William Bertelsen (Gougeon Brothers Inc.). The hydromat test method standardized in D 6416/D 6416M determines the two-dimensional flexural stiffness and strength properties of sandwich composite plates subjected to a distributed out-of-plane load.

The procedure tests a square panel, simply-supported on four sides, that is uniformly loaded over a portion of its surface using a water-filled bladder (see Figure 3). The bladder contact area has a readily definable geometric shape. Surface pressure is increased by moving the test frame, which compresses the bladder against the panel surface. Panel deflection, surface strains and bladder pressure are measured continuously throughout the test.

The test method contains multiple loading procedures. First, procedures are provided using a steel plate of defined geometry to ensure that the fixture and bladder loading are appropriately calibrated prior to panel test. Once the test panel is installed in the fixture, an initial loading is conducted to determine a fixture assembly fastener torque level that corresponds to simply supported boundary conditions at the panel edges. Subsequent loadings are used to determine the load/pressure vs. displacement response of the panel under small deflections, as well as the initial failure strength of the panel. Acceptable failures initiate at a distance of least one panel thickness from a supported edge.

As simply supported boundary conditions are used, the in-situ bending and shear stiffnesses of the sandwich panel can be determined using a close-form solution [1]. The solution currently published in the standard assumes the facings are of equal thickness and isotropic, and that the core is isotropic. D30.09 is developing an electronic adjunct for the standard to enable calculation of bending and shear stiffnesses for orthotropic facings.



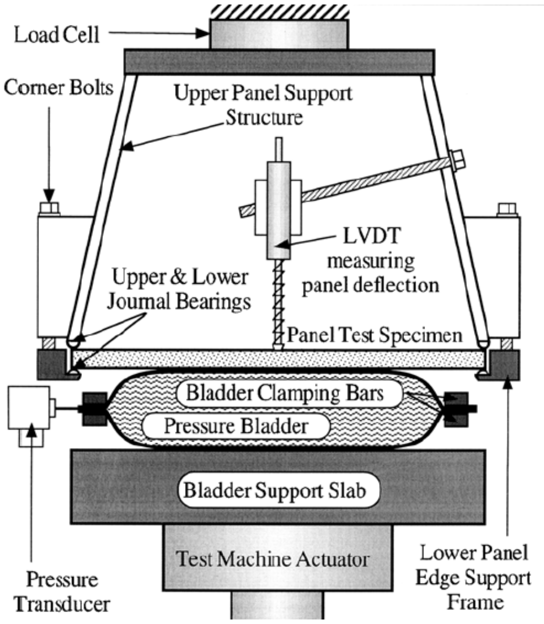
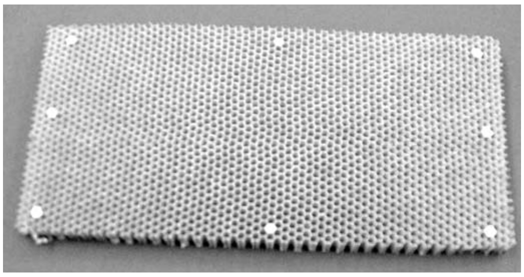


Figure 3: Two-dimensional plate flexure test apparatus.

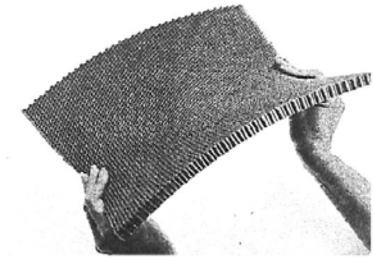
Core Dimensional Stability and Poisson's Ratio

Under the leadership of Thomas Bitzer (Hexcel), two new standards were published in 2002 that address characteristics of core materials used in sandwich constructions. Test method D 6772 covers the determination of core dimensional stability in the two plan dimensions, which is a concern during part fabrication when the core is heated. A sample of core is weighed, marked in eight locations (using potting for honeycomb cores as required, see Figure 4) and measured in the longitudinal (ribbon) and transverse directions. The core is heated to a representative curing temperature (173°C), held at temperature for a specified period, cooled to room temperature and re-measured. The dimensional changes at the eight locations are reported as a percentage of the initial measured dimensions.

Test method D 6790 is used to determine the Poisson's ratio of honeycomb core materials. A flat square sample of core is bent around a cylinder of known radius (610 mm is recommended), making sure the specimen remains in contact with the cylinder along its centerline. Using a straightedge that spans the specimen, depth and chord measurements are taken, and then used to calculate the anticlastic curvature radius of the core (see Figure 4 for an example of anticlastic behavior). The Poisson's ratio is then calculated by dividing the cylinder radius by the anticlastic curvature radius.



Dimensional Stability (D 6772)



Poisson’s Ratio (D 6790)

Figure 4: Core dimensional stability and Poisson’s ratio tests.

Core Energy Absorption

Early in the past decade, D30.09 began the development of a new standard test method to generate core properties used in crash simulation analyses for energy-absorbing sandwich structures. In 2007, Committee D30 published D 7336/D 7336M, which is used to determine the static compressive crush stress and crush stroke properties of honeycomb core materials.

The test method is based upon C 365/C365M specimen geometry, apparatus and procedures, as shown in Figure 5. However, the standard is limited to testing of unstabilized honeycomb core materials; it is not intended for testing of stabilized core specimens or honeycomb sandwich constructions.

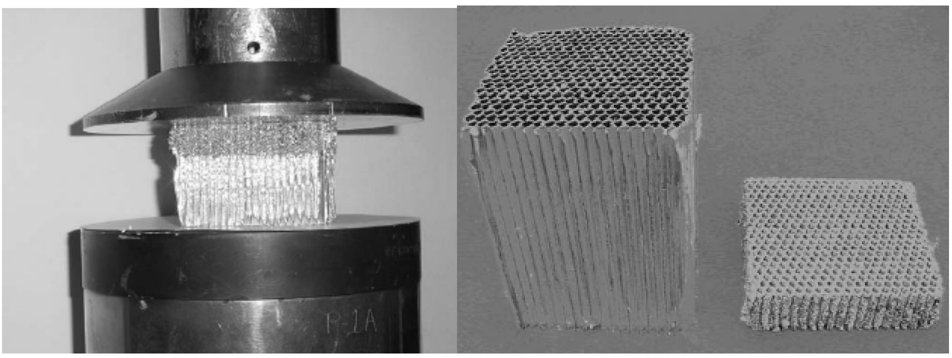


Figure 5: ASTM D 7336 test setup for honeycomb core crush properties generation.

Compressive force is applied to the specimen past the initial failure force, crushing the honeycomb core material under continuous displacement. Apparatus and procedures are provided for pre-crushing the specimen, as pre-crushed specimens tend to exhibit greater uniformity of data than do non pre-crushed specimens. Use of serrated plates capable of providing a relatively uniform pre-crush depth of 1.0 ± 0.5 mm is required.

Force vs. displacement data are used to determine the crush stress and crush stroke (see Figure 6). It is noted that dynamic crush properties may vary from those obtained under static loading, depending upon the core thickness, density and impact velocity.

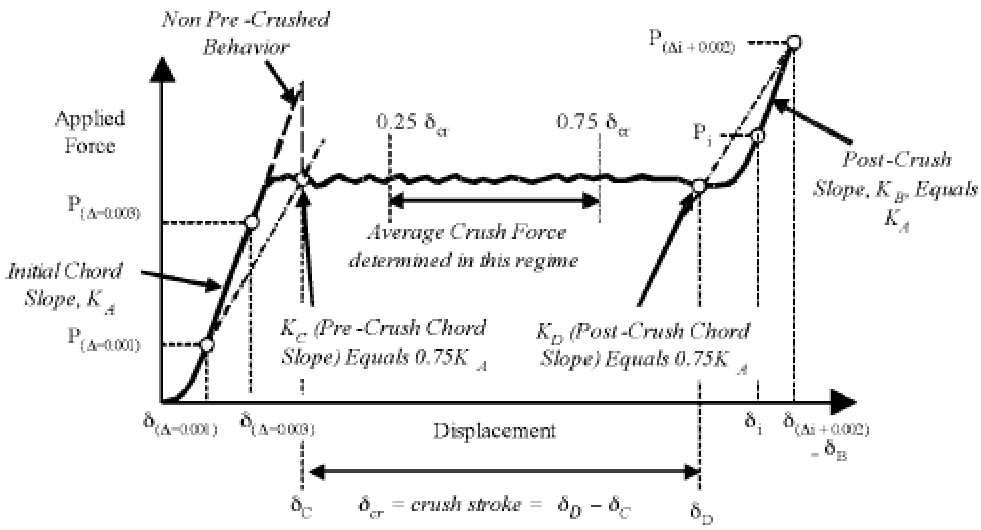


Figure 6: ASTM D 7336 definitions describing crush force vs. displacement/deflection.

CURRENT STANDARDS DEVELOPMENT EFFORTS

In 2009, D30.09 is continuing to support the development of new sandwich standards by guiding ongoing research and test maturation efforts in the areas of core-to-facing cleavage, durability, damage resistance and damage tolerance. Additionally, D30.09 plans to support the standardization of sandwich test methods for the civil infrastructure composites industry.

Core-to-Facing Cleavage

Two D30.09 members, Dr. Daniel Adams (University of Utah) and Dr. James Ratcliffe (National Institute of Aerospace), are performing research to develop a new standard test method for facing cleavage properties of sandwich panels. Facing cleavage is defined as disbond of the facesheet from the core material. Current efforts are focused on evaluating candidate Mode I and Mode II fracture toughness test methods, identifying the most promising methods for continued development, and performing sensitivity studies to evaluate permissible ranges of specimen geometric, stiffness and strength properties.

Test Methods for Civil Infrastructure

In March 2005, representatives of the American Concrete Institute (ACI) Committee 440 on Fiber-Reinforced Polymer Reinforcements joined D30, with the goal of transitioning seventeen ACI 440 documents into D30 standard guides, practices, and/or test methods. Key participants in this activity include Dr. Russell Gentry and Dr. Abdul Zureick from the Georgia Institute of Technology and Dr. Charles Bakis of Pennsylvania State University. To date, four ACI 440 standards were published as D30 standards. It is anticipated that in the future, D30.09 will support the adaptation of sandwich structure test methods for use in civil infrastructure applications.

Sandwich Durability, Damage Resistance and Damage Tolerance

D30 has published several standards that address structural properties associated with the durability, damage resistance and damage tolerance of composite laminates. To date, the sole D30.09 standard addressing such issues for sandwich structures is C 394 (core shear fatigue). The development of durability, damage resistance and damage tolerance standards for sandwich composite structures is a long-standing objective of the subcommittee.

The committee is currently in the process of planning a workshop to be held at its fall 2009 meeting in Wichita, KS. The purpose of the workshop is to develop a strategic plan for the development of sandwich durability, damage resistance and damage tolerance standards. It is anticipated that the workshop will define a developmental timeline for sandwich standards analogous to laminate test methods for static indentation (D 6264/D 6264M), impact damage resistance (D 7136/D 7136M) and damage tolerance (D 7137/D 7137M).

CONCLUSIONS

Over the past decade, Committee D30 has developed six new test methods for sandwich structures, and has significantly revised eight existing test methods. Test method revisions have served to improve the technical content and ease-of-use of the standards, reduced data variation, and improved the ability of the composites industry to compare data. Continued development of new test methods will serve to improve performance and expand the applications for sandwich composite structures.

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