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A Comparison of CEN and ASTM Test Methods for Composite Materials

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16. Abstract

A detailed test method comparison was performed to assess the equivalence of test methods for composite materials, with emphasis on the Committee for European Standardization and ASTM International test methods referred to in the SAE International Aerospace Material Specification (AMS) 2980 and 3970 specifications. This comparison included both the parameters associated with two comparable test methods and the additions and changes listed in the AMS specifications. For the types of tests where only one test method is referred to in the SAE specifications, a second comparable ASTM or Suppliers of Advanced Composite Materials Association test method was selected for comparison purposes. In total, two test methods were reviewed and compared for a total of 16 different types of tests. For each type of test, three comparison tables are presented, focusing on geometric features of the specimen and test fixture, parameters associated with the test procedure, and procedures for data reduction and reporting. Each table contains a list of individual parameters specified in the test methods as well as any additions or changes provided in the AMS 2980 and 3970 specifications. For every parameter listed in the comparison tables, an assessment of the equivalence was made using a 0-4 rating scale. A brief summary of each test method comparison is provided, which emphasizes the most significant differences between the test methods.

Based on the comparative assessments performed, 4 of the 16 types of tests were recommended for follow-on testing to further assess test method equivalency. Note that the selection of these four tests for follow-on testing only reflects the need for additional test data to assess equivalency and is not a reflection of their degree of equivalency relative to the other tests. The four types of tests recommended for follow-on testing are lamina compression testing to assess the effects of gage length, laminate compression testing to assess the effects of loading method, in-plane shear testing to investigate the effects of specimen thickness, and constituent content determinations to investigate the effects of specimen size and weighing accuracy.

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EXECUTIVE SUMMARY

A detailed test method comparison was performed to assess the equivalence of test methods for composite materials, with emphasis on the Committee for European Standardization and ASTM International test methods referred to in the SAE International Aerospace Material Specification (AMS) 2980 and 3970 specifications. This comparison included both the parameters associated with two comparable test methods and the additions and changes listed in the AMS specifications. For the types of tests where only one test method is referred to in the SAE specifications, a second comparable ASTM or Suppliers of Advanced Composite Materials Association test method was selected for comparison purposes. In total, two test methods were reviewed and compared for a total of 16 different types of tests. For each type of test, three comparison tables are presented, focusing on geometric features of the specimen and test fixture, parameters associated with the test procedure, and procedures for data reduction and reporting. Each table contains a list of individual parameters specified in the test methods as well as any additions or changes provided in the AMS 2980 and 3970 specifications. For every parameter listed in the comparison tables, an assessment of the equivalence was made using a 0-4 rating scale. A brief summary of each test method comparison is provided, which emphasizes the most significant differences between the test methods.

Based on the comparative assessments performed, 4 of the 16 types of tests were recommended for follow-on testing to further assess test method equivalency. Note that the selection of these four tests for follow-on testing only reflects the need for additional test data to assess equivalency and is not a reflection of their degree of equivalency relative to the other tests. The four types of tests recommended for follow-on testing are lamina compression testing to assess the effects of gage length, laminate compression testing to assess the effects of loading method, in-plane shear testing to investigate the effects of specimen thickness, and constituent content determinations to investigate the effects of specimen size and weighing accuracy.

1. INTRODUCTION.

1.1 BACKGROUND TO COMPARISON STUDY.

The motivation for this comparative evaluation of U.S. and European test methods for composite materials dates back to the early 1990s. At that time, a composite materials characterization program was initiated to generate a data set and subsequently qualify a composite material system for commercial aircraft repair [1]. The material to be qualified was a wet lay-up composite material to be processed with a vacuum-only cure and used for airframe repair. The carbon fiber used (HTA 5131, Tenax Fibers, Wuppertal, Germany) was woven into a 3 K plain weave (Hexcel Fabrics S.A., Lyon, France) and impregnated with Epocast 52 A/B epoxy resin (Vantico A&T, Los Angeles, CA). Two resin impregnation methods were used, referred to as the squeeze-out method and the vertical bleed method. A variety of laminate and sandwich panel configurations were produced and cured at 200°F under vacuum pressure.

The material qualification program was performed according to SAE International Aerospace Material Specification (AMS) 2980 [2] and Commercial Aircraft Composite Repair Committee (CACRC) requirements, which used Committee for European Standardization (CEN) test methods. The goal of this material characterization program, sponsored by the manufacturers of the fiber and resin, was to qualify a composite material system to be used in the repair of composite structures on commercial aircraft. Mechanical testing performed included tension, compression, in-plane shear, open-hole tension, filled-hole tension, open-hole compression, filled-hole compression, bearing, compression-after-impact, tension-tapered joint, and tension-stepped joint tests. At the completion of testing, the mechanical test results were processed into MIL Handbook-acceptable form to provide statistical data.

In the mid-1990s, a MIL-Handbook-17 Composite Materials Handbook Committee reviewed the test methods used in this material qualification program and compared them to the test methods recommended by MIL-HDBK-17 [3]. They noted that CEN test methods were used extensively in this qualification program, whereas MIL-HDBK-17 focuses on ASTM International test methods. The MIL-HDBK-17 committee determined that the CEN and ASTM test methods differed in several aspects, raising concerns that the SAE specified tests do not produce equivalent results to the MIL-HDBK-17-recommended test methods. Results of the MIL-HDBK-17 committee review were published by email in October 1995 [4].

Following this review, discussions continued between MIL-HDBK-17 and CACRC personnel. Although the CACRC continued using CEN test methods, similar ASTM test methods were added to the SAE specifications as an alternate for some tests. Additionally, for several types of tests included in both SAE AMS 2980 [2] (for wet lay-up material) and SAE AMS 3970 [5] (for prepreg material), several parameters were specified that limited potential differences in test results between the CEN and ASTM test methods. For several types of tests, however, it remained unclear if the ASTM and CEN test methods would produce equivalent test results. In May 2002, a joint meeting was held between CACRC and the MIL-HDBK-17 committees. Following this meeting, Mr. Rich Fields reviewed the test methods in the initial release of SAE AMS 3970 [5] and wrote a summary of findings and conclusions [6]. Mr. Fields concluded that results from some CEN test methods would not be expected to be equivalent to results for the same properties obtained using MIL-HDBK-17-recommended test methods.

The detailed test method comparison contained in this report is directed towards assessing the equivalence of the different test methods (primarily CEN and ASTM) referred to in the SAE AMS 2980 and 3970 specifications. Of interest is both a direct comparison of the test methods as well as an investigation of the effects of additions and changes given in the AMS specifications. For the types of tests where only one test method is referred to in the SAE specifications, a second comparable ASTM or Suppliers of Advanced Composite Materials Association (SACMA) test method was selected for comparison purposes. In total, two test methods were reviewed and compared for a total of 16 different types of tests. In addition to a detailed comparison of test method parameters, the significance of differences in parameters was assessed. For those tests where the significance of an important difference was not known, follow-on mechanical testing was proposed for the second round of this investigation. The types of tests recommended for follow-on mechanical testing and the specific parameters to be assessed are summarized in the final section of this report.

1.2 METHOD OF COMPARATIVE EVALUATION.

For each of the 16 types of tests considered, two different test methods were carefully reviewed and compared. For each type of test, the results of the comparative evaluation have been arranged into three comparison tables. The first table focuses on geometric features of the specimen and test fixture. Included in this table are important dimensions and tolerances associated with both the test specimen and fixture. The second table focuses on parameters associated with the test procedure, which include parameters associated with specimen preparation and instrumentation, procedures for specimen preconditioning, loading, and testing, and accuracy requirements for measured quantities. The third table focuses on procedures for data reduction and reporting, which include procedures, formulas, and statistical methods used to calculate and report test quantities.

In addition to listing specific parameters associated with each of the test methods reviewed, the significance of differences in parameters was assessed and included in the comparison tables. For every parameter compared, an assessment of the equivalence was made using the following rating scale:

- 0—No difference, essentially the same, not expected to produce any effect on results
- 1—Insignificant difference, potential to produce insignificant effect on results
- 2—Minimal difference, difference of minimal significance, potential to produce minimal effect on results
- 3—Moderate difference, difference of moderate significance, potential to produce moderate effect on results
- 4—Major difference, difference of major significance, potential to produce major effect on results
- NC—Not comparable

An initial draft of these comparison tables was prepared and distributed to a selected group for evaluation. This group of evaluators consisted of:

- Mr. Rich Fields, Lockheed Martin Orlando, Chairman of ASTM D 30 Committee and Co-Chairman of MIL-HDBK-17 Testing Working Group
- Mr. Peter Shyprykevich, Federal Aviation Administration
- Dr. Donald F. Adams, President of Wyoming Test Fixtures, Inc.
- Dr. John Tomblin, Director of the National Institute for Aviation Research at Wichita State University

The author and evaluators met at Wichita State University in August 2003 to discuss the comparison and assessment tables as well as to determine which tests would require follow-on testing to assess equivalence. As a result of this meeting, changes were made to both the format and the content of the comparison and assessment tables. Additionally, four types of tests were identified as requiring follow-on testing in the second round of this investigation to assess equivalence.

In the following section, test methods are compared for 16 types of tests for composite materials. A brief summary of the comparison is followed by the three comparative tables for each type of test. The final section of this report presents the tests that were identified as requiring follow-on testing in the second round of this investigation to assess equivalence.

2. TEST METHOD COMPARISONS.

In this section, each of the 16 types of tests is compared and the significance of differences is assessed. Three comparison tables are presented, focusing on geometric features of the specimen and test fixture, parameters associated with the test procedure, and procedures for data reduction and reporting. Each table contains a list of individual parameters specified in the test methods as well as any additions or changes provided in the AMS 2980 and 3970 specifications. The column of AMS-specified additions/changes is placed between the columns containing the description of parameters from the two test methods. The column heading for the AMS specifications states which of the test methods the additions/changes are intended to modify. For further clarification, the column of AMS additions/changes is separated from the test methods by either a single line or double line, depending on whether the test method is included in the AMS specifications. A single line (|) is used when the test method is listed in the AMS specifications, whereas a double line (‖) is used when the test method is not listed.

For every parameter listed in the comparison tables, an assessment of the equivalence was made using a 0-4 rating scale. The definitions used for each number rating are:

- 0—No difference, essentially the same, not expected to produce any effect on results
- 1—Insignificant difference, potential to produce insignificant effect on results
- 2—Minimal difference, difference of minimal significance, potential to produce minimal effect on results

- 3—Moderate difference, difference of moderate significance, potential to produce moderate effect on results

- 4—Major difference, difference of major significance, potential to produce major effect on results

For cases where an assessment of equivalence is not possible, a rating of NC (not comparable) is used. A brief summary of each test method comparison is provided, which emphasizes the most significant differences between the test methods.

In the comparisons that follow, the two test methods selected were based on those referred to in the AMS specifications. For several types of tests, both a CEN and an ASTM test method are referred to in the AMS specification and are, therefore, used for comparison. In several other cases, however, only a CEN test method is referred to in the AMS specifications. For these cases, a similar ASTM test method existed, either a draft ASTM standard or a SACMA-recommended method was selected. For one type of test, the AMS specifications referred only to a SACMA-recommended method. For this case, a comparable ASTM standard was identified and used for comparison.

Of the CEN test methods used for comparison, several of the standards are currently draft or preliminary standards and are denoted as prEN test methods. Other test methods, which have been approved by CEN, are denoted as EN test methods.

2.1 LAMINA TENSION TESTING.

The two test methods considered, EN 2561 and ASTM D 3039, are similar test methods for determining tensile properties of composite materials (tables 1 through 3). However, EN 2561 is limited in scope to 0° unidirectional carbon fiber composites, whereas ASTM D 3039 is applicable to balanced and symmetric laminates as well as discontinuous fiber polymer composites. The AMS 2980 and 3970 specifications provide additions and changes to either standard for testing woven fabric laminates. Although different specimen widths and thicknesses are specified for the different types of laminates (unidirectional, woven fabric, and balanced and symmetric laminates), the stated widths are consistent among the specifications for each laminate type.

A comparison of specimen geometries revealed only minor differences in dimensions and tolerances that were considered to produce insignificant effects on results. Differences in tabbing requirements may produce a minimal effect on results. Whereas both EN 2561 and ASTM D 3039 specify a minimum of five specimens, the AMS 2980 and 3970 specifications require six specimens. Different micrometers specified in EN 2561 and ASTM D 3039 for measuring specimen thickness as well as different data ranges for calculating the modulus of elasticity and Poisson's ratio may produce minimal effects on results. Whereas ASTM D 3039 requires the reporting of failure modes to follow a three-part code and does not specify requirements for acceptable failures, the EN 2561 and the AMS specifications require that specimens fail within the gage section (between the grips) but do not require the reporting of the observed failure mode.

TABLE 1. LAMINA TENSION TESTING (WARP/WEFT)—SPECIMEN GEOMETRIC COMPARISONS

Property	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Laminate lay-up	0° Unidirectional (Specimen axis parallel to the direction of the fibers)	$[(90/0)]_{4S}$ (Tensile Weft) (AMS 2980-2) $[(0/90)]_{4S}$ (Tensile Warp) (AMS 3970-2)	All balanced and symmetric laminates	NC
Overall specimen length	250 ±1 mm	250 ±3 mm	Balanced and symmetric: 250 mm	0
Specimen gage length	120 mm	125 mm minimum	Not specified	NC
Specimen width	15 mm (0° unidirectional, Specimen type B)	25 mm (woven laminate)	0° unidirectional: 15 mm Balanced and symmetric: 25 mm	NC
Specimen width tolerance	±0.5 mm	±0.25 mm 0.08-mm parallelism	±1% of specimen width	0
Specimen thickness	1 ±0.2 mm (0° unidirectional) (Specimen type B)		• 0° unidirectional: 1.0 mm recommended • Balanced and symmetric: 2.5 mm recommended	0
Specimen thickness tolerance	Not specified	0.08-mm face-to-face parallelism	±4% of specimen thickness	1
Use of tabs	Required, unless using grips with adjustable grip pressure	Optional, to be agreed between parties involved	As needed	0
Tab material	1581 type glass-epoxy laminate, arranged at ±45°		Most consistently used: E-glass, woven or nonwoven, at ±45° to loading	0
Tab length	65 ±15 mm (0° unidirectional)		• 0° unidirectional: 56 mm recommended • Balanced and symmetric: friction tabs recommended	1
Tab thickness	Between 0.5 and 1.0 mm		• 0° unidirectional: 1.5 mm recommended • 90°unidirectional: 1.5 mm recommended	1

TABLE 1. LAMINA TENSION TESTING (WARP/WEFT)—SPECIMEN GEOMETRIC COMPARISONS (Continued)

Property	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Tab thickness tolerance	Not specified		±1% of tab thickness	2
Tab bevel angle	90° (0° unidirectional)		0° unidirectional: 7° or 90° recommended	2

TABLE 2. LAMINA TENSION TESTING (WARP/WEFT)—TEST PROCEDURE COMPARISONS

Procedure	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Load indicator	Accurate to within 1% of the load range used		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Grips	The jaws shall entrap the tabs of the specimens		Highly desirable to use rotationally self-aligning grips to reduce bending stress	1
Specimen alignment	Sufficient to avoid the introduction of any bending loads		Recommends limiting percent bending to a range of 3%-5% for strain levels > 1000με	0
Test Speed	2 mm/min		Constant head-speed tests: 2 mm/min Strain controlled tests: 0.01 min^{-1}	0
Sampling	Minimum of five	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Strain gage selection	Accurate to within 1% in the strain range used		• Required active gage length of at least 3 mm (6 mm recommended for most materials) • Recommended active gage length ≥ the characteristic repeating unit of the weave for woven fabric laminates • Recommended resistance ≥ 350 Ω	1
Extensometers	Accurate to within 1% in the strain range used		• Recommended gage length in the range of 10 to 50 mm • Extensometer shall satisfy Practice E 83	1
Specimen conditioning	• EN 2743 for tests in the initial state • EN 2489 for tests after immersion • EN 2823 for tests after humidity exposure		• Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity • Requires maintaining temperature to within ±3°C and relative vapor level to within ±3%	1

TABLE 2. LAMINA TENSION TESTING (WARP/WEFT)—TEST PROCEDURE COMPARISONS (Continued)

Procedure	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Measurement of specimen width	• Flat-faced micrometer accurate to 0.01 mm • Measure in center of specimen and two opposite points located 30 mm from center • Use average of three measurements		Micrometer with flat anvil accurate to within 1% of specimen width (~±25 μm) tolerance	1
Measurement of specimen thickness	• Flat-faced micrometer accurate to 0.01 mm • Measure in center of specimen and two opposite points located 30 mm from center • Use average of three measurements		Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm)	2

TABLE 3. LAMINA TENSION TESTING (WARP/WEFT)—DATA REDUCTION/REPORTING COMPARISONS

Quantity	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Specimen area, A	Average of three width measurements times average of three thickness measurements		Average of three area measurements within gage section ($A = w \times h$)	1
Ultimate tensile strength	Use average area for each specimen		Use average area for each specimen Report to three significant figures	0
Ultimate tensile strength related to the fiber, σ_f (calculated as a function of fiber cross-sectional area, based on hypothesis that all tensile load is carried by the fibers)	$\sigma_f = \frac{P_R \rho_f}{n\, b\, M_{sf}}$ where: P_R = failure load ρ_f = fiber density n = number of plies b = average specimen width M_{sf} = mass per unit area of fiber (per ply)		Not addressed	NC
Ultimate tensile strain	Expressed as a percentage	Measure and report failure strain	Report to three significant figures	0
Tensile modulus of elasticity	Secant modulus measured between 10% and 50% of failure load	Modulus reference points: 1000-3000 $\mu\varepsilon$	Chord modulus between 1000-3000 $\mu\varepsilon$ Report to three significant figures Report strain range used	2

TABLE 3. LAMINA TENSION TESTING (WARP/WEFT)—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Tensile modulus of elasticity related to the fiber, E_f (calculated as a function of fiber cross-sectional area, based on the hypothesis that all tensile load is carried by the fibers)	$\sigma_f = \frac{\Delta P_R \rho_f}{n\, b\, M_{sf}\, \Delta\varepsilon}$ where: ΔP_R = difference in failure load ρ_f = fiber density n = number of plies b = average specimen width M_{sf} = mass per unit area of fiber (per ply) $\Delta\varepsilon$ = difference in axial strains		Not addressed	NC
Poisson's ratio	Measured between 10% and 50% of failure load		Chord method: between 1000-3000 με Report to three significant figures Report strain range used	2
Failure Mode	Failure shall occur within the free length of the specimen but may extend under the end tabs or within the test machine jaws	Tension failure within the gage length lateral angle direction	Report mode and location of failure using three part failure mode code (given in standard)	2
Statistics	Individual values, arithmetic means, and standard deviations		Individual values, mean (average) value, standard deviation, coefficient of variation	1

TABLE 3. LAMINA TENSION TESTING (WARP/WEFT)—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	EN 2561 Specifications	AMS 2980/3970 Additions/ Changes to EN 2561/ D 3039 (Section 6.5.2)	ASTM D 3039 Specifications	Importance of Difference
Other reporting requirements	Material identification/info		Material identification/info	0
	Specimen preparation		Specimen preparation	0
	Specimen dimensions		Specimen dimensions	0
	Incidents/deviations		Variations/anomalies/problems	0
	Test method used		Date/revision of test method used	0
	Aging/exposure conditions		Conditioning parameters and results	0
	Method of strain measurement		Method of strain measurement/placement	0
	Load/strain diagram		Stress-strain curves and tabulated data	1
			Date/location of test	1
			Test operator	1
			Equipment used	1
			Temperature/humidity of testing lab	1
			Grip pressure	1
			Alignment results	1
			Data acquisition sampling rate	1
			Speed of testing	1
			Percent bending results (if evaluated)	1
			Calibration dates for test	1

2.2 LAMINATE TENSION TESTING.

Although ASTM D 3039 pertains to the tensile testing of quasi-isotropic composite laminates, it does not have a comparable open-hole test configuration such that the effect of the open hole can be determined. As a result, the prEN 6035 test specifications were compared to the ASTM D 5766 test method (open-hole tensile strength) but without a hole present in the specimen (tables 4 through 6). ASTM D 5766 describes a uniaxial tension test of a balanced, symmetric laminate that is performed in accordance with ASTM D 3039, but with a centrally located hole and without strain or displacement transducers. Thus, many aspects of the ASTM D 3039 and D 5766 test procedures and data reduction and recording methods are the same. The AMS 2980 and 3970 specifications provide additions and changes to either the prEN 6035 or the ASTM D 5766 standards, primarily relating to the specimen geometry.

A comparison of specimen geometries revealed only minor differences in dimensions with the exception of specimen widths. Whereas a width-tapered specimen with a 30-mm gage section is specified in prEN 6035, a constant width 36-mm specimen is specified in ASTM D 5766. AMS 2980 and 3970 modify both specifications to an untapered 38.1-mm-wide specimen. Differences in tabbing requirements provided in the prEN 6035 and the ASTM D 5766 test methods may produce a minimal effect on results. AMS 2980 and 3970 require six specimens, whereas both EN 2561 and ASTM D 5766 specify a minimum of five specimens. Additionally, different micrometers specified in EN 2561 and ASTM D 5766 for measuring specimen thickness may produce minimal effects on results.

TABLE 4. LAMINATE TENSION TESTING

Property	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.6)	ASTM D 5766 Specifications (With no hole)	Importance of Difference
Laminate lay-up	Quasi-isotropic or directed composite laminates with unidirectional plies or woven fabrics reinforcement	$[(0/90)/(45/-45)]_{3S}$ (AMS 2980-2) $[(45/-45)/(0/90)/(-45/45)/(90/0)]_{2S}$ (AMS 3970-2)	Balanced and symmetric $[45/0/-45/90]_{ns}$	0
Overall specimen length	Not specified		• 200-300 mm, in accordance with D 3039 • Balanced and symmetric: 250 mm	1
Specimen gage length	180 ±0.5 mm	180-mm minimum	Not specified	NC
Specimen width	Width-tapered specimen: 30-mm gage section 45 mm in tab regions	Untapered specimen, 38.1 mm	36 mm	2
Specimen width tolerance	±0.2 mm in gage section	±0.1 mm 0.08-mm parallelism	±1% of specimen width (D 3039) ±1 mm (D 5766)	1
Specimen thickness	• Tapes: according to lay-up • Fabric: as close to 4 mm as possible		As close as possible to 2.5 mm Permissible range of 2-4 mm	1
Specimen thickness tolerance	Coefficient variation in the thickness measurements shall be smaller than 2% per laminate	0.08-mm face-to-face parallelism	In accordance with D 3039: ±4% of specimen thickness	1
Tab material	Two plies of fabric with fibers oriented at ±45°	Use of tabs optional, to be agreed between parties involved	• In accordance with D 3039: • Most consistently used: E-glass, woven or nonwoven, at ±45° to loading	0
Tab length	Not specified		• In accordance with D 3039: • Balanced and symmetric laminates: friction tabs recommended	NC
Tab thickness	two plies of ±45 fabric		Not specified for friction tabs	NC

TABLE 4. LAMINATE TENSION TESTING (Continued)

Property	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.6)	ASTM D 5766 Specifications (With no hole)	Importance of Difference
Tab thickness tolerance	Not specified		In accordance with D 3039: ±1% of tab thickness	2
Tab bevel angle	90°		Not specified for friction tabs	2

TABLE 5. LAMINATE TENSION TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.6)	ASTM D 5766 Specifications (With no hole)	Importance of Difference
Load indicator	Accurate to within 1% of the load range used		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Grips	Not addressed		Highly desirable to use rotationally self-aligning grips to reduce bending stress	1
Specimen alignment	Specimen aligned within 1° and centered on machine axis		Recommends limiting percent bending to a range of 3%-5% for strain levels > 1000 με	1
Test speed	2 mm/min	2 mm/min	2 mm/min	0
Sampling	Five specimens	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Specimen conditioning	Specimen storage and testing to be carried out at 23° ±2°C and 50% ±5% relative humidity		• Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity • Requires maintaining temperature to within ±3°C and relative vapor level to within ±3%	1
Measurement of specimen width	• Vernier caliper accurate to nearest 0.1 mm • Average of three measurements in gage section		Micrometer with flat anvil accurate to within 1% of specimen width (~±25 μm) tolerance	1
Measurement of specimen thickness	Flat-face micrometer accurate to nearest 0.01 mm		Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm)	2

TABLE 6. LAMINATE TENSION TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.6)	ASTM D 5766 Specifications (With no hole)	Importance of Difference
Specimen area, A	Average of three width measurements times average of three thickness measurements (within gage section)		Average of three area measurements within gage section ($A = w \times h$)	1
Tensile strength	Use average area for each specimen		Use average area for each specimen Report to three significant figures	0
Nominal tensile strength	• Use average width for each specimen • Use nominal specimen thickness as specified in material specification		Not addressed	NC
Ultimate tensile strain	Not addressed	Measure and report failure strain	Not addressed	NC
Tensile modulus of elasticity	Not addressed	Modulus reference points: 1000-3000 $\mu\varepsilon$	Not addressed	NC
Failure mode	Not addressed	Any tension failure within the gage length	In accordance with D 3039: Report mode and location of failure using three-part failure mode code (given in standard)	2
Statistics	Individual values, mean value, and standard deviation of tensile strength		Individual values, mean (average) value, standard deviation, and coefficient of variation	1

TABLE 6. LAMINATE TENSION TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.6)	ASTM D 5766 Specifications (With no hole)	Importance of Difference
Other reporting requirements	Date/location of test		Date/location of test	0
	Material identification/info		Material identification/info	0
	Specimen preparation		Specimen preparation	0
	Specimen dimensions		Specimen dimensions	0
	Test operator		Test operator	0
	Incidents/deviations		Variations/anomalies/problems	0
	Equipment used		Equipment used	0
	Test method used		Date/revision of test method used	0
	Aging/exposure conditions		Conditioning parameters and results	0
	Test parameters used		Temperature/humidity of testing lab	1
			Grip pressure	
			Alignment results	
			Data acquisition sampling rate	
			Speed of testing	
			Percent bending results (if evaluated)	
			Calibration dates for test	1

2.3 OPEN-HOLE TENSION TESTING.

The two test methods considered, prEN 6035 and ASTM D 5766, are similar test methods for determining the open-hole tensile strength of composite laminates (tables 7 through 9). The AMS 2980 and 3970 specifications provide additions and changes to either the prEN 6035 or the ASTM D 5766 standards, primarily relating to the specimen geometry. One significant difference in specimen geometries is the specimen widths, which range from 30 mm (prEN 6035) to 36.1 mm (ASTM D 5766). The AMS 2980 and 3970 specifications modify both values to a width of 38.1 mm. Although a 6.35-mm-diameter hole is specified in both the prEN 6035 and the AMS specifications, ASTM D 5766 requires a 6-mm-diameter hole. The resulting specimen width-to-hole diameter ratio varies from 4.7 for prEN 6035 to 6.0 for both the ASTM D 5766 and the AMS 2980 and 3970 specifications. AMS 2980 and 3970 require six specimens, whereas both EN 2561 and ASTM D 5766 specify a minimum of five specimens. Additionally, different micrometers specified in EN 2561 and ASTM D 5766 for measuring specimen may produce minimal effects on results.

TABLE 7. OPEN-HOLE TENSION TESTING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.7)	ASTM D 5766 Specifications	Importance of Difference
Laminate lay-up	Quasi-isotropic or directed composite laminates with unidirectional plies or woven fabrics reinforcement	$[(0/90)/(45/-45)]_{3S}$ (AMS 2980-2 $[(45/-45)/(0/90)/(-45/45)/(90/0)]_{2S}$ (AMS 3970-2)	Balanced and symmetric $[45/0/-45/90]_{ns}$	0
Overall specimen length	Not specified		• 200-300 mm, in accordance with D 3039 • Balanced and symmetric: 250 mm (recommended)	1
Specimen gage length	180 ±0.5 mm	180-mm minimum	Not specified	NC
Specimen width	30 mm	38.1 mm	36 mm	3
Specimen width tolerance	±0.2 mm	• ±0.1 mm • 0.08-mm side-to-side parallelism	±1% of specimen width	1
Specimen thickness	• Tapes: according to lay-up • Fabric: as close to 4 mm as possible		As close as possible to 2.5 mm Permissible range of 2-4 mm	1
Specimen thickness tolerance	Coefficient variant in the thickness measurements shall be smaller than 2% per laminate	±0.1 mm	In accordance with D 3039: ±4% of specimen thickness	1
Hole diameter	6.35 + 0.09/-0.0 mm	6.35 + 0.09/-0.0 mm	6 ±0.6 mm	3
Tolerance on hole location	Not specified	Within 0.1 mm of the axial centerline	Within 0.1 mm of the axial centerline	0
Use of tabs	Two plies of ±45 fabric, 90° taper angle		Not required, and generally not needed	1

TABLE 8. OPEN-HOLE TENSION TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.7)	ASTM D 5766 Specifications	Importance of Difference
Load indicator	Accurate to within 1% of the load range used		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Grips	Not addressed		Highly desirable to use rotationally self-aligning grips to reduce bending stress	1
Specimen alignment	Specimen aligned within 1° and centered on machine axis		Recommends limiting percent bending to a range of 3%-5% strain levels > 1000 με	1
Test speed	2 mm/min	2 mm/min	2 mm/min	0
Sampling	Five specimens	Six specimens	At least five specimens	2
Hole preparation	Special precautions have to be taken to ensure that no delamination occurs during drilling of the holes.		Finished hole must be clean and smooth with sharp unbeveled edges, but not polished and without any delamination damage	1
Specimen conditioning	Specimen storage and testing to be carried out at 23° ±2°C and 50% ±5% relative humidity		• Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity • Requires maintaining temperature to within ±3°C and relative vapor level to within ±3%	1
Measurement of specimen width	• Vernier caliper accurate to nearest 0.1 mm • Average of three measurements in gage section		Micrometer with flat anvil accurate to within 1% of specimen width (~±25 μm) tolerance	1
Measurement of specimen thickness	Flat-face micrometer accurate to nearest 0.01 mm		Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm)	2
Measurement of hole diameter	Not specified	Micrometer with accuracy of ±0.025 mm	Micrometer or gage capable of determining the hole diameter to ±0.025 mm	NC

TABLE 9. OPEN-HOLE TENSION TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.7)	ASTM D 5766 Specifications	Importance of Difference
Specimen area, A	Average of three width measurements times average of three thickness measurements (within gage section)		Average of three area measurements within gage section ($A = w \times h$)	1
Ultimate open-hole tensile strength	Use gross area for each specimen	Report failure stress	Use gross area for each specimen Report to three significant figures	0
Nominal open-hole tensile strength	• Use nominal specimen thickness as specified in material specification • Use gross specimen width		Not addressed	NC
K_T	Unnotched tensile strength divided by the notched (open hole) tensile strength		Not addressed	NC
Width to diameter ratio	Not addressed	Report width to hole diameter ratio	Calculate actual width to diameter ratio for each specimen and the nominal width to diameter ratio using nominal values	NC
Diameter to thickness ratio	Not addressed		Calculate/report the actual diameter to thickness ratio for each specimen and the nominal diameter to thickness	NC
Failure Mode	Not addressed	Any tension failure through the hole is acceptable	• Failures that do not occur at the hole are not acceptable failure modes • Specify lateral, angled, or multimode failure and use three-part failure mode code (given in D 3039 standard)	1
Statistics	Individual values, mean value, and standard deviation of open-hole tensile strength		Individual values, mean (average) value, standard deviation, and coefficient of variation of open-hole tensile strength	1

TABLE 9. OPEN-HOLE TENSION TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6035 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6035/ D 5766 (Section 6.5.7)	ASTM D 5766 Specifications	Importance of Difference
Other reporting requirements	Date/location of test		Date/location of test	0
	Material identification/info		Material identification/info	0
	Specimen preparation		Specimen preparation	0
	Specimen dimensions		Specimen dimensions	0
	Test operator		Test operator	0
	Incidents/deviations		Variations/anomalies/problems	0
	Equipment used		Equipment used	0
	Test method used		Date/revision of test method used	0
	Aging/exposure conditions		Conditioning parameters and results	0
	Test parameters used		Temperature/humidity of testing lab	1
			Grip pressure	
			Alignment results	
			Data acquisition sampling rate	
			Speed of testing	
			Percent bending results (if evaluated)	
			Calibration dates for test	1

2.4 LAMINA COMPRESSION TESTING.

The two test methods considered, prEN 2850-B and SACMA SRM 1 R-94, are similar test methods for determining compressive properties of composite materials (tables 10 through 12). This type of compression test, sometimes referred to as a modified ASTM D 695 compression test, features an end-loaded, face-supported specimen. Whereas untabbed specimens are used for modulus determinations, tabbed specimens are used for strength determination. Note that prEN 2850-B describes two types of compression tests; this comparison is based on method B. The AMS 2980 and 3970 specifications provide additions and changes only to prEN 2850-B; the SACMA SRM 1 standard is not referred to in either AMS specification.

A comparison of specimen geometries revealed several minor differences in dimensions and tolerances that are not expected to produce significant effects on results. Some confusion exists concerning the specification of specimen gage lengths, however. Whereas similar gage lengths are listed for the prEN 2850-B and SACMA SRM 1 test methods (5 mm versus 4.75 mm, respectively), the AMS 2980 and 3970 specifications, which modify the prEN 2850-B test method, specify a 12.5-mm gage length. It is possible that this significantly larger gage length given in the AMS 2980 and 3970 specifications refers to a different quantity. The shorter gage lengths specified in both the prEN 2850-B and SACMA SRM 1 test methods are clearly shown as the length of the untabbed region of the specimen used for strength determination. The opening in the face support, or cover plate, used for untabbed specimens during modulus determination is shown as 12.7 mm in length in the SACMA SRM 1 test method. Since the 12.5-mm gage length is simply stated in the AMS 2980 and 3970 specifications without referring to a drawing, it is not clear whether this dimension refers to the tabbed or the untabbed specimen configurations. However, this 12.5-mm dimension is believed to refer to the length of the opening in the face support in the modulus specimens.

Whereas both prEN 2850-B and SACMA SRM 1 specify a minimum of five specimens, the AMS 2980 and 3970 specifications require six specimens. Different data ranges for calculating the modulus of elasticity between prEN 2850-B and SACMA SRM 1 may produce minimal effects on results.

TABLE 10. LAMINA COMPRESSION TESTING (WARP/WEFT)—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 2850-B Specifications	AMS 2980/3970 Additions/ Changes to prEN 2850-B (Section 6.5.3)	SACMA SRM 1R-94 Specifications	Importance of Difference
Laminate lay-up	Unidirectional laminates Fabrics	$[(90/0)]_{6S}$ (Compressive Weft) (AMS 2980-2) $[(90/0)]_{6S}$ (Compressive Weft) $[(0/90)]_{6S}$ (Compressive Warp) (AMS 3970-2)	Unidirectional laminates Fabrics	1
Overall specimen length	75 to 80 mm		80 mm ±0.1 mm	1
Specimen gage length	5 mm (distance between tabs in specimens used for strength determination)	12.5 mm (opening in the face support for specimens used for modulus determination?)	4.75 mm (distance between tabs in specimens used for strength determination)	2-3
Specimen gage length tolerance	±0.5/-0 mm		±0.1 mm	1
Specimen width	12.5 mm		15.0 mm	1
Specimen width tolerance	• ±0.2 mm • 0.05-mm side-to-side parallelism		±0.1 mm	1
Specimen thickness	Not specified		• Unidirectional materials: 1.02-mm nominal thickness • Fabric specimens: 3.05-mm nominal thickness	1
Use of tabs	• Untabbed specimen for modulus measurement • Tabbed specimen for strength measurement • Either bonded or integral tabs		• Untabbed specimen for modulus measurement • Tabbed specimen for strength measurement	0
Tab material	Recommends using the same material as the specimen		Composite material in a 0/90 orientation (fabric or tape)	1

TABLE 10. LAMINA COMPRESSION TESTING (WARP/WEFT)—SPECIMEN GEOMETRIC COMPARISONS (Continued)

Property	prEN 2850-B Specifications	AMS 2980/3970 Additions/ Changes to prEN 2850-B (Section 6.5.3)	SACMA SRM 1R-94 Specifications	Importance of Difference
Tab length	Length required to produce 5-mm gage length		Length required to produce 4.75-mm gage length	1
Tab bevel angle	90°		90°	0
Test fixture	• Partially dimensioned drawings provided • Two different sets of specimen supports • Strength measurement: support pieces serrated over entire length of specimen • Modulus measurement: support pieces without serration in central 12.7-mm length of specimen (for strain gages)		• Fully dimensioned drawings provided • Two different sets of specimen support plates (modulus and strength) • Strength measurement: support pieces serrated over entire length of specimen • Modulus measurement: support pieces without serration in central 12.7-mm length of specimen (for strain gages)	0

TABLE 11. LAMINA COMPRESSION TESTING (WARP/WEFT)—TEST PROCEDURE COMPARISONS

Procedure	prEN 2850-B Specifications	AMS 2980/3970 Additions/ Changes to prEN 2850-B (Section 6.5.3)	SACMA SRM 1R-94 Specifications	Importance of Difference
Load indicator	Accurate to within 1% of the load range used		As defined by ASTM E 4	1
Specimen alignment	In order to avoid buckling, an accurate alignment shall be ensured in a suitable way	Back-to-back strain gage measurements shall be obtained on the first specimen for each test condition	Not addressed	1
Test speed	1 mm/min		1 mm/min	0
Sampling	Five specimens	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Strain measurement	Strain gages accurate to within 1% in the strain range used		• Strain gage or suitable compressometer • Strain gage should be 3 mm or less • Back-to-back strain gages area recommended to check for bending	1
Measurement of specimen width	• Flat-faced micrometer accurate to 0.01 mm • Measure in the gage length		• Flat-face micrometer suitable for reading 0.03-mm accuracy • Measure to within 0.01 mm at several points	1
Measurement of specimen thickness	• Flat-faced micrometer accurate to 0.01 mm • Measure twice in the gage length • Use average of two measurements		• Double-ball micrometer suitable for reading 0.03-mm accuracy • Measure to within 0.01 mm at several points	1
Test fixture bolt torque	Apply a gripping load of 0.5 Nm	First torque all bolts sequentially to a low torque, then increase sequentially to the specified torque	0.7 to 1.0 Nm	1

TABLE 12. LAMINA COMPRESSION TESTING (WARP/WEFT)—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 2850-B Specifications	AMS 2980/3970 Additions/ Changes to prEN 2850-B (Section 6.5.3)	SACMA SRM 1R-94 Specifications	Importance of Difference
Specimen area, A	Width measurements times average of two thickness measurements		Average width measurements times average thickness measurements	1
Ultimate compressive strength	Use average area for each specimen		Use average area for each specimen Report to three significant figures	0
Compression modulus of elasticity	Secant modulus measured between 10% and 50% of failure load	Modulus reference points: 1000-3000 με	Secant modulus between 1000-3000 με Report to three significant figures	2
Failure mode	Test is only valid if failure occurs in the free length of the test piece. There shall be no bushing of the ends.	Compression failure within the gage length including through thickness shear, brooming, transverse shear, or splitting	Retest specimens that break at some obvious flaws or at tab debonds, or failure within the tab area	1
Statistics	Individual values, arithmetic means, and standard deviations		Individual values, average value, standard deviation, and coefficient of variation	1
Other reporting requirements	• Material identification/info • Specimen preparation • Specimen dimensions • Incidents/deviations • Test method used • Aging/exposure conditions • Load vs time, disp. or strain diagram		• Material identification/info • Specimen preparation • Specimen dimensions • Deviations from test method • Test method used • Pretest conditioning history • Relative humidity/temperature conditions • Date/location of test • Test operator • Strain gage or compressometer • Fiber volume for each specimen	0 0 0 0 0 0 0 0 1 1 1 1 1

2.5 LAMINATE COMPRESSION TESTING.

The laminate compression test method referred to in the AMS 2980 and 3970 specifications is the SACMA SRM 3-94 open-hole compression test method, but using a specimen without a hole (tables 13 through 15). Since the resulting test method is not similar to any ASTM compression tests without holes, a comparison is made to ASTM D 6484 using a specimen without a central hole. This test method is very similar to SACMA SRM 3 and therefore provides for a good comparison. Note, however, that the AMS 2980 and 3970 specifications provide additions and changes only to SACMA SRM 3; the ASTM D 6484 standard is not referred to in either AMS specification.

A comparison of specimen geometries and tolerances revealed only minor differences, none of which are expected to produce significant effects on results. AMS 2980 and 3970 require six specimens, whereas both SACMA SRM 3 and ASTM D 6484 specify a minimum of five specimens. Whereas strain measurement methods differ between SACMA SRM 3 and ASTM D 6484, both are intended for testing an open-hole specimen, and thus the comparison is of limited significance when used for unnotched compression testing. Although the test fixture specified in the two test methods is very similar, the method of load introduction differs significantly. Whereas ASTM D 6484 requires hydraulic wedge grips to be used to grip the test fixture, the SACMA SRM 3 test method allows the test fixture to be end-loaded between two parallel platens of the test machine.

TABLE 13. LAMINATE COMPRESSION TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS

Property	SACMA SRM 3 1994 Specifications (Without hole)	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.8)	ASTM D 6484 Specifications (Without hole)	Importance of Difference
Laminate lay-up	$[(+45/0)/(-45/90)]_{2S}$ for unidirectional tapes $[(+45/0)/(-45/90)]_{NS}$ for fabrics (~2.5 mm thickness)	$[(0/90)/(45/-45)]_{3S}$ (AMS 2980-2) $[(45/-45)/(0/90)/(-45/45)/(90/0)]_{2S}$ (AMS 3970-2)	Multidirectional fiber orientations (minimum of two directions) and balanced and symmetric stacking sequences. 3- to 5-mm permissible thickness range.	1
Overall specimen length	305 mm		300 ±0.25 mm	1
Specimen width	38.1 mm		36 mm	1
Specimen width tolerance	±0.1 mm		±0.25 mm	1
Specimen thickness	• Tapes: 16-ply quasi-isotropic • Fabric: 2.5-mm nominal thickness having quasi-isotropic orientation		4-mm nominal thickness Permissible range of 3-5 mm	1
Ratio of ungripped specimen length to specimen width	• Not specified; based on fixture/specimen dimensions		2.7	1
Support fixture	• Face supports specimen • Long grip/short grip assembly with support plates • Cutout on both faces of fixture		• Face supports specimen • Long grip/short grip assembly with support plates • Cutout on both faces of fixture • Thermal-sprayed specimen gripping areas • Stainless steel shims to maintain a 0.00- to 0.12-mm tolerance gap between support plates and long grip	0 0 0 NC NC

TABLE 14. LAMINATE COMPRESSION TESTING

Procedure	SACMA SRM 3 1994 Specifications (Without hole)	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.8)	ASTM D 6484 Specifications (Without hole)	Importance of Difference
Load indicator	As defined by ASTM E 4		• Accuracy over the load range(s) of interest of within ±1% of the indicated value • As defined by ASTM E 4	1
Specimen gripping	• Method I (preferred): place fixture in hydraulic grips • Method II: place fixture with bolts uniformly torqued to 0.6 N-m onto loading platens		• Hydraulic wedge grips shall apply sufficient pressure to prevent slippage • Retighten four bolts to approximately 7 N-m after gripping pressure is applied	2-3
Specimen alignment	Place fixture in hydraulic grips being sure to maintain alignment		Take care to align the long axis of the gripped fixture with the test description	0
Test speed	1 mm/min	1 mm/min	To produce failure in 1-10 min 2 mm/min suggested	1
Sampling	At least five specimens	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Measurement of specimen width	Flat-face micrometer suitable for reading 0.03-mm accuracy		Micrometer with flat anvil accurate to within 1% of specimen width	1
Measurement of specimen thickness	Double-ball micrometer suitable for reading 0.03-mm accuracy		• Double-ball micrometer accurate to within 1% of specimen thickness (~±2.5 μm) on irregular surfaces • Micrometer with flat anvil accurate to within 1% of specimen thickness (~±2.5 μm) on very smooth-tooled surfaces	1
Strain measurement	Suitable strain gage		25-mm edge-mounted extensometer No discussion of strain gages	2
Loading of specimen/fixture	• Method I (preferred): specimen/ fixture are gripped and loaded • Method II: specimen is clamped in fixture and end-loaded between two parallel platens of a test machine		• Fixture is hydraulically gripped and compressive load is sheared by means of friction into the test specimen. • Fixture does not allow specimens to be end-loaded	2-3

TABLE 15. LAMINATE COMPRESSION TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	SACMA SRM 3 1994 Specifications (Without hole)	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.8)	ASTM D 6484 Specifications (Without hole)	Importance of Difference
Specimen area, A	Based on average specimen thickness and width		Width times thickness	1
Ultimate compressive strength	Report to three significant figures		Report to three significant figures	0
Ultimate compressive strain	• For linear elastic response: calculate using ultimate stress and modulus • For nonlinear behavior, read strain directly	Measure and report failure strain	Not addressed	NC
Compressive modulus of elasticity	• Secant modulus • Modulus reference points: 1000-3000 $\mu\varepsilon$	Modulus reference points: 1000-3000 $\mu\varepsilon$	Not addressed	NC
Failure mode	• Retests shall be performed for specimens that break at some obvious flaw • Identify failure mode and location	Compression failure within the gage length including through thickness shear, brooming, or transverse shear	Three-place failure mode descriptor developed for specimen with hole, not applicable for specimen without hole	2
Statistics	Individual values, mean (average) value, standard deviation, and coefficient of variation for properties determined		Individual values, mean (average) value, standard deviation, and coefficient of variation for properties determined	0

TABLE 15. LAMINATE COMPRESSION TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	SACMA SRM 3 1994 Specifications (Without hole)	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.8)	ASTM D 6484 Specifications (Without hole)	Importance of Difference
Other reporting requirements	• Material identification/info		• Material identification/info	0
	• Specimen preparation		• Specimen preparation	0
	• Specimen dimensions		• Specimen dimensions	0
	• Deviations from test method		• Variations/anomalies/problems	0
	• Test method used		• Date/revision of test method used	0
	• Pretest conditioning history		• Conditioning parameters and results	0
	• Relative humidity/temperature conditions		• Temperature/humidity of testing lab	0
	• Fiber volume for each specimen		• Test operator	1
			• Date/location of test	1
			• Equipment used	1
			• Gaps between fixture pieces as measured by feeler gages	1
			• Grip pressure	1
			• Alignment results	1
			• Data acquisition sampling rate	1
			• Speed of testing	1
			• Percent bending results (if evaluated)	1
			• Calibration dates for test	1

2.6 OPEN-HOLE COMPRESSION TESTING.

Although only the SACMA SRM 3-94 open-hole compression test method is referred to in the AMS 2980 and 3970 specifications, a comparison is made to ASTM D 6484, a similar open-hole compression test method (tables 16 through 18). Therefore, this comparison parallels that performed for laminate compression testing, which followed these test methods using a specimen without a hole. In addition to the differences noted in the laminate compression comparison, a few additional differences exist related to the hole in the specimen. Although both the specimen width and the hole diameter are approximately 5% different between the two test methods, the ratio of specimen width to hole diameter remains the same (6.0). Whereas guidance for hole preparation is provided in ASTM D6485, the SACMA test method simply states that the "hole must not have delamination or other damage." The difference in the fixture-gripping method (required use of hydraulic grips in ASTM D 6484 versus the permitted use of end-loading in SACMA SRM 3) is perceived to be of lesser importance for open-hole compression testing than for laminate compression testing (no hole), since failures must occur at the location of the hole to be acceptable.

TABLE 16. OPEN-HOLE COMPRESSION TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS

Property	SACMA SRM 3 1994 Specifications	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.9)	ASTM D 6484 Specifications	Importance of Difference
Laminate lay-up	$[(+45/0)/(-45/90)]_{2S}$ for unidirectional tapes $[(+45/0)/(-45/90)]_{NS}$ for fabrics (~2.5 mm thickness)	$[(0/90)/(45/-45)]_{3S}$ (AMS 2980-2) $[(45/-45)/(0/90)/(-45/45)/(90/0)]_{2S}$ (AMS 3970-2)	• Multidirectional fiber orientations (minimum of two directions) • Balanced and symmetric • 3- to 5-mm permissible thickness range	1
Overall specimen length	305 mm		300 ±0.25 mm	1
Specimen width	38.1 mm		36 mm	2
Specimen width tolerance	±0.1 mm		±0.25 mm	1
Specimen thickness	• Tapes: 16-ply quasi-isotropic • Fabric: 2.5-mm nominal thickness, quasi-isotropic orientation		4-mm nominal thickness Permissible range of 3-5 mm	1
Hole diameter	6.35 mm	6.35 mm	6 mm	2
Tolerance on hole diameter	±0.08 mm in text ±0.12 mm on figure	±0.09 mm, -0.0 mm	±0.06 mm	1
Ratio of specimen width to hole diameter	6		6	0

TABLE 16. OPEN-HOLE COMPRESSION TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS (Continued)

Property	SACMA SRM 3 1994 Specifications	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.9)	ASTM D 6484 Specifications	Importance of Difference
Support fixture	• Face supports specimen • Long grip/short grip assembly with support plates • Cutout on both faces of fixture		• Face supports specimen • Long grip/short grip assembly with support plates • Cutout on both faces of fixture • Thermal-sprayed specimen gripping areas • Stainless steel shims to maintain a 0.00- to 0.12-mm tolerance gap between support plates and long grip	0 0 0 NC NC

TABLE 17. OPEN-HOLE COMPRESSION TESTING—TEST PROCEDURE COMPARISONS

Procedure	SACMA SRM 3 1994 Specifications	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.9)	ASTM D 6484 Specifications	Importance of Difference
Load indicator	As defined by ASTM E 4		• Accuracy over the load range(s) of interest of within ±1% of the indicated value • As defined by ASTM E 4	1
Specimen gripping	• Method I (preferred): place fixture in test machine hydraulic grips • Method II: place fixture with bolts uniformly torqued to 0.6 N-m onto loading platens		• Hydraulic wedge grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the support fixture • Retighten four bolts to approximately 7 N-m after hydraulic gripping pressure is applied	1
Specimen alignment	Place the fixture in the test machine hydraulic grips being sure to maintain alignment		Take care to align the long axis of the gripped fixture with the test description	0
Test speed	1 mm/min	1 mm/min	To produce failure in 1-10 min 2 mm/min suggested	1
Sampling	At least five specimens	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Hole preparation	Hole must not have delaminations or other damage		Holes should be drilled undersized and reamed to final dimensions. Take special care to ensure that creation of the hole does not delaminate or otherwise damage the material surrounding the hole.	2
Specimen conditioning	Following SACMA SRM 11		Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity Requires maintaining temperature to within ±3°C and relative vapor level to within ±3%	1

TABLE 17. OPEN-HOLE COMPRESSION TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	SACMA SRM 3 1994 Specifications	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.9)	ASTM D 6484 Specifications	Importance of Difference
Measurement of specimen width	Flat-face micrometer suitable for reading 0.03-mm accuracy		Micrometer with flat anvil accurate to within 1% of specimen width (~±76 μm)	1
Measurement of specimen thickness	Double-ball micrometer suitable for reading 0.03 mm accuracy		• Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm) on irregular surfaces • Micrometer with flat anvil accurate to within 1% of specimen thickness (~±2.5 μm) on very smooth-tooled surfaces	1
Measurement of hole diameter	Not addressed		Micrometer or gage capable of determining the hole diameter to ±0.025 mm	NC
Strain measurement	Suitable strain gage located 25 mm from the center of the circular hole		25-mm gage length extensometer No discussion of strain gages	1
Loading of specimen/fixture	• Method I (preferred): specimen and fixture are gripped into place and loaded • Method II: specimen is clamped in the fixture and place between two parallel platens of a test machine and end-loaded		• Fixture is hydraulically gripped and compressive load is sheared by means of friction into the test specimen • Fixture does not allow specimens to be end-loaded	1

TABLE 18. OPEN-HOLE COMPRESSION TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	SACMA SRM 3 1994 Specifications	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.9)	ASTM D 6484 Specifications	Importance of Difference
Specimen area, A	Gross area measurement based on average specimen thickness and width		Gross area measurement (width times thickness) in the vicinity of the hole	1
Ultimate open-hole compressive strength	• Use gross area for each specimen • Report to three significant figures		Use gross area for each specimen Report to three significant figures	0
Width to diameter ratio	Not addressed		Calculate/report the actual width-to-diameter ratio for each specimen and the nominal width-to-diameter ratio using nominal values	NC
Diameter to thickness ratio	Not addressed		Calculate/report the actual diameter-to-thickness ratio for each specimen and the nominal diameter-to-thickness ratio	NC
Failure mode	Identify failure mode and location	Any compression failure through the hole is acceptable	• Failures that do not occur at the hole are not acceptable • Use three-place failure mode descriptor	1
Statistics	Individual values, mean (average) value, standard deviation, and coefficient of variation for properties determined		Individual values, mean (average) value, standard deviation, and coefficient of variation for properties determined	0

TABLE 18. OPEN-HOLE COMPRESSION TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	SACMA SRM 3 1994 Specifications	AMS 2980/3970 Additions/ Changes to SACMA SRM 3 (Section 6.5.9)	ASTM D 6484 Specifications	Importance of Difference
Other reporting requirements	• Material identification/info		• Material identification/info	0
	• Specimen preparation		• Specimen preparation	0
	• Specimen dimensions		• Specimen dimensions	0
	• Deviations from test method		• Variations/anomalies/problems	0
	• Test method used		• Date/revision of test method used	0
	• Pretest conditioning history		• Conditioning parameters and results	0
	• Relative humidity/temperature conditions		• Temperature/humidity of testing lab	0
	• Fiber volume for each specimen		• Test operator	1
			• Date/location of test	1
			• Equipment used	1
			• Gaps between fixture pieces as measured by feeler gages	1
			• Grip pressure	1
			• Alignment results	1
			• Data acquisition sampling rate	1
			• Speed of testing	1
			• Percent bending results (if evaluated)	1
			• Calibration dates for test	1

2.7 FILLED-HOLE COMPRESSION TESTING.

There are no specifications for filled-hole compression testing in either the AMS 2980 or 3970 specifications (tables 19 through 21). Nonetheless, a comparison was made between a CEN test method (prEN 6036) and an ASTM test method (ASTM D 6742) for filled-hole compression testing. Whereas prEN 6036 is a complete test method, ASTM D 6742 supplements the ASTM standard for open-hole compression testing (D 6484).

The two test methods being compared are fundamentally different in the manner in which the specimen is gripped and loaded. Whereas prEN 6036 directly loads the specimen into grips (the use of tabs is optional), ASTM D 6742 uses the same support fixture used by ASTM D 6484. This test fixture supports the faces of the specimen, gripping over a 100-mm length at either end.

In addition to the difference in the method of gripping and loading, the specimen width and hole size differ between the two test methods, and result in a significantly different ratio of specimen width to hole diameter. Additional differences in the tolerance of the hole diameter, the hole countersink, and the fastener specification are all believed to be between minimal and moderate significance.

TABLE 19. FILLED-HOLE COMPRESSION TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS

Property	prEN 6036 Specifications	ASTM D 6742 Specifications	Importance of Difference
Laminate lay-up	Quasi-isotropic or directed laminates Number of layers dependant on layer thickness	• Multidirectional fiber orientations (minimum of two directions) and balanced and symmetric stacking sequences • 3- to 5-mm permissible thickness range	1
Overall specimen length	Dependant on tab length	300 ±0.25 mm	1
Specimen gage length	30 ±0.2 mm	Not applicable	1
Specimen width	30 mm	36 mm	2-3
Specimen width tolerance	±0.2 mm	±0.25 mm	1
Specimen thickness	• Tapes: depending on layer thickness • Fabric: quasi-isotropic laminate with thickness as close as possible to 4 mm	4-mm nominal thickness Permissible range of 3-5 mm	0
Hole diameter	6.35 mm	6 mm	2-3
Tolerance on hole diameter	+0.09 mm, -0.0 mm	• Both the hole and fastener diameters must be accurately measured and recorded • Typical aerospace tolerance on fastener hole clearance: +0.075/-0.000 µm • Small changes in clearance can affect failure mode and strength	2-3
Hole countersink	100° conical countersink Depth not addressed	• Preferred ratio of countersunk head depth-to-thickness ratio is in the range of 0.0 to 0.7 • Countersink flushness will affect strength results and must be accurately measured and recorded	2-3
Ratio of specimen width to hole diameter	4.72	6	2-3
Ratio of hole diameter to thickness of specimen	Not addressed	In the range from 1.5 to 3.0	NC

TABLE 19. FILLED-HOLE COMPRESSION TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS (Continued)

Property	prEN 6036 Specifications	ASTM D 6742 Specifications	Importance of Difference
Ratio of ungripped specimen length to specimen width	Not addressed; based on grip/tab dimensions	2.7	NC
Fastener	NAS 1580 V4T bolt MS21042-L4 nut Flat AN 960C416 Washer	• Fastener shall be specified as an initial test parameter and reported • Nominal fastener diameter shall be 6 mm • Washer type, number, and locations shall be specified as an initial test parameter	2-3
Use of tabs	• Optional • If used, they shall be strain compatible with composite being tested	Not used	NC
Support fixture	No support fixture; specimen loaded directly into grips	• Face supports specimen • Long grip/short grip assembly with support plates • Cutout on both faces of fixture • Thermal-sprayed specimen gripping areas • Stainless steel shims to maintain a 0.00- to 0.12-mm tolerance gap between support plates and long grip	3-4

TABLE 20. FILLED-HOLE COMPRESSION TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6036 Specifications	ASTM D 6742 Specifications	Importance of Difference
Load indicator	Accurate to within 1% of the load range used	• Accuracy over the load range(s) of interest of within ±1% of the indicated value. • As defined by ASTM E 4	0
Specimen gripping	Suitable grips or used with compression jig featuring a grip and movement alignment system	• Hydraulic wedge grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the support fixture • Retighten four bolts to approximately 7 N-m after hydraulic gripping pressure is applied	2-3
Specimen alignment	Specimen aligned within 1° and centered on machine axis	Take care to align the long axis of the gripped fixture with the test description	1
Test speed	0.5 mm/min	To produce failure in 1-10 min 2 mm/min suggested	1
Sampling	Five specimens	At least five specimens	0
Hole preparation	Special precautions to be taken to ensure that no delaminations occur during machining	Holes should be drilled undersized and reamed to final dimensions	1
Specimen conditioning	Specimen storage and testing to be carried out at 23° ±2°C and 50% ±5% relative humidity	• Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity • Requires maintaining temperature to within ±3°C and relative vapor level to within ±3%	0
Measurement of specimen width	Vernier caliper accurate to nearest 0.1 mm Average of three measurements in gage section	Micrometer with flat anvil accurate to within 1% of specimen width (~±76 μm)	1
Measurement of specimen thickness	Flat-face micrometer accurate to nearest 0.01 mm Average of three measurements in gage section	• Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm) on irregular surfaces • Micrometer with flat anvil accurate to within 1% of specimen thickness (~±2.5 μm) on very smooth-tooled surfaces	1

TABLE 20. FILLED-HOLE COMPRESSION TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6036 Specifications	ASTM D 6742 Specifications	Importance of Difference
Measurement of hole diameter	Not addressed	Micrometer or gage capable of determining the hole diameter to ±0.025 mm	NC
Fastener torque	7 N-m	Fastener shall be tightened to the required value using a calibrated torque wrench	1
Strain measurement	Not required	25-mm gage length extensometer No discussion of strain gages	1
Loading of specimen/fixture	Specimen loaded directly into grips	• Fixture is hydraulically gripped and compressive load is sheared by means of friction into the test specimen • Fixture does not allow specimens to be end-loaded	2-3

TABLE 21. FILLED-HOLE COMPRESSION TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6036 Specifications	ASTM D 6742 Specifications	Importance of Difference
Specimen area, A	Gross area measurement based on average specimen thickness and width	Gross area measurement (width times thickness) in the vicinity of the hole	1
Ultimate filled-hole compressive strength	Use gross area for each specimen	Use gross area for each specimen Report to three significant figures	0
Nominal filled-hole compressive strength	• Use nominal specimen thickness as specified in material specification • Use gross specimen width	Not addressed	NC
K_T	Unnotched tensile strength divided by the filled hole tensile strength	Not addressed	NC
Width-to-diameter ratio	Not addressed	Calculate/report the actual width-to-diameter ratio for each specimen and the nominal width-to-diameter ratio using nominal values	NC
Diameter-to-thickness ratio	Not addressed	Calculate/report the actual diameter-to-thickness ratio for each specimen and the nominal diameter-to-thickness ratio	NC
Countersink depth-to-thickness ratio	Not addressed	Calculate/report the actual countersink depth-to-thickness ratio for each specimen and the nominal countersink depth-to-thickness ratio	NC
Failure mode	Not addressed	• Failures that do not occur at or near the fastener hole are not acceptable • Use three-place failure mode descriptor	NC
Statistics	Individual values, mean (average) value, and standard deviation for properties determined	Individual values, average value, standard deviation, and coefficient of variation for properties determined	1

TABLE 21. FILLED-HOLE COMPRESSION TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6036 Specifications	ASTM D 6742 Specifications	Importance of Difference
Other reporting requirements	Material identification/info	• Material identification/info	0
	Specimen preparation	• Specimen preparation	0
	Specimen dimensions	• Specimen dimensions	0
	Test operator	• Test operator	0
	Incidents/deviations	• Variations/anomalies/problems	0
	Date/location of test	• Date/location of test	0
	Test method used	• Date/revision of test method used	0
	Aging/exposure conditions	• Conditioning parameters and results	0
	Temperature/humidity of testing lab	• Temperature/humidity of testing lab	0
	Equipment used	• Equipment used	0
	Test parameters used	• Location of fastener head (bag side or tool side)	1
		• Washer type/material, number used	1
		• Fastener information and installation specifications, including torque used	1
		• Countersink geometry	1
		• Gaps between fixture pieces as measured by feeler gages	1
		• Grip pressure	1
		• Alignment results	1
		• Data acquisition sampling rate	1
		• Speed of testing	1
		• Percent bending results (if evaluated)	1
		• Calibration dates for test	1

2.8 IN-PLANE SHEAR TESTING.

The two test methods considered, prEN 6031 and ASTM D 3518, are similar test methods for determining the in-plane shear properties of composite materials using ±45° type laminates loaded in tension (tables 22 through 24). Whereas both prEN 6031 and ASTM D 3518 specify a minimum of five specimens, the AMS 2980 and 3970 specifications require six specimens. Otherwise, the only significant difference between the two test methods is the prescribed specimen thickness. Although both the prEN 6031 test method and the AMS 2980 and 3970 specifications require an 8-ply ±45° laminate for either unidirectional tape or woven fabric, ASTM D 3518 requires 16-, 20-, or 24-ply unidirectional tape laminates or 8-, 12-, or 16-ply woven fabric laminates. ASTM D 3518 refers to an investigation by Kellas et al. [7] where a specimen thickness effect on strength was observed. Thus, lower strengths are expected to be produced from the testing of thinner ±45° specimens, a result of the reduced load-carrying capacity of the surface plies relative to the inner plies. Based on this observation, the different laminate thickness specified in the prEN 6031 and the ASTM D 3518 standards have the potential to produce a moderate effect on the maximum shear stress and shear strain.

TABLE 22. TENSILE IN-PLANE SHEAR TESTING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 6031 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6031/ D 3518 (Section 6.5.4)	ASTM D 3518 Specifications	Importance of Difference
Laminate lay-up	45/-45 fully symmetrical 8-ply unidirectional tape or woven fabric	$[(45/-45)/(-45/45]_{2S}$ (AMS 2980-2 and AMS 3970-2)	• Unidirectional tape: $[45/-45]_{nS}$, where $4 \leq n \leq 6$ (16, 20, or 24 plies) • Woven fabric: $[45/-45]_{nS}$, where $2 \leq n \leq 4$ (8, 12, or 16 plies)	1
Overall specimen length	230 ±1 mm	230 ±1 mm	Recommended 200-300 mm	1
Specimen gage length	130 ±1 mm		Not specified	1
Specimen width	25 mm	25 mm	25 mm recommended	0
Specimen width tolerance	±0.25 mm	±0.25 mm 0.08-mm side-to-side parallelism	±1% of specimen width	1
Specimen thickness	8 x cured ply thickness		• 16, 20, or 24 plies for unidirectional tape • 8, 12, or 16 plies for woven fabric	3
Thickness tolerance	Not specified	±0.2-mm thickness tolerance 0.08-mm face-to-face parallelism	±4% of specimen thickness (D 3039)	1
Use of tabs	Specimen shall have 50-mm-long tabs		Optional, normally not required	1

TABLE 23. TENSILE IN-PLANE SHEAR TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6031 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6031/ D 3518 (Section 6.5.4)	ASTM D 3518 Specifications	Importance of Difference
Load indicator	Accurate to within 1% of the load range used		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Grips	Wedge action or hydraulic		Highly desirable to use rotationally self-aligning grips to reduce bending stress	1
Specimen alignment	As accurate as possible		Recommends limiting percent bending to a range of 3% to 5% strain levels > 1000 με	1
Test speed	1 mm/min until 2% strain, 10 mm/min thereafter	2 mm/min	Constant head-speed tests: 2 mm/min Strain controlled tests: 0.01 min^{-1}	1
Sampling	Five specimens	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Strain gage selection	5- to 10-mm active gage length		• Required active gage length of at least 3 mm (6 mm recommended for most materials) • Recommended active gage length ≥ the characteristic-repeating unit of the weave for woven fabric laminates • Recommended resistance ≥ 350 Ω	1
Extensometers	• Bidirectional extensometer can be used • Accurate to within 1%		• Recommended gage length in the range of 10 to 50 mm • Extensometer shall satisfy Practice E 83	1

TABLE 23. TENSILE IN-PLANE SHEAR TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6031 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6031/ D 3518 (Section 6.5.4)	ASTM D 3518 Specifications	Importance of Difference
Specimen conditioning	Specimen storage and testing to be carried out at 23° ±2°C and 50% ±5% relative humidity		• Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity • Requires maintaining temperature to ±3°C and relative vapor level to ±3%	1
Measurement of specimen width	• Vernier caliper accurate to nearest 0.1 mm • Average of three measurements in gage section		Micrometer with flat anvil accurate to within 1% of specimen width (~±25 μm) tolerance	1
Measurement of specimen thickness	• Flat-face micrometer accurate to nearest 0.01mm • Average of three measurements in gage section		Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm)	1

TABLE 24. TENSILE IN-PLANE SHEAR TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6031 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6031/D 3518 (Section 6.5.4)	ASTM D 3518 Specifications	Importance of Difference
Specimen area, A	Average of three width measurements times average of three thickness measurements (within gage section)		Average of three area measurements within gage section ($A = w \times h$)	1
Maximum shear stress	• Use maximum tensile load during testing • Use average of three width and three thickness measurements for area	• Determine shear stress at: 0.2% offset shear strain, 5% shear strain, and ultimate • Calculated and reported using both the average measured laminate thickness and the nominal laminate thickness	• Use maximum load at or below 5% shear strain • Calculated using the average specimen area • Report to three significant figures • Calculation of 0.2% offset shear strength is optional	1
Maximum shear strain	Not addressed	Not addressed	• Use minimum of 5% or γ_{12} at maximum shear stress • Report to three significant figures	NC
Shear modulus	Modulus reference points: 500-2500 με	• Modulus reference points: 2000-6000 με • Calculated and reported using both the average measured laminate thickness and the nominal laminate thickness	• Chord modulus over a 4000 ±200 με shear strain range, starting with the lower strain point in the range of 1500 to 2500 με • Report to three significant figures • Report shear strain range used	1
Failure mode	Not addressed	• No tension or shear failure before defined strain levels • Ultimate failure within the gage length	Not addressed	NC
Statistics	Individual values, mean value, and standard deviation of tensile strength		Individual values, average value, standard deviation, and coefficient of variation	1

TABLE 24. TENSILE IN-PLANE SHEAR TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6031 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6031/ D 3518 (Section 6.5.4)	ASTM D 3518 Specifications	Importance of Difference
Other reporting requirements	Date/location of test		Date/location of test	0
	Material identification/info		Material identification/info	0
	Specimen preparation		Specimen preparation	0
	Specimen dimensions		Specimen dimensions	0
	Test operator		Test operator	0
	Incidents/deviations		Variations/anomalies/problems	0
	Equipment used		Equipment used	0
	Test method used		Date/revision of test method used	0
	Aging/exposure conditions		Conditioning parameters and results	0
	Test parameters used		Temperature/humidity of testing lab	1
			Grip pressure	
			Alignment results	
			Data acquisition sampling rate	
			Speed of testing	
			Strain transducer type/placement	
			Strain gage information	
			Stress-strain curves and tabulated data	
			Percent bending results (if evaluated)	
			Calibration dates for test	1

2.9 BEARING STRENGTH TESTING.

The two test methods considered, prEN 6037 and ASTM D 5961 procedure A, are similar test methods for determining the bearing strength of multidirectional composite laminates using a double-shear, tensile-loading procedure (tables 25 through 27). The AMS 2980 and 3970 specifications provide additions and changes only to prEN 6037; the ASTM D 5961 standard is not referred to in either AMS specification. Note, however, that the only additions or changes specified in AMS 2980 and 3970 are the laminate lay-up and that six specimens be tested. prEN 6037 also requires six specimens, whereas ASTM D 5961 requires that at least five specimens be tested.

A comparison of specimen geometries revealed several minor differences in specimen length, edge distance, specimen width, hole diameter, and resulting ratio of specimen width to hole diameter. Since localized bearing failure is produced in this test, none of these differences are expected to produce significant effects on results. However, tolerance differences for the hole diameter and pin diameter produce differences in hole clearance. For prEN 6037, the resulting hole clearance (difference between the hole and pin diameter) will range between 0.0127 and 0.127 mm, whereas for ASTM D 5961, the hole clearance will range between 0.00 and 0.06 mm. This difference in range may produce minimal differences in the measured bearing strength. The loading procedure also differs between the two test methods, with prEN 6037 including an unload/reload step following the estimated yield load that is not present in ASTM D 5961.

Perhaps the most significant difference between the two test methods is the specification of fastener torque. Note that prEN 6037 specifies no torque and a minimum clearance on either side of the specimen. In contrast, ASTM D 5961 specifies a standard fastener torque of 2.2-3.4 N-m but allows for any variation if documented. Using this standard value of fastener torque could produce moderate to major differences in the results compared to the specified clearance in prEN 6037. This difference in bearing strength results from the difference in restraint against out-of-plane hole deformation that is provided by the fixture or the fastener. Note, however, that this difference could be reduced or eliminated if the torque was reduced or eliminated, as permitted in ASTM D 5961.

TABLE 25. BEARING TESTING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Laminate lay-up	• Tape: multidirectional directed or quasi-isotropic laminates • Fabric: quasi-isotropic laminate	$[(0/90)/(45/-45)]_{3S}$ (AMS 2980-2) $[(45/-45)/(0/90)/(-45/45)/(90/0)]_{2S}$ (AMS 3970-2)	• Multidirectional fiber orientations • Balanced and symmetric stacking sequences	1
Overall specimen length	150 mm ±1		135 mm	1
Required specimen width	35 mm ±0.1		36 mm	1
Required specimen width tolerance	±0.1 mm		±1 mm	1
Specimen thickness	According to laminate lay-up 4-mm nominal thickness		4-mm nominal thickness Permissible range of 3-5 mm	0
Hole diameter	6.35 mm		6 mm	1
Hole tolerance	+0.0889/-0.00 mm		+0.03/-0.00 mm	2
Fastener (pin) Diameter	6.35 mm		6 mm	1
Fastener (pin) tolerance	-0.0127/-0.0381 mm		±0.00/-0.03 mm	2
Edge distance	20 mm		18 ±1mm	1

TABLE 25. BEARING TESTING—SPECIMEN GEOMETRIC COMPARISONS (Continued)

Property	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Ratio of specimen width to hole diameter	5.5		6	1
Ratio of hole diameter to thickness of specimen	Not addressed		1.5-3.0 preferred	NC
Tabs	• Specimen type 1: optional -50 mm length • Specimen type 2: without tabs		Tabs not required	1

TABLE 26. BEARING TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Test procedures provided	Gives two procedures for double shear: • Specimen type 1: gripped with optional tabs • Specimen type 2: pin-loaded with 1/2″ hole		Load applied to specimen by means of a double-shear clevis using the loaded fastener or pin (procedure A).	1
Load indicator	• Accurate to within 1% • Select load range such that failure will occur between 20% and 80% of the full scale		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Specimen alignment	Ensure specimen is perfectly aligned and centered on the machine axis. Take extreme care with this operation since it affects the results and the scatter.		Take care to align the long axis of the gripped fixture with the test direction	0
Test speed	1 mm/min		Constant head-speed tests: 2 mm/min Strain controlled tests: 0.01 min^{-1}	1
Sampling	Six specimens	Six specimens (AMS 2980-2 and AMS 3970-2)	At least five specimens	2
Hole preparation	Follow EN 2565 method B for carbon and EN 2374 method B for glass		• Holes should be drilled undersized and reamed to final dimensions • Special care shall be taken to ensure that creation of the specimen hole does not delaminate or otherwise damage the surrounding material	1
Specimen conditioning	Specimen storage and testing to be carried out at 23° ±2°C and 50% ±5% relative humidity		• Standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity • Requires maintaining temperature to within ±3°C and relative vapor level to within ±3%	1

TABLE 26. BEARING TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Measurement of specimen width	Micrometer with flat anvil accurate to within 0.01 mm		Micrometer with flat anvil accurate to within 1% of specimen width (~±25 μm)	1
Measurement of specimen thickness	• Micrometer with flat anvil accurate to within 0.01 mm • Average of three measurements selected as representative of neighborhood of the hole		• Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm) on irregular surfaces • Micrometer with flat anvil accurate to within 1% of specimen thickness (~±2.5 μm) on very smooth-tooled surfaces	1
Measurement of hole diameter	Micrometer with flat anvil accurate to within 0.01 mm		Accurate to within 1% of hole diameter	1
Fastener torque	No torque applied (leave 0.1-mm clearance on each side of specimen)		• 2.2-3.4 N-m (nominal) • The nominal test configuration uses a relatively low level of fastener installation torque to give conservative bearing stress results • Results are affected by the installed fastener preload	3-4
Measurement of fastener torque	Not applicable		Torque wrench capable of determining the applied torque to within ±0% of desired value	NC
Measurement of bearing strain	Extensometer (50-mm gage length recommended) or equivalent strain measuring device accurate to within 1% in the load range used		Bearing strain data shall be determined by a bearing strain indicator able to measure longitudinal hole deformation relative to the fixture simultaneously on opposite edges of the specimen	1
Loading procedure	• Load specimen to estimated yield load, then unload to a value of about 10%-20% • Reloaded until failure occurs		Specimen is loaded until a maximum is reached and load has dropped off about 30% from maximum	2

TABLE 27. BEARING TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Ultimate bearing strength	Failure load divided by bearing area		Failure load divided by bearing area Report to three significant figures	0
Bearing strain	Not addressed		Average displacement from two indicators divided by the hole diameter	NC
Bearing chord stiffness	Not addressed		Chord stiffness in the essentially linear portion of the bearing stress/bearing strain curve	NC
Effective origin	Not addressed		Intersection of the chord stiffness line with the bearing strain axis	NC
Ultimate bearing strain	Not addressed		Bearing strain at ultimate load using the effective origin for bearing strain	NC
Yield bearing strength vs offset bearing strength	Yield bearing strength: • Text: load at 2% permanent hole elongation divided by bearing area • Figure: Suggests using the intersection of load/ elongation curve and 2% offset stiffness line (using reloading slope)		Offset bearing strength: Using effective origin, the intersection of the bearing stress/strain curve with the bearing chord stiffness line that has a specified strain offset (ex: 2%)	NC
Initial peak bearing strength	Not addressed		Bearing stress at initial peak when followed by a sharp drop in bearing strength	NC

TABLE 27. BEARING TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Failure mode	• Determined using five figures in standard • Tensile failure of specimen or fastener failure unacceptable		• Report mode and location of failure using three-part failure mode code (given in standard) • Net tension or cleavage failure modes not acceptable	1
Statistics	Individual values, mean value, and standard deviation of yield and ultimate bearing strength		Individual values, mean (average) value, standard deviation, and coefficient of variation of properties	1
Data recording	Record the load vs elongation diagram		Record load vs bearing strain continuously or at frequent intervals. If specimen is to be failed, record the maximum load, the failure load, and the strain at or near point of rupture.	1
Other reporting requirements	Date/location of test Material identification/info Specimen preparation Specimen dimensions Test operator Incidents/deviations Equipment used Test method used Aging/exposure conditions		• Date/location of test • Material identification/info • Specimen preparation • Specimen dimensions • Test operator • Variations/anomalies/problems • Equipment used • Date/revision of test method used • Conditioning parameters and results	0 0 0 0 0 0 0 0 0

TABLE 27. BEARING TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6037 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6037 (Section 6.5.10)	ASTM D 5961 Specifications (Double shear, procedure A)	Importance of Difference
Other reporting requirements (continued)	Test parameters used		• Width to diameter ratio for each specimen • Edge distance ratio for each specimen • Diameter to thickness ratio for each specimen and nominal value • Average ply thickness of the material • Fastener or pin type • Fastener or pin diameter • Fastener torque (if appropriate) • Hole clearance • Bearing strain indicator placement on specimen • Temperature/humidity of testing lab • Grip pressure • Data acquisition sampling rate • Speed of testing • Calibration dates for test	1 1

2.10 COMPRESSION AFTER IMPACT TESTING.

Although both of the compression after impact test methods compared involve drop-weight impact testing followed by edgewise compression testing, these two test methods serve very different purposes (tables 28 through 30). Test method prEN 6038 focuses on the energy level associated with barely visible impact damage (BVID), a damage state defined as producing a 0.3-mm-deep indentation in the impacted surface. In contrast, SACMA SRM 2R is intended as either a screening or comparison test and uses a single impact energy level. Note that the two AMS specifications, AMS 2980 and 3970, provide additions and changes only to prEN 6038; the SACMA SRM 2R standard is not referred to in either AMS specification. Thus, the AMS specifications serve the same general purpose of prEN 6038 and focus on examining the BVID and the compression after impact strength associated with this damage state.

Although there are many significant differences in the test procedures between the two compression after impact test methods considered, the specimen, impact support fixture, and compression after impact test fixture specifications are very similar. The most significant difference is the recommended mass of the impactor. Significant differences between the two test methods include the number and magnitude of specified impact energy levels, the method of postimpact nondestructive inspection, and the number of specimens impacted and compression-tested. The most significant of the modifications listed in the AMS specifications involve the number of impact energy levels used. Whereas prEN 6038 requires impacting at a total of seven different energy levels, the AMS specifications start the impacting with the lowest energy level and increase the impact energy until an indentation depth of 0.3 mm is created. Once this indentation depth has been obtained, only one additional impact energy level is required.

TABLE 28. COMPRESSION AFTER IMPACT TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS

Property	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Laminate lay-up	Quasi-isotropic specimen • Tape: [(45/0/-45/90]nS with n chosen to obtain thickness ~ 4 mm • Fabric: [(45/-45)/(90/0)]mS with n chosen to obtain thickness ~ 4 mm	$[(45/-45)/(90/0)]_{6S}$ (AMS 2980-2) $[(45/-45)/(0/90)/(-45/45)/(90/0)]_{3S}$ (AMS 3970-2)	Quasi-isotropic specimen • Tape: 24-48 plies of tape [(45/0/-45/90]nS • Fabric: sufficient plies to achieve 4.5-5.6 mm thickness	1
Specimen length	150 mm		150 mm	0
Specimen length tolerance	±0.1 mm		±0.25 mm	1
Specimen width	100 mm		100 mm	0
Specimen width tolerance	±0.1 mm		±0.25 mm	1
Parallelism and perpendicularity	• Specimen sides: 0.02-mm parallelism and perpendicular requirement • Specimen ends: 0.0125-mm parallelism requirement		Ends shall be machined perpendicular to the longitudinal surfaces to within 0.03 mm	1
Impact machine	• Drop-weight impact tester • Capable of capturing the drop weight after the first impact		• Drop-weight impact tester (dimensioned figure provided) • Capable of avoiding any rebound hits of the specimen	0 0
Method of supporting specimen during impact	Secure to 20-mm-thick steel base plate using four rubber-tipped clamps		Secure to 19-mm-thick aluminum support base using four rubber-tipped clamps	1
Unsupported area during impact	75 ±0.1 mm by 125 ±0.2 mm		76.2 mm by 127 mm	1

TABLE 28. COMPRESSION AFTER IMPACT TESTING—SPECIMEN/FIXTURE GEOMETRIC COMPARISONS (Continued)

Property	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Impactor	• Mass: 1-3 kg or 4-6 kg to within ±10g • Sphere radius: 8 ±0.25 mm • Material: steel with R_m= 2000 MPa		• Mass: 5.6 kg recommended • Hemispherical radius: Section 6.3: 7.875 mm Section 9.1.1: 7.95 mm • Material: steel, hardened tip	2 1 1
Compression after impact test fixture	• Simply supports test specimen along all four edges • Drawings of fixture given without dimensions or references	.	• Simply supports test specimen along all four edges • Drawings of fixture given with dimensions	0 2

TABLE 29. COMPRESSION AFTER IMPACT TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Load indicator	• Accurate to within 1% in the relevant load range • Select load range so that failure occurs between 20% and 80% of the scale		As defined by ASTM E 4	1
Specimen conditioning	Specimen storage and testing to be carried out at 23° ±2°C and 50% ±5% relative humidity		Using SACMA-recommended method SRM 11	1
Sampling	• One specimen at each of seven defined energy levels • Three specimens at BVID level for compression testing	• One or more specimens to determine energy levels • Three specimens per energy level for compression testing (AMS 2980-2 and AMS 3970-2)	Minimum of five specimens at one energy level	4
Measurement of specimen width	• Vernier slide calipers calibrated to 0.01-mm accuracy • Three measurements at different points of the specimen		• Micrometer with flat-face suitable for reading to 0.03-mm accuracy • Average of no less than two measurements taken near the specimen center	1
Measurement of specimen thickness	• Flat-face micrometer calibrated to 0.01-mm accuracy • Three measurements at different points of the specimen		• 7-mm ball-nose micrometer suitable for reading to 0.03-mm accuracy • Average of four measurements taken around the impact area prior to impact	1

TABLE 29. COMPRESSION AFTER IMPACT TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Impact energy levels	• 9, 12, 16, 20, 25, 30, and 40 Joules • BVID level: energy corresponding to an indentation depth of 0.3 mm	Three impact energy levels: 1. Energy level producing 0.3-mm indentation 2. One energy level below the 0.3-mm impact energy level 3. Two energy levels above the 0.3-mm impact energy level	One impact energy level: 6.7 Joules per mm of panel thickness	4
Impact energy level tolerance	Not specified	±10%	Not specified	NC
Postimpact nondestructive inspection	Inspect and assess the visibility of the indentation and any fiber breaks on both faces of the specimen	On at least one representative specimen of each impact level determined for compression testing	An ultrasonic scan of the impacted specimen and the general configuration of the delaminations shall be recorded	4
Measurement of impact depth	• Depth gage with 3-mm-diameter hemispherical adapter calibrated to 0.01-mm accuracy • Measure the depth in the deepest part of the indented area. Next, measure the depth at four points 20 mm from the center of indentation, and subtract from the depth at the deepest part. The indented depth is the average of these four values.		Not addressed	NC

TABLE 29. COMPRESSION AFTER IMPACT TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Strain gage placement and usage	• 25 ±1 mm inward from upper corners and from top and bottom of the specimen • If required in relevant specification, two strain gages should be on the front face of the lowest impact energy specimen	Gages to be placed on both faces of the specimen (four gages total) and coupled to the recorder such that panel buckling can be detected	• 25.4 mm downward and inward from upper corners of the specimen • Gages to be placed on both sides of the specimen (four gages total). Output of each gage shall be plotted individually to check for buckling • Strain gages can be omitted if dimensional variation in specimen are within tolerances given	0 0 NC
Specimen alignment	Carefully align the impacted specimen in the test rig		Test is sensitive to parallelism of specimen ends as well as perpendicularity and system alignment	0
Test speed	0.5 mm/min	1 mm/min	1 mm/min	0

TABLE 30. COMPRESSION AFTER IMPACT TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Impact energy, E	Either $E = m\,g\,h$ or $E = ½\,m \times v^2$		Either E = drop weight times drop height divided by specimen thickness or $E = ½\,m \times v^2$ divided by specimen thickness	2
Specimen area, A	Width times thickness		Average width times average thickness	0
Compressive strength after impact	Break failure load divided by specimen area		Ultimate compressive load divided by specimen area	0
Nominal compressive strength after impact	Break failure load divided by specimen width times the nominal thickness of the specimens		Report normalization method used, if any, for compressive strength	1
Compression modulus	Not addressed		• Optional • Using load data at 1000 and 3000 με • Strains based on the average of all four strain gages	NC
Ultimate strain at failure	Not addressed		Optional	NC
Specified failure mode	Not addressed	Compression failure including at least a portion of the impacted area	Specimens that fail at a location other than the central impacted zone are not acceptable (retests shall be performed)	0
Statistics	Not addressed		Individual values, average value, standard deviation, and coefficient of variation for properties determined	NC

TABLE 30. COMPRESSION AFTER IMPACT TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6038 Specifications	AMS 2980/3970 Additions/ Changes to prEN 6038 (Section 6.5.11)	SACMA SRM 2R 1994 Specifications	Importance of Difference
Other reporting requirements	• Material identification/info		• Material identification/info	0
	• Specimen preparation		• Specimen preparation	0
	• Specimen dimensions		• Specimen dimensions	0
	• Deviations from test method		• Deviations from test method	0
	• Test operator		• Test operator	0
	• Date/location of test		• Date/location of test	0
	• Visibility and depth of indentation • Any breaks in the fibers on both faces of the specimen	• Impact indentation depths of all specimens • Visual damage on both sides of the specimens	• Damaged area • Method used to determine the configuration of the damaged area	4
	• Equipment used • Test method used		• Impact method used	0
	• Curve of compression strength versus energy			NC
	• Curve of indentation depth versus energy			NC
	• BVID energy level and corresponding value of strength			NC
	• Test parameters used		• Specimen pretest conditioning history • Temperature/humidity of testing lab • Fiber volume fraction of each specimen	1 1 1

2.11 MODE I FRACTURE TOUGHNESS TESTING.

Of the two AMS specifications considered, only AMS 3970 includes Mode I fracture toughness testing (table 31 through 33). Of the two test methods compared, prEN 6033 and ASTM D 5528, only prEN 6033 is referred to in the AMS 3970 specification. However, the only additions or changes to prEN 6033 specified in AMS 3970 are the laminate lay-up and that six specimens be tested. Interestingly, the number of test specimens is not specified in prEN 6033, whereas at least five specimens are specified in ASTM D 5528.

Although both prEN 6033 and ASTM D 5528 use a double-cantilever beam specimen to calculate the Mode I fracture toughness, significant differences exist in the specimen configurations. The most significant differences involve the length of the specimen and the length and thickness of the film insert used to produce a delamination in the specimen. Significant differences also exist in the specimen loading procedure, including both the preloading procedure and the subsequent loading. Further, significant differences exist in the method used to calculate the Mode I fracture toughness, G_{IC}. In prEN 6033, G_{IC} is calculated using the area between the loading and unloading curves (force versus crosshead displacement) over a 100-mm length of crack propagation. ASTM D 5528 recommends the use of a modified beam theory method for calculating G_{IC} values as a function of delamination length. Thus, while a single value of G_{IC} is calculated and reported in prEN 6033, a series of G_{IC} values are calculated and three values reported in ASTM D 5528.

TABLE 31. MODE I FRACTURE TOUGHNESS TESTING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 6033 Specifications	AMS 3970 Additions/ Changes to prEN 6033 (Section 6.5.19)	ASTM D 5528 Specifications	Importance of Difference
Laminate lay-up	• Unidirectional laminate for tape material • 0º/90º laminate for fabric material	$[(0/90)]_{6S}$ (AMS 3970-2)	• Unidirectional laminates with an even number of plies • Delamination growth occurring in the 0° direction	1
Overall specimen length	250 ±5 mm		At least 125 mm	2
Specimen width	25.0 mm		20 to 25 mm nominally	1
Specimen width tolerance	±0.2 mm		Not specified	NC
Specimen thickness	3.0 ±0.2 mm		4-mm nominal thickness Permissible range of 3-5 mm	1
Length of film insert	25 ±1 mm		• Approximately 63 mm • Initial delamination length of approximately 50 mm plus extra length to bond hinges or load blocks	2-3
Release film insert for delamination	Double layer of polytetrafluorethylene foil, 0.02-0.03 mm thick, and placed at the midplane of the laminate		• Nonadhesive insert at the mid-plane of the laminate with film thickness no greater than 13 µm • Polytetrafluorethylene film recommended for epoxy matrices cured at or below 177°C • Polyimide film recommended for polyimide, bismaleimide, or thermoplastic matrices processed above 177°C	3-4
Method of load introduction	Bent aluminum strips (0.5-0.7 mm thick) or hinged metallic tabs (1.0-1.5 mm thick)		Either metal piano hinge tabs or loading blocks	1

TABLE 32. MODE I FRACTURE TOUGHNESS TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6033 Specifications	AMS 3970 Additions/ Changes to prEN 6033 (Section 6.5.19)	ASTM D 5528 Specifications	Importance of Difference
Load indicator	Accurate to within 1% in the load range used		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Alignment	• Misalignment of the grip faces must be less than 0.05 mm at 300 mm separation, increasing by less than 0.1 mm per meter at separations above 300 mm • Parallelism between loading heads should be better than 0.4 mm at any position of the crosshead		Make sure that the specimen is aligned and centered in the grips	1
Test speed	10 mm/min		Constant crosshead rate between 1 and 5 mm/min	1-2
Sampling	Not specified	Six specimens (AMS 3970-2)	At least five specimens	2
Specimen conditioning	Specimen conditioning and testing at 23° ±2°C and 50% ±5% relative humidity		Store and test specimens at standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity	1
Measurement of specimen width	• Slide caliper with accuracy to the nearest 0.05 mm • Measured to the nearest 0.1 mm		• Micrometer with flat anvil accurate to within 1% of specimen width (~±25 μm), • Measure thickness of each specimen at the midpoint and at 25 mm from either end and report average value	1
Measurement of specimen length	Average of a minimum of three measurements along the length of the specimen to be recorded		Not required	NC

TABLE 32. MODE I FRACTURE TOUGHNESS TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6033 Specifications	AMS 3970 Additions/ Changes to prEN 6033 (Section 6.5.19)	ASTM D 5528 Specifications	Importance of Difference
Measurement of specimen thickness	Not required		• Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 μm) on irregular surfaces • Micrometer with flat anvil accurate to within 1% of specimen thickness (~±2.5 μm) on very smooth-tooled surfaces • Measure thickness of each specimen at the midpoint and at 25 mm from either end and report average value • Thickness variation in a specimen shall not exceed 0.1 mm	NC
Determining position of delamination front	• Optical microscope with magnification of 15X to 25X • Thin layer of white ink applied to side faces may be used to facilitate measurement		• Optical microscope with magnification no greater than 70X capable of pinpointing the delaminations front with an accuracy of at least ±0.5 mm • Coat specimen edges ahead of insert with typewriter correction fluid and mark with thin vertical lines	1 1
Opening displacement indicator	Crosshead deflection		If the deformation of the testing machine (with specimen grips) is less than 2% of the opening displacement of the specimen, the crosshead deflection may be used. If not, an external gage or transducer with an accuracy of ±1%.	2-3

TABLE 32. MODE I FRACTURE TOUGHNESS TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6033 Specifications	AMS 3970 Additions/ Changes to prEN 6033 (Section 6.5.19)	ASTM D 5528 Specifications	Importance of Difference
Loading procedure	• Preload until an initial crack length of 10 to 15 mm has been achieved. Mark position of crack tip after preloading on both sides of the specimen. • Load the specimen until a total crack length of about 100 mm has been achieved, record load and crosshead displacement • Mark the final crack length on both sides of the specimen • Unload the specimen • Determine the propagated crack length		• Preload specimen, recording the point at which the visual onset of delamination movement is observed • Stop loading after an increment of delamination growth of 3 to 5 mm has occurred. Unload and mark the position of the tip of the precrack on both edges of the specimen. • Reload specimen, record load and displacement values at many delamination length increments up to 50 mm • Unload the specimen and mark the positions of the delaminate crack tip on both edges of the specimen	2-3

TABLE 33. MODE I FRACTURE TOUGHNESS TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6033 Specifications	AMS 3970 Additions/ Changes to prEN 6033 (Section 6.5.19)	ASTM D 5528 Specifications	Importance of Difference
Mode I fracture toughness, G_{IC}	Referred to as Mode I fracture toughness energy $G_{IC} = \{A/(a + w)\} \times 10^6$ (J/m^2) where A = energy to achieve total propagated crack length: the area between the loading and unloading curves from the initial crack length to the final crack length. a = propagated crack length: difference in length between the initial crack length and the final crack length (in millimeters) w = width of the specimen (in millimeters)		• Referred to as Mode I interlaminar fracture toughness • Suggested data reduction method is the Modified Beam Theory (MBT) Method: $G_{IC} = (3\ P\ \delta)/\{2\ b\ (a+\lvert\Delta\rvert)\}$ where P = load δ = load point displacement b = specimen width (average of 3 measurements) a = delamination length Δ = correction for rotation at delamination front (additional delaminate length). Determined experimentally from plot of cube root of compliance vs delamination length.	3-4
Statistics	Not addressed		Individual values, mean (average) value, standard deviation, and coefficient of variation of properties	NC
Data recording	Load vs crosshead displacement diagram		• Load vs displacement curve for each specimen • Delamination resistance curve (R curve) for each specimen (plot of G_{IC} versus delamination length) • G_{IC} value at onset of nonlinearity in load vs displacement curve • G_{IC} value at visual initiation of growth • G_{IC} value at 5% offset/maximum load (5%/max)	1 3 3 3 3

TABLE 33. MODE I FRACTURE TOUGHNESS TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6033 Specifications	AMS 3970 Additions/ Changes to prEN 6033 (Section 6.5.19)	ASTM D 5528 Specifications	Importance of Difference
Other reporting requirements	• Date/location of test		Date/location of test	0
	• Material identification/info		Material identification/info	0
	• Specimen preparation		Specimen preparation	0
	• Specimen dimensions		Specimen dimensions	0
	• Aging/exposure conditions		Conditioning parameters and results	0
	• Individual test results and calculations		Standard data reporting sheet	0
	• Test operator			1
	• Incidents/deviations			1
	• Equipment used			1
	• Test method used			1
	• Set of typical load vs crosshead displacement curves (individual curves kept by test laboratory)			1
	• Fiber bridging in the crack			1
	• Movement of the crack to plies adjacent to the mid-plies			1
	• Test parameters used			1
			Load rate	1
			Fiber volume fraction	1
			Void content	1
			Temperature/humidity of testing lab	1
			Hinge/loading block info	

2.12 MODE II FRACTURE TOUGHNESS TESTING.

As was the case for Mode I testing, Mode II fracture toughness testing was only included in AMS 3970 specifications (tables 34 through 36). Further, AMS 3970 refers only to the prEN 6034 test method. The only additions or changes to prEN 6034 specified in AMS 3970 are the laminate lay-up that six specimens to be tested. As was the case for Mode I testing, however, the number of test specimens is not specified in the prEN test method.

Although currently there is no ASTM standard for Mode II fracture toughness testing, a comparison is made between prEN 6034 and a draft ASTM standard for Mode II fracture toughness testing. Whereas the draft ASTM test method (4ENF) uses a four-point loading end-notch flexure configuration, prEN 6034 uses a three-point loading configuration. As a result of this fundamental difference in loading configuration, a comparison of the specimen geometries has limited value. However, meaningful comparisons may be made between the length and thickness of the film insert. Significant differences exist in both quantities between the two test methods. Further, prEN 6034 uses the residual part of a previously tested G_{IC} specimen, whereas the draft ASTM 4ENF test method uses an untested specimen that is precracked under Mode II loading. Significant differences also exist in the method used to calculate the Mode II fracture toughness, G_{IIC}. Whereas prEN 6034 produces a single value of G_{IC}, three different G_{IIC} values are calculated and reported in the draft ASTM 4ENF test method.

TABLE 34. MODE II FRACTURE TOUGHNESS TESTING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 6034 Specifications	AMS 3970 Additions/ Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Laminate lay-up	• Unidirectional laminate for tape material • 0º/90º laminate for fabric material	$[(0/90)]_{6S}$ (AMS 3970-2)	• Unidirectional laminates with an even number of plies • 32-ply laminate often works well	1
Overall specimen length	• Greater than 110 mm • The test specimen shall be cut from the residual part of G_{IC} specimen tested or at least loaded and cracked per EN 6033		• Outer span length +20 mm + twice the roller diameter • (Approximately 132 to 160 mm)	1
Specimen width	25.0 mm		Recommended width of 25 mm	0
Specimen width tolerance	±0.2 mm		The variation in specimen width shall not exceed 3% of the specimen's average width	1
Specimen thickness	3.0 ±0.2 mm		• 32-ply laminate often works well • May be modified to obtain a suitable value for maximum specimen slope (6.9° or less)	1
Release film insert for delamination	As per EN 6033 (Mode I testing): Double layer of polytetrafluorethylene foil, 0.02-0.03 mm thick, and placed at the mid-plane of the laminate		• Nonadhesive insert at the mid-plane of the laminate with film thickness no greater than 13 µm • Polytetrafluorethylene film recommended for epoxy matrices cured at or below 177°C • Polyimide film recommended for polyimide, bismaleimide, or thermoplastic matrices processed above 177°C	3-4
Length of film insert in specimen	40 ±1 mm (the length used in G_{IC} specimens – to be precracked for Mode II testing)		Greater than or equal to: (distance from the outer to inner roller on test fixture) + (the larger of either two laminate thicknesses or 15 mm) +10 mm + roller diameter	NC

TABLE 34. MODE II FRACTURE TOUGHNESS TESTING—SPECIMEN GEOMETRIC COMPARISONS (Continued)

Property	prEN 6034 Specifications	AMS 3970 Additions/ Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Test fixture description	Three-point bending fixture		Four-point bending fixture	2-3
Span between outer rollers	100 ±0.5 mm		• 100 mm or 120 mm is a good starting point • Larger values provide a larger distance between the upper loading rollers for crack propagation and are often preferable • May be modified to obtain a suitable value for maximum specimen slope (6.9° or less)	NC
Span between inner rollers	Not applicable (three-point flexure)		• Ratio of inner span length and outer span length either 0.5 or 0.6 • May be modified to obtain a suitable value for maximum specimen slope (6.9° or less)	NC
Central (inner) loading roller diameter	12.5 ±0.1 mm		6.3-9.6 mm	2
Outer support roller diameter	5.0 ±0.1 mm		6.3-9.6 mm	1

TABLE 35. MODE II FRACTURE TOUGHNESS TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6034 Specifications	AMS 3970 Additions/ Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Load indicator	Accurate to within 1% in the load range used		Accuracy over the load range(s) of interest of within ±1% of the indicated value	0
Alignment	Place the specimen in the test fixture to produce an initial crack length of 35 ±1 mm		Make sure that the marks on each edge of the specimen are positioned appropriately such that the specimen and fixture are aligned	1
Test speed	1 mm/min		Constant crosshead rate between 0.1 and 1 mm/min	1-2
Sampling	Not specified	Six specimens (AMS 3970-2)	At least five specimens	2
Specimen conditioning	Specimen conditioning and testing at 23° ±2°C and 50% ±5% relative humidity		Store and test specimens at standard laboratory atmosphere: 23° ±3°C and 50% ±10% relative humidity	1
Measurement of specimen width	Vernier caliper accurate to the nearest 0.1 mm		• Micrometer with flat anvil accurate to within 1% of specimen width (~±25 µm) • Measure at three points along the length of the specimen in which the delamination will be propagated and report average value	1
Measurement of specimen length	Vernier caliper accurate to the nearest 0.1 mm		Measure to the nearest 1 mm	1
Measurement of specimen thickness	A minimum of three measurements distributed over the specimen using a flat-face micrometer accurate to the nearest 0.1 mm		• Micrometer with double-ball interface accurate to within 1% of specimen thickness (~±2.5 µm) on irregular surfaces • Micrometer with flat anvil accurate to within 1% of specimen thickness (~±2.5 µm) on very smooth-tooled surfaces • Measure thickness of each specimen at six points and report average value	1

TABLE 35. MODE II FRACTURE TOUGHNESS TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6034 Specifications	AMS 3970 Additions/ Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Initial crack length	35 ±1 mm from delamination front to outer support		(Distance from the outer to inner roller on test fixture) + (larger of either two laminate thicknesses or 15 mm)	NC
Displacement indicator	Device for recording the displacement of the loading nose as a function of load accurate to within 1% in the deflection range used		If the deformation of the testing machine (with loading fixture) is less than 2% of the opening displacement of the specimen, the crosshead deflection may be used. If not, use two external transducers with an accuracy of ±1% to measure the vertical displacement of the two upper loading rollers and average the two measurements.	1
Determining position of delamination front	• Measured by a vernier caliper accurate to the nearest 0.1 mm using an optical microscope with magnification of 15X to 25X • Thin layer of white ink applied to side faces may be used to facilitate measurement		• Use two optical microscopes (no greater than 70X) positioned on both sides of specimen or mirror used in conjunction with one microscope • Coat specimen edges ahead of insert with a light, uniform coating of white- or silver-colored spray paint	1-2 0
Compliance calibration procedure	Not required		Perform two sets of compliance calibration: 1. Compliance calibration from initial insert • Load specimen to approximately 50% of the predicted critical load while recording the load-displacement behavior • Unload and reposition specimen in fixture with the next larger delamination length. Reload to 50% of predicted critical load • Repeat process for five specimen positionings 2. Compliance calibration from precrack • Precrack specimen by loading until either a 5 ±1 mm increase in delamination length or a notable drop in load occurs • Perform a second pretest compliance calibration (five specimen positionings) in the same manner as described above	NC

TABLE 35. MODE II FRACTURE TOUGHNESS TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6034 Specifications	AMS 3970 Additions/ Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Precracking	Produce initial crack in a defined Mode I procedure (EN 6033) or cut specimens from the residual part of G_{IC} specimen tested or at least loaded and cracked per EN 6033		Precrack specimen by loading until either a 5 ±1 mm increase in delamination length or a notable drop in load occurs	2-3
Loading procedure	• Load the specimen, optically observing the crack tip to detect the crack propagation onset • Record the critical load at delamination crack onset and stop the loading as soon as evidence of crack propagation has been confirmed by a small load drop		• Load specimen until either a 5 ±1 mm increase in delamination length from precrack or a notable drop in load occurs • Split open specimen after test to inspect quality and shape of insert and precrack	2

TABLE 36. MODE II FRACTURE TOUGHNESS TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6034 Specifications	AMS 3970 Additions/Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Mode II fracture toughness, G_{IIC}	Referred to as Mode II fracture toughness energy $G_{IIC} = \frac{9000\, P\, a^2\, d}{2\, w\, (1/4\, L^3 + 3a^3)}$ J/m^2 where: d = displacement at crack delamination onset, mm P = critical load to propagate the crack, N a = initial crack length, mm w = width of the specimen, mm L = span length, mm		• Referred to as Mode II interlaminar fracture toughness • Suggested data reduction method is the Compliance Calibration Method: $G_{IIC} = \frac{m\, P^2}{2\, B}$ where: P = load at which fracture occurs B = width of specimen m = slope of plot of compliance versus delamination length • Calculate three values of G_{IIC}: G_{IIC} value at onset of nonlinearity in load vs displacement curve G_{IIC} value at visual initiation of growth G_{IIC} value at 5% offset/maximum load (5%/max)	3-4
Statistics	Not addressed		Individual values, mean (average) value, standard deviation, and coefficient of variation of properties	NC
Data recording	Load vs displacement diagram		Load vs displacement curve for each specimen Plots of compliance versus delamination length	0 NC

TABLE 36. MODE II FRACTURE TOUGHNESS TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6034 Specifications	AMS 3970 Additions/ Changes to prEN 6034 (Section 6.5.20)	ASTM Draft Standard – 4ENF Specifications	Importance of Difference
Other reporting requirements	• Date/location of test		Date/location of test	0
	• Material identification/info		Material identification/info	0
	• Specimen preparation		Specimen preparation	0
	• Specimen dimensions		Specimen dimensions	0
	• Aging/exposure conditions		Conditioning parameters and results	0
	• Individual test results and calculations		Standard data reporting sheet	0
	• Test operator			1
	• Incidents/deviations			1
	• Equipment used			1
	• Test method used			1
	• Set of typical load vs crosshead displacement curves (individual curves kept by test laboratory)			1
	• Movement of the crack to plies adjacent to the midplies			1
	• Test parameters used		Type and thickness of insert	1
			Fiber volume fraction	1
			Void content	1
			Span length of roller supports	1
			Load rate	1
			Temperature/humidity of testing lab	1

2.13 GLASS TRANSITION TEMPERATURE DETERMINATION.

The two AMS specifications considered, AMS 2980 and 3970, both provide additions and changes to procedure A of test method prEN 6032 (tables 37 through 39). Although not referred to in the AMS specifications, a draft ASTM standard for determining the glass transition temperature by dynamic mechanical analysis (DMA) is used as a comparison test method to prEN 6032. Note that this draft ASTM standard is very similar to SACMA 18R-94, "Glass Transition Temperature (T_g) Determination by DMA of Oriented Fiber-Resin Composites." All three test methods detail the determination of the glass transition temperature using DMA.

The size of the specimen used and the actual DMA test procedure are not specified in the two test methods compared, but rather are determined based on the manufacturer of the DMA equipment. Whereas the draft ASTM standard specifies two specimens, prEN 6032 specifies three specimens. AMS 2980 and 3970 specify six specimens per test condition. Other differences in test procedures and data reduction/reporting requirements are of minimal significance. Overall, it is believed that differences in DMA equipment produced by different manufacturers may produce more significant variability in test results than the parameters from the two test methods reviewed in the following tables.

TABLE 37. GLASS TRANSITION TEMPERATURE TESTING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 6032-A Specifications	AMS 2980/3970 Additions/ Changes to prEN 6032 (Section 6.5.5)	ASTM Draft Standard (T_g by DMA) Specifications	Importance of Difference
Specimen lay-up	0° for tape, warp for fabric	Laminate: $[(90/0)]_{4S}$ (AMS 2980-2) Laminate: $[(0/90)]_{4S}$ (AMS 3970-2)	Polymer matrix composites reinforced by continuous, oriented, high-modulus fibers	1
Specimen length and width	Actual	According to requirements of the test equipment	• Consult instrument manufacturer's manual • A span-to-thickness ratio greater than ten is typical • Typical specimen size: 25 mm x 12 mm x 1 mm	1

TABLE 38. GLASS TRANSITION TEMPERATURE TESTING—TEST PROCEDURE COMPARISONS

Procedure	prEN 6032-A Specifications	AMS 2980/3970 Additions/ Changes to prEN 6032 (Section 6.5.5)	ASTM Draft Standard (T_g by DMA) Specifications	Importance of Difference
Measurement of specimen width	Flat-faced micrometer accurate to the nearest 0.01 mm or vernier caliper accurate to nearest 0.1 mm		Micrometer suitable for reading to 0.025-mm accuracy	1
Measurement of specimen thickness	Flat-faced micrometer accurate to the nearest 0.01 mm.		Micrometer suitable for reading to 0.025-mm accuracy	1
Specimen conditioning	Specimen storage and testing to be carried out at 23% and 50% ±5% relative humidity		• Dry specimen testing: Dry specimens according to ASTM D 5229 Procedure D then store in desiccator or sealed bag. • Wet specimen testing: Condition in accordance with ASTM D 5229 Procedure B and test within 30 minutes • Recommends weighing specimens before and after T_g testing to ensure that results were not affected by moisture	1-2
Recommended equipment	List of five DMA instruments and suppliers given in Annex A of standard		Requirements: Oven capable of heating to above the glass transition temperature and capable of controlling the heat rate to the specified value	1
Test procedure	According to equipment manufacturer's instructions		Follow the manufacturer's procedure	0
Test data	Room temperature to at least 20ºC higher than peak on loss modulus and tan delta vs temperature curves	Start at room temperature Storage modulus at 23º, 80º, and 120ºC	• Begin at room temperature or at least 50ºC below T_g • End at least 50ºC above T_g but below decomposition temperature	1
Heating rate	5.0º ±0.2ºC per minute	5.0º ±0.2ºC per minute	5.0º ±1ºC per minute	1

TABLE 38. GLASS TRANSITION TEMPERATURE TESTING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 6032-A Specifications	AMS 2980/3970 Additions/ Changes to prEN 6032 (Section 6.5.5)	ASTM Draft Standard (T_g by DMA) Specifications	Importance of Difference
Strain range	Not specified	• Within linear viscoelastic range • Less than 1000 με recommended	• Kept within the linear viscoelastic range • Less than 0.1% ε is standard	1-2
Frequency of vibration	Fixed at 1 Hz (Method A)		1 Hz	0
Sampling	Three specimens per test condition	Six specimens tested per test condition (AMS 2980-2 and AMS 3970-2)	Two test specimens for each sample	1-2
Equipment calibration	According to the manufacturer's instructions		• In accordance with ASTM E 1867 for temperature signals • In accordance with the equipment manufacturer's recommendation for storage modulus • Must be calibrated in the same mode as will be used for testing	0

TABLE 39. GLASS TRANSITION TEMPERATURE TESTING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 6032-A Specifications	AMS 2980/3970 Additions/ Changes to prEN 6032 (Section 6.5.5)	ASTM Draft Standard (T_g by DMA) Specifications	Importance of Difference
Specimen area, A	Average of three width measurements times average of three thickness measurements		Not addressed	1
Required plot	Plot: Storage modulus Loss modulus Tan delta (optional)	Linear (temperature) and log (modulus) scales	Log of storage modulus versus linear temperature	2
Glass transition temperature	• Referred to as T_g onset • Temperature at intersection of two extrapolated tangents to storage modulus curve: – Tangent A: linear region of curve from start temperature to beginning of dramatic slope of curve (before the onset of the glass transition event) – Tangent B: tangent left of the point of inflection (T_g loss) on decreasing part of curve (after the onset of the glass transition event)		• Referred to as T_g • Temperature at intersection of two tangents to storage modulus curve: – Tangent to storage modulus curve below the transition temperature – Tangent to the storage modulus curve at the inflection point of the modulus drop step	1
T_g loss	Temperature corresponding to the maximum of the loss modulus curve		Not addressed	NC
T_g peak	• Optional • Temperature corresponding to the maximum value of tan delta		Not addressed	NC
Slope angle β	• Optional • Slope of storage modulus curve represented by tangent A (T_g onset determination)		Not addressed	NC

TABLE 39. GLASS TRANSITION TEMPERATURE TESTING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 6032-A Specifications	AMS 2980/3970 Additions/ Changes to prEN 6032 (Section 6.5.5)	ASTM Draft Standard (T_g by DMA) Specifications	Importance of Difference
Quantitative check	T_g results should be within 2.0ºC of their mean. If greater, results should be scrutinized for acceptability.		Not addressed	NC
Statistics	Individual values for each specimen, mean value of T_g results (for quantitative check)		Not addressed	NC
Other reporting requirements	Material identification		• Material identification	0
	Specimen dimensions		• Specimen dimensions	0
	Equipment used		• Equipment used	0
	Aging/exposure conditions		• Specimen conditioning history	0
	Strain frequency		• Frequency of test	0
	Date/location of test		• Date of test	0
	Test operator		• Test operator	0
	Displacement amplitude and strain rate		• Deformation amplitude or strain	0
	Incidents/deviations		• Deviations from test method	0
	Specimen preparation		• Cure or process cycle	1
			• Specimen conditioning history	1
		• Transducers and controllers		1
		• Percent change in storage modulus at 80º and 120ºC relative to 23ºC		1
	Test parameters used			1
			• Specimen loading condition and clamping details	1
		• Loading mode		1
		• Strain range	• Flow rate of the purge gas	
		• Purge gas and flow rate		

2.14 CONSTITUENT CONTENT DETERMINATION.

The two test methods considered, EN 2564 method A and ASTM D 3171 method I procedure B, are similar test methods for determining the constituent content of composite laminates (tables 40 through 42). The matrix material is removed by acid digestion in both test methods, allowing for the determination of the fiber and matrix content (by weight or volume) as well as the void volume fraction. Of the two AMS specifications considered, only AMS 3970 includes constituent content determination. Further, only EN 2564 is referred to in the AMS 3970 specification. Other than specifying the laminate lay-up, SAE 3970 does not provide any additions or changes to EN 2564.

Two significant differences exist between the two test methods. First, the difference in the required specimen size between the two test methods could produce moderate effects on results. Whereas EN 2564 requires a 20 mm by 10 mm (200 mm^2) rectangular specimen 2 mm thick, ASTM D 3171 requires a minimum surface area of 625 mm^2 and specifies a minimum mass requirement. Secondly, the required weighing accuracy is significantly different between the two test methods. ASTM D 3171 requires that weights be determined to the nearest 0.1 mg, whereas EN 2564 only requires an accuracy to the nearest ±1 mg. These differences between these two test methods have the potential to produce moderate effects on the constituent content determinations.

TABLE 40. CONSTITUENT CONTENT—SPECIMEN GEOMETRIC COMPARISONS

Property	EN 2564 Method A Specifications	AMS 3970 Additions/ Changes to EN 2564 (Section 6.6.3)	ASTM D 3171 Procedure B Specifications	Importance of Difference
Laminate lay-up	Not specified	$[(90/0)]_{6S}$ $[(45/-45)/(-45/45)]_{2S}$ (AMS 3970-2)	Not specified	0
Test specimen shape and size	• Rectangular, 20 mm x 10 mm • Thickness of 2 mm • Specimens of different dimension may be used subject to agreement of user and manufacturer		• Minimum mass of 0.5 g for constituent volume only • Minimum mass of 1.0 g if void content is to be obtained • Minimum specimen surface area of 625 mm^2 • Roughly rectangular in dimensions	3
Other test specimen requirements	Cut at least 10 mm from edges of laminate		Cutting must not cause the specimen to fray	1

TABLE 41. CONSTITUENT CONTENT—TEST PROCEDURE COMPARISONS

Property	EN 2564 Method A Specifications	AMS 3970 Additions/ Changes to EN 2564 (Section 6.6.3)	ASTM D 3171 Procedure B Specifications	Importance of Difference
Sampling	Minimum of three specimens evenly distributed in the laminate		Minimum of three specimens	0
Drying procedure	Dry in desiccator until difference in mass of successive weightings is less than 2 mg		Dry specimens to equilibrium condition in accordance with D 5229 procedure D	1
Weighing accuracy	Weigh to ±1 mg		Weigh each specimen to the nearest 0.0001 g (0.1 mg)	3
Density measurement	Determine specimen density in accordance with ISO 1183 method A		Determine specimen density in accordance with D 792 or D 1505	1-2
Acid digestion procedure	• Dry the sintered glass crucible • Place specimen in flask • Add 20 ml of sulphuric acid • Heat to 160° ±10°C until acid begins to fume, then discontinue heating • Drip of hydrogen peroxide solution into acid until solution becomes and remains clear • Cool solution and pour into beaker containing 100 ml of distilled water • Filter contents through sintered glass crucible • Wash with 10 ml acetone • Dry crucible/contents at 120° ±10°C for at least 45 min • Cool crucible/contents in desiccator for 20 minutes • Weigh crucible/contents to ±1 mg		• Weigh specimen • Place specimen in beaker • Add a minimum of 20 ml of sulphuric acid and heat until mixture starts to fume • Add 35 ml of hydrogen peroxide • Cool solution and filter contents into preweighed sintered glass filter under vacuum • Wash fibers three times with distilled water An acetone wash may be used as final wash • Dry filter/contents at 100°C for 1 hour or until sample is dried • Cool to room temperature in desiccator • Weigh crucible and contents to the nearest 0.0001g (0.1 mg)	1

TABLE 42. CONSTITUENT CONTENT—DATA REDUCTION/REPORTING COMPARISONS

Property	EN 2564 Method A Specifications	AMS 3970 Additions/Changes to EN 2564 (Section 6.6.3)	ASTM D 3171 Procedure B Specifications	Importance of Difference
Fiber content by mass (weight percent)	$W_f = 100 \times \frac{mass\ of\ residual\ fiber}{initial\ specimen\ mass}$ Expressed as a percentage		$W_r = 100 \times \frac{mass\ of\ residual\ fiber}{initial\ specimen\ mass}$ Expressed as a percentage	0
Fiber content by volume	$V_f = W_f \times \frac{specimen\ density}{fiber\ density}$ Expressed as a percentage		$V_r = W_r \times \frac{specimen\ density}{fiber\ density}$ Expressed as a percentage	0
Matrix content by mass	$W_r = 100 - W_f$ Expressed as a percentage		$W_m = 100 - W_r$ Expressed as a percentage	0
Matrix content by volume	$V_r = (100 - W_f) \times \frac{specimen\ density}{fiber\ density}$ Expressed as a percentage		$V_m = (100 - W_r) \frac{specimen\ density}{fiber\ density}$ Expressed as a percentage	0
Void content by volume	$V_o = 100 - V_f - V_r$ Expressed as a percentage		$V_o = 100 - V_r - V_m$ Expressed as a percentage	0
Statistics	Individual values and arithmetic means		Individual, average, and standard deviation for properties	1
Other reporting requirements	Test method used Incidents affecting results Material identification/info Period of conditioning Exposure time at test atmosphere		Date/revision of test method used Variations/anomalies/problems Material identification/info Procedure used Matrix density used/ source of value Drying times/temperatures	0 0 0 1 1 1 1 1

2.15 MOISTURE CONDITIONING PROCEDURE.

The two test methods considered, prEN 2823 and ASTM D 5229 procedure B, are similar procedures for conditioning specimens to be used in subsequent testing to determine the effects of moisture conditioning on physical or mechanical properties (tables 43 through 45). Note that ASTM D 5229 also specifies a fluid immersion procedure, which will be presented in the following section. Both test methods involve humidity aging at elevated temperature until moisture equilibrium is reached. The AMS 2980 and 3970 specifications provide extensive additions and changes to prEN 2823. Since humidity aging could cause postcuring effects on the specified materials, AMS 2980 specifies that DMA tests be performed on both water-immersed and humidity-aged specimens to determine which moisture conditioning procedure should be selected. In contrast, AMS 3970 specifies humidity aging only. Of the many differences noted between the two test methods and the additions and changes listed in the AMS specifications, none are expected to produce significant effects on results.

TABLE 43. MOISTURE CONDITIONING—SPECIMEN GEOMETRIC COMPARISONS

Property	prEN 2823 Specifications	AMS 2980/3970 Additions/ Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Test specimen requirements	• Shape/dimensions specified in the test method for subsequent test • In final form: machined, drilled, tabbed, etc.		• Mass of at least 5 g • Thickness shall not vary by more than ±5% over the thickness of the specimen	1
Traveler specimens (Representative of specimens to be tested and accompany test specimens in the climatic chamber. Used to monitor moisture absorption.)	• Rectangular or square • Length and width greater than 25 mm • Mass greater than 1.5 g • Quality of faces/edges identical to that of test specimens • Taken from same panel as test specimens, but without tabs, holes, etc.	• Length and width greater than 25 mm • Spare specimens may be used provided the specimens do not have tabs	• Required if moisture change in the material cannot be properly measured by weighing the test specimen itself (ex: tabbed specimens) • Mass of at least 5 g	1

TABLE 44. MOISTURE CONDITIONING—TEST PROCEDURE COMPARISONS

Procedure	prEN 2823 Specifications	AMS 2980/3970 Additions/Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Determination of wet conditioning procedures	Humidity aged	• Humidity aged or fluid immersion • AMS 2980: Humidity aging is expected to give postcure effects. Perform screening test program (described in AMS 2980-2).	Humidity aged	1
Storage conditions and times during panel, subpanel, and specimen manufacturing	Specimens shall not undergo any special conditioning before exposure	• Storage at 23° ±5°C in moisture-proof bag with desiccant • Permitted open time for specimen manufacturing is 14 days at ambient condition	Not addressed	NC
Climatic chamber	Capable of keeping the specified temperature to within ±1°C and relative humidity to within ±3%		Capable of maintaining the required temperature to within ±1°C and relative humidity to within ±3%	0
Number of traveler specimens	3	3	1	1-2
Measurement of specimen dimensions	Not addressed		• Following any preconditioning and again after aging procedure • Thickness: average of measurements at three or more locations with an accuracy of ±1% or better • Side dimensions: nominal dimensions measured to the nearest 1.0 mm	NC
Aging procedure	Aging in humidity chamber at elevated temperature	• Aging in humidity chamber or immersion in water at elevated temperature (AMS 2980-2) • Aging in humidity chamber at elevated temperature (AMS 3970)	Aging in humidity chamber at elevated temperature	1

TABLE 44. MOISTURE CONDITIONING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 2823 Specifications	AMS 2980/3970 Additions/Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Temperature for specimen aging	70° ±2°C (Check that equilibrium condition is reached at this temperature (if not, choose lower temperature)	70° ±2°C (AMS 2980-2 and 3970-2)	• Maximum for 121°C cure epoxies: 70°C • Maximum for 177°C cure epoxies: 80°C	1
Moisture condition for specimen aging	• 85% +5/-1% relative humidity (standard) • 95% +5/-1% relative humidity (optional)	• Humidity aged (AMS 2980-2 and 3970-2): 85% ±5% relative humidity (standard) or 95% ±5% (optional) • Water immersed (AMS 2980-2): total immersion	• No required relative humidity level • Reference to MIL-HDBK-17B: – 85% ±5% relative humidity considered worst-case aircraft service environment – Two-step accelerated conditioning schemes (95%-98% followed by lower level) can be used – Liquid immersion not equivalent to 100% relative humidity	1-2
Duration for specimen aging	• Based on satisfying a minimum mass • Difference between three successive weighings on traveler specimens • Equilibrium defined as the point where the maximum difference in mass (between three weighings) divided by the maximum mass is $\leq 5 \times 10^{-4}$	• Humidity aged (AMS 2980-2 and 3970-2): Until saturation • Water immersed: (AMS 2980-2) 336 ±16 hours	• Until effective moisture equilibrium is reached: defined as the point where the average moisture content of the material changes by less than 0.01% within the span of the reference time period (time interval between weighings) • Minimum of three weighings necessary: pretest weighing and two final weighings	1-2

TABLE 44. MOISTURE CONDITIONING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 2823 Specifications	AMS 2980/3970 Additions/Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Time interval between weight gain measurements	168 hours (7 days)		• If moisture diffusivity D_z known, the greater of: $0.02(\text{thickness})^2/D_z$ (seconds) or 86,400 sec (1 day) • If moisture diffusivity D_z not known, 604,000 sec (7 days)	1
Procedure for weight gain measurement	• Remove traveler specimens from climatic chamber and wipe to remove condensation • Allow specimens to cool to room temperature in a sealed container • Immediately weigh		• Remove specimen from conditioning chamber and place in specimen bag until it reaches room temperature. Remove and wipe to remove surface moisture. • Immediately weigh to nearest 0.1 mg • Maximum 30 min/weighing out of conditioning chamber • Maximum 5 min/weighing out of specimen bag	1
Accuracy of weight gain measurement	0.1 mg	0.02% (absolute)	• 0.1 mg for specimen mass between 5 and 50 g • 1.0 mg for specimen mass greater than 50 g	1
Determination of moisture absorbed by specimens	Dry traveler specimens in oven: 72 hrs at 50° ±5°C 72 hrs at 70° ±5°C required time at 90° ±5°C to obtain a constant mass		Not addressed as part of procedure B	NC
Strain gage bonding	Not specified	Maximum 1 hour at ambient condition	Not addressed	NC
Open time in test cabinet	Not specified	Maximum 1 hour at 23° ±2°C	Not addressed	NC

TABLE 44. MOISTURE CONDITIONING—TEST PROCEDURE COMPARISONS (Continued)

Procedure	prEN 2823 Specifications	AMS 2980/3970 Additions/Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Specimen storage before testing	Specimen may be maintained for a maximum of 72 hours in a sealed container	• Humidity aged: (AMS 2980-2 and 3970-2): 23° ±5°C wrapped in a wet towel. Maximum time of 8 hours. • Water immersed: (AMS 2980-2): 23° ±5°C in water bath or wet towel. Maximum time of 8 hours.	Not addressed	NC
Testing at ambient temperature after exposure	Test performed within 30 min following removal from storage		Not addressed	NC
Testing at temperatures other than ambient after exposure	• Minimize time between placing specimen in fixture and completing the test • Suggests less than 15 min for ambient to 50°C • Suggests less than 5 min for carbon specimens from 1-2 mm thickness and for temperatures ranging from 50°-100°C		Not addressed	NC

TABLE 45. MOISTURE CONDITIONING—DATA REDUCTION/REPORTING COMPARISONS

Quantity	prEN 2823 Specifications	AMS 2980/3970 Additions/ Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Percentage of absorbed moisture	Based on difference in mean of weighings of traveler specimens between equilibrium and after drying		Not addressed in procedure B	NC
Statistics	Mean value of traveler specimen weights		Average, standard deviation, and coefficient of variation for moisture properties (for sample populations of three or more)	1
Other reporting requirements	• Test method used • Incidents affecting results • Material identification/info • Temperature of conditioning • Type of traveler specimen • Length of exposure • Method of storing specimens before testing • Time specimens are maintained at test temperature before testing • Actual testing time	• Panel curing date • Diagram of weight gain versus aging time • Condition and history of specimen before aging • Aging equipment and placement of panels in the equipment • Equipment control diagram about aging conditions and time	• Procedure used • Variations/anomalies/problems • Material identification/info • Temperature used for conditioning • Plots of percent mass change versus $(\text{time})^{1/2}$	0 0 0 0 1 1 1 1 1 1 1 1 1 1

TABLE 45. MOISTURE CONDITIONING—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	prEN 2823 Specifications	AMS 2980/3970 Additions/ Changes to EN 2823 (Sections 6.2 and 6.3.4)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Other reporting requirements (continued)		• Panel curing date • Diagram of weight gain versus aging time • Condition and history of specimen before aging • Aging equipment and placement of panels in the equipment • Equipment control diagram about aging conditions and time	• Date/location of test • Test operator • Laminate stacking sequence • Density, volume percent reinforcement, void content, and average ply thickness • Method of preparing test specimens • Calibration dates/methods for measurement and test equipment • Results of preconditioning • Specimen dimensions prior to and following moisture conditioning • Type of chamber used • Moisture level used for conditioning • Measurement time interval • Temperature and relative humidity of the testing lab • Specimen mass at each time level • Plots of percent mass change versus (time)½ • Equilibrium moisture content, in percent	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

2.16 FLUID IMMERSION PROCEDURE.

The two test methods considered, EN 2849 and ASTM D 5229 procedure B, both provide procedures for fluid immersion of specimens for use in subsequent testing to determine the effects of moisture conditioning on physical or mechanical properties (tables 46 through 48). Note that ASTM D 5229 is the same test method used for moisture conditioning through humidity aging, as discussed in the section 2.1.5. For fluid immersion, ASTM D 5229 procedure B requires that specimens be immersed until moisture equilibrium is obtained, and details a method of periodic weighings for establishing when equilibrium has been reached. In contrast, EN 2489 refers to the particular material standard to be used for subsequent testing for this information. Both the AMS 2980 and 3970 specifications provide extensive additions and changes to EN 2849 only. These specifications include detailed immersion procedures for specific fluids (water, fuel, solvent, hydraulic fluid, and hydraulic fluid/water mixture) as well as specimen storage positions during fabrication, prior to fluid immersion, and prior to subsequent material testing. Although many differences are noted between the two test methods and the additions and changes listed in the AMS specifications, none are expected to produce significant effects on results.

TABLE 46. FLUID IMMERSION METHOD—SPECIMEN GEOMETRIC COMPARISONS

Property	EN 2489 Specifications	AMS 2980/3970 Additions/ Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Test specimen requirements	Shape/dimensions specified in the test method		• Mass of at least 5 g • Thickness shall not vary by more than ±5% over the thickness of the specimen	1
Traveler specimens (Representative of specimens to be tested and accompany test specimens in the fluid immersion. Used to monitor fluid absorption.)	Not addressed	• Length and width greater than 25 mm • Spare specimens may be used provided the specimens do not have tabs	• Required if moisture change in the material cannot be properly measured by weighing the test specimen itself (ex: tabbed specimens) • Mass of at least 5 g	1

TABLE 47. FLUID IMMERSION METHOD—TEST PROCEDURE COMPARISONS

Procedure	EN 2489 Specifications	AMS 2980/3970 Additions/Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Selected fluids for immersion	As detailed in the material standard, EN 2379	• Water: distilled water (AMS 2980 only) • Fuel: Test Fuel 1 – JET A1, NATO code F-34 kerosene-low freeze point • Solvent: Methyl Ethyl Ketone, laboratory grade • Hydraulic Fluid: Tri-N-butyl phosphate ester, laboratory grade • Hydraulic Fluid/Water Mixture: 50%:50% mixture by volume of Tri-N-butyl phosphate ester and distilled water (AMS 3970 only)	None listed, but standard states "can also be used with fluid moisture other than water"	1
Determination of fluid composition	In case of a fluid of unknown or variable composition, it is important that all samples of fluids are taken from the same container.	Not required	Not addressed	1
Fluid temperature during immersion	If not specified in material standard, choose in preference one of the following temperatures: 23° ±2°C 70° ±2°C 100° ±2°C	From AMS 2980-2 and 3970-2: • Water: 70° ±2°C (AMS 2980-2 only) • Fuel: 23° ±2°C • Solvent: 23° ±2°C • Hydraulic Fluid: 70° ±2°C • Hydraulic Fluid/Water Mixture: 70° ±2°C (3970-2 only)	Maximum recommended temperature listed: 121°C cure epoxies: 70°C 177°C cure epoxies: 80°C Other: 25°C less than wet T_g	1

TABLE 47. FLUID IMMERSION METHOD—TEST PROCEDURE COMPARISONS (Continued)

Procedure	EN 2489 Specifications	AMS 2980/3970 Additions/Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Duration of fluid immersion	If not specified in material standard, choose in preference one of the following periods of immersion: • 24 hours for a short test • 4 weeks for a normal test • 26 weeks for a long test	From (AMS 2980-2 and 3970-2): • Water: 336 ±16 hours (AMS 2980-2 only) • Fuel: 1000 ±64 hours • Solvent: 60-90 minutes • Hydraulic Fluid: 1000 ±64 hours • Hydraulic Fluid/Water Mixture: 1000 ±64 hours (AMS 3970-2 only)	• Until effective moisture equilibrium is reached: defined as the point where the average moisture content of the material changes by less than 0.01% within the span of the reference time period (time interval between weighings). • Minimum of three weighings necessary: pretest weighing and two final weighings	1-2
Fluid replacement during immersion	Replace fluid periodically to maintain composition	Not required	Not addressed	1
Maintaining temperature during fluid immersion	Temperature-controlled vessel capable of maintaining beakers at immersion temperature accurate to ±2°C		Temperature-controlled liquid bath	1
Other conditions/requirements of fluid immersion procedure	• Immersion should be carried out in the dark • Use at least 4 ml of fluid per cm^2 of total specimen surface area • Immerse the specimen completely • Point contact between beaker walls and specimen supports • Stir fluid at least once per day and readjust level if needed	• Use new fluid only • Fluid shall be at required temperature when immersing specimens	Expose both surfaces of the specimen to the test environment	1
Number of traveler specimens	Not required	3	1	1

TABLE 47. FLUID IMMERSION METHOD—TEST PROCEDURE COMPARISONS (Continued)

Procedure	EN 2489 Specifications	AMS 2980/3970 Additions/Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Visual inspection following immersion	Examine each specimen after immersion with a magnifying glass, if necessary, while comparing it with a specimen that has not been immersed	Not required	Not addressed	NC
Storage conditions and times during panel, subpanel, and specimen manufacturing	Not addressed	• Storage at 23° ±5°C in moisture-proof bag with desiccant • Permitted open time for specimen manufacturing is 14 days at ambient condition	Not addressed	NC
Specimen storage conditions and times prior to fluid immersion	Not addressed	• Storage at 23° ±5°C in moisture-proof bag with desiccant for maximum of 14 weeks after panel curing date • Requirement: specimen moisture content of 0.20% by weight	Not addressed	NC
Specimen storage before testing	If drying specimen following immersion, cool specimen in a sealed container. Carry out test within 15 minutes following the removal from the sealed container.	• Water: 23° ±5°C in water bath or wet towel for 8 hours max. (AMS 2980 only) • Fuel: 23° ±5°C in fuel bath for 8 hours max. • Solvent: no storage allowed • Hydraulic Fluid: 23° ±5°C in hydraulic fluid bath for 8 hours max. • Hydraulic Fluid/Water Mixture: 23° ±5°C in hydraulic fluid/water mixture bath for 8 hours max. (AMS 3970 only)	Not addressed	1

TABLE 47. FLUID IMMERSION METHOD—TEST PROCEDURE COMPARISONS (Continued)

Procedure	EN 2489 Specifications	AMS 2980/3970 Additions/Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Procedure for weight gain measurement	Not addressed	• Remove traveler specimens from fluid and wipe to remove condensation • Determine weight gain immediately	• Remove specimen from conditioning chamber (immersion?) and place in specimen bag until it reaches room temperature. Remove and wipe to remove surface moisture. • Immediately weigh to nearest 0.1 mg • Maximum 30 min/weighing out of conditioning chamber • Max 5 min/weighing out of specimen bag	1
Time interval between weight gain measurements	Not addressed	Before and immediately after immersion	• If moisture diffusivity D_z is known, the greater of: 0.02(thickness)2/D_z (seconds) or 86,400 sec (1 day) • If moisture diffusivity Dz is not known, 604,000 sec (7 days)	1-2
Accuracy of weight gain measurement	Not addressed	0.02% (absolute)	• 0.1 mg for specimen mass between 5 and 50 g • 1.0 mg for specimen mass greater than 50 g	1
Strain gage bonding	Not addressed	Max 1 hour at ambient condition	Not addressed	NC
Open time in test cabinet	Not addressed	Max 1 hour at 23° ±2°C	Not addressed	NC
Testing at temperatures other than ambient after immersion	Maintain specimen in test fixture at specified temperature for specified period or sufficient time for specimen to achieve specified temperature without an unacceptable loss of absorbed fluid		Not addressed	NC

TABLE 48. FLUID IMMERSION METHOD—DATA REDUCTION/REPORTING COMPARISONS

Quantity	EN 2489 Specifications	AMS 2980/3970 Additions/ Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Statistics	Not addressed		Average, standard deviation, and coefficient of variation for moisture properties (for sample populations of three or more)	1
Reporting requirements	• Test method used		• Procedure used	0
	• Incidents affecting results		• Variations/anomalies/problems	0
	• Material identification/info		• Material identification/info	0
		Immersion temperature	• Temperature used for conditioning (immersion?)	0
	• Type of specimen used			1
	• Method of specimen preparation			1
	• Specimen dimensions			1
	• Location of specimens within the laminate			1
		• Panel curing date		1
		• Type of fluid		1
		• Immersion period (including dates)		1
		• Type of container		1
		• Dimensions of traveler specimens		1
		• Weight gain after immersion	• Plots of percent mass change versus $(\text{time})^{1/2}$	1
			• Date/location of test	1
			• Test operator	1
			• Laminate stacking sequence	1
			• Density, volume percent reinforcement, void content, and average ply thickness	1
			• Method of preparing test specimens	1
			• Calibration dates/methods for measurement and test equipment	1

TABLE 48. FLUID IMMERSION METHOD—DATA REDUCTION/REPORTING COMPARISONS (Continued)

Quantity	EN 2489 Specifications	AMS 2980/3970 Additions/ Changes to EN 2489 (Sections 6.2 and 6.3.3)	ASTM D 5229 Procedure B Specifications	Importance of Difference
Reporting requirements (continued)			• Results of preconditioning • Specimen dimensions prior to and following moisture conditioning • Type of chamber used • Moisture level used for conditioning • Measurement time interval • Temperature and relative humidity of the testing lab • Specimen mass at each time level • Equilibrium moisture content, in percent	1 1 1 1 1 1 1

3. FOLLOW-ON TESTING.

Based on the comparative assessments of equivalence presented in section 2 and input received from the evaluators at the August meeting (section 2.1), 4 of the 16 types of tests were selected for follow-on testing to further assess test method equivalency. Note that the selection of these four tests for follow-on testing only reflects the need for additional test data to assess equivalency and is not a reflection of their degree of equivalency relative to other tests. The four types of tests selected for follow-on testing and the parameter(s) to be investigated are presented in the following sections. All testing will be performed using autoclave, prepreg carbon/epoxy composite materials.

3.1 LAMINA COMPRESSION TESTING: EFFECTS OF GAGE LENGTH.

The test method comparison for lamina compression testing presented in section 2.4 revealed a potentially significant difference in specimen gage lengths. Although similar gage lengths are listed for the prEN 2850-B and SACMA SRM 1 test methods (5 mm versus 4.75 mm, respectively), the AMS 2980 and 3970 specifications specify a 12.5-mm gage length. It is not well understood how this difference in gage length (4.75 mm versus 12.5 mm) will affect the delivered compression strengths produced in lamina compression testing. Thus, follow-on testing has been recommended to determine the effects of specimen gage length on delivered lamina compression strength. Testing is proposed using specimens with both 4.75-mm (~3/16-in.) and 12.5-mm (~1/2-in.) gage length specimens. Both unidirectional prepreg laminates and 0/90 prepreg fabric laminates will be tested. Testing will be conducted at room temperature/ambient as well as 82ºC (180ºF)/wet conditions.

3.2 LAMINATE COMPRESSION TESTING: EFFECTS OF LOADING METHOD.

The two test methods compared for laminate compression testing follow procedures generated for open-hole compression testing, but use a specimen without a hole. The test fixture specified in these two test methods, SACMA SRM 3 and ASTM D 6484, is very similar. As described in section 2.5, however, the method used to load the test fixture differs significantly and may produce differences in delivered compression strengths. Whereas ASTM D 6484 currently requires hydraulic wedge grips to be used to grip the test fixture, the SACMA SRM 3 test method allows the test fixture to be end-loaded between two parallel platens of the test machine. Thus, follow-on testing has been recommended to determine the effects of loading method on the delivered compression strength of composite laminates. Testing will be performed both with the test fixture gripped (hydraulic wedge grips) and with the test fixture end-loaded. Both multidirectional prepreg laminates and prepreg fabric laminates will be tested. Testing will be conducted at room temperature/ambient as well as 82ºC (180ºF)/wet conditions.

3.3 IN-PLANE SHEAR TESTING: EFFECTS OF SPECIMEN THICKNESS.

As described in section 2.8, the two test methods compared for in-plane shear testing both use +45° type laminates loaded in tension. Although both the prEN 6031 test method and the AMS 2980 and 3970 specifications require an 8-ply +45° laminate for either unidirectional tape or woven fabric, ASTM D 3518 requires 16-, 20-, or 24-ply unidirectional tape laminates or 8-, 12-, or 16-ply woven fabric laminates. As discussed in section 2.8, a specimen thickness effect on

strength has been reported [7], resulting in lower delivered shear strengths from thinner +45° specimens. To further investigate the effects of specimen thickness, follow-on testing has been recommended using multiple thickness specimens fabricated from both prepreg tape and prepreg fabric materials. Testing will be conducted at room temperature/ambient as well as 82ºC (180ºF)/wet conditions.

3.4 CONSTITUENT CONTENT DETERMINATION: EFFECTS OF SPECIMEN SIZE AND WEIGHING ACCURACY.

Both of the test methods described in section 2.14, EN 2564 Method A and ASTM D 3171 Method I procedure B, use an acid digestion procedure to determine the constituent content of composite laminates. Two significant differences between the test methods will be investigated in follow-on testing. First, the effect of differences in the required specimen size reported between the two test methods will be investigated. Whereas EN 2564 requires a 200 mm^2 rectangular specimen 2 mm thick, ASTM D 3171 requires a minimum surface area of 625 mm^2 and specifies a minimum mass requirement. Second, the difference in the required weighing accuracy between the two test methods will be investigated. Although ASTM D 3171 requires that weights be determined to the nearest 0.1 mg, EN 2564 only requires accuracy to the nearest ±1 mg. Follow-on testing will be used to investigate the significance of both of these differences on the constituent content determinations. Both unidirectional prepreg laminates and prepreg fabric laminates will be used in these determinations.

4. CONCLUSIONS.

The detailed test method comparison between ASTM and primarily EN test specifications was performed for 16 tests. Nine test methods appear to be equivalent. Of the remaining seven test methods four were chosen for further comparison by performing the tests to determine whether the differences in test methods are significant. These were lumina and laminate compression testing, in-plane shear testing, and constituent content determination.

Three tests, compression after impact (CAI) and Mode I and Mode II fracture properties tests were deemed sufficiently different so that no reasonable correlation will be obtained from additional testing. The CAI test methods serve different purposes—this is explained in the test summary. The Mode II tests are very different—one is a three point bend and the other is a four point bend. Additionally, the ASTM test method used is only a draft standard. The differences between the prEN and ASTM test methods for Mode I are not quite so obvious, but there are nonetheless significant differences: length and thickness of the insert and the definition of G (area under curve over a 100-mm length of propagation versus an R-curve containing several G measurements).

The general conclusion from this study is that except for fracture properties, the CEN test methods will provide test results similar to the ASTM test methods for at least nine test methods with an additional four test methods having a very good chance to meet equivalency through follow-on testing.

The current research has also provided a blueprint on how to conduct a test equivalency study to permit data inclusion into MIL-Handbook-17 from nonstandard tests.

5. REFERENCES.

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