Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–2011/25 December 2011

Survivability, Structures, and Materials Department

Technical Report

Guidelines for Developing and Inserting Material Properties into the Code 65 Composite Material Database

by

Maureen E. Foley and Daniel C. Hart

NSWCCD-65-TR–2011/25 Guidelines for Developing and Inserting Material Properties into the Code 65 Composite Material Database

DEPARTMENT OF THE NAVY
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IN REPLY REFER TO
9078
Ser 65/13-09
20 Dec 12

From: Commander, Naval Surface Warfare Center, Carderock Division

To: Director of Research (Code 6030), Naval Surface Warfare Center, Carderock Division (Dr. Jack L. Price)

Subj: GUIDELINES FOR DEVELOPING AND INSERTING MATERIAL PROPERTIES INTO THE CODE 65 COMPOSITE MATERIAL DATABASE

Ref: (a) Office of Naval Research Work Request N0001410WX30316

Encl: (1) NSWCCD-65-TR–2011/25, *Guidelines for Developing and Inserting Material Properties into the Code 65 Composite Material Database*

1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to develop a composite materials database for modeling and simulation of large-scale composite structures. Enclosure (1) establishes guidelines for developing test plans used to determine composite material properties (screening and design allowables). The test plans would be used for future NAVSEA composite material applications. These guidelines are based on current and previous modeling and simulation projects for submarines, surface ships, aircraft carriers and expeditionary vehicles.

2. Comments or questions may be referred to Dr. Maureen Foley, Code 655, phone (301) 227-5040, e-mail, Maureen.Foley@navy.mil.

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NAVSURFWARCEN CARDEROCKDIV
BETHESDA MD [Codes 3850 (TIC),
60 SharePoint, 65, 652, 652 (Telegadas, Bonanni,
Taylor), 653, 655, 655 (Coffin, Foley, Hart, Noland,
Pohlit, Stager, Udinski), 616 (Sorathia),
664 (Draisen, Painter, Ripley), 74 (Ransom)]

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Enclosure (1)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
1-Dec-2011	Final	-

4. TITLE AND SUBTITLE
Guidelines for Developing and Inserting Material Properties into the Code 65 Composite Material Database

5a. CONTRACT NUMBER N0001410WX30316
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Maureen E. Foley and Daniel C. Hart

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCCD-65-TR–2011/25

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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West Bethesda, MD 20817-5700

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Navy's focus on lighter and faster ships has resulted in the increased use of composite materials for new ship designs. There are a variety of resources available that contain background information on composite materials and the methodology for the development of design and materials allowables for composite structures. However, these guidelines have generally focused on composite materials for aerospace applications, which tend to be very different from Navy applications in materials selection and manufacturing methods. The goal of this report is to establish guidelines for materials tests plans for use in determining composite material properties (screening and design allowables). The composite material properties are ultimately included in the Composite Materials Database maintained by the Structures and Composites Division at the Naval Surface Warfare Center, Carderock Division. The materials properties are subsequently used in modeling and simulation activities for future Navy applications. These guidelines presented in this report are based on current and previous modeling and simulation activities for submarine, surface ship, aircraft carrier and expeditionary vehicle platforms.

15. SUBJECT TERMS
composite materials, material properties

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr. Maureen Foley
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	SAR	65	**19b. TELEPHONE NUMBER** *(include area code)* (301)-227-5040

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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Administrative Information

The Structures and Composites Division (Code 65) of the Survivability, Structures and Materials Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD), performed the work described in this report. The work was funded by the NSWCCD Section 219 funds under Office of Naval Research Work Request N0001410WX30316 as part of an effort to create a Composite Materials Database from the results of testing on previous composite materials characterization efforts that NSWCCD personnel have been involved.

Acknowledgements

The authors would like to thank Dr. John Barkyoumb and the Science Technology Council at NSWCCD for the Section 219 funding to perform the development of the NSWCCD Composite Materials Database.

Background

The Navy's focus on lighter and faster ships has resulted in the increased use of composite materials in new ship designs. Current examples of large composite structures are the Advanced Enclosed Mast/Sensor System (AEM/S) of the LPD-17-class ships, the composite deckhouse of the DDG1000, and submarine sonar domes. The field of composite materials is one of constant evolution in the materials (fibers, matrices and fabric form), as well as available manufacturing methods. A baseline assessment of the state-of-the art in composite materials was developed in the *Composites Gap Map* in 1995.[1] Current guidelines for material characterization and design practices for composite materials can be found in the Composite Materials Handbook, MIL-HDBK-17,[2] *Surface Ship Topside Composite Structures Best Practices*,[3] *Rules for Materials and Welding*[4] and *Guide for Building and Classing of Naval Vessels*.[5] The last two being published by ABS. Material characterization guidelines typically recommend methods documented by the American Society for Testing and Materials (ASTM).

The process for developing composite structures requires the use of unique composite materials properties, manufacturing techniques, joining methods, integration strategies, and different experimental/analytical methods.

For the purposes of this document, a single layer of cured, fabric-reinforced composite is considered a "lamina" and multiple single layers of cured fabric is considered a "laminate". In general, each lamina can either be a uni-directional fabric with all the fibers aligned in the same direction, or a woven fabric with fibers aligned in two directions. For a woven fabric lamina, the 1-direction corresponds to the fabric warp direction and the 2-direction corresponds to the fabric fill direction. Individual ply orientation is the measure of the angle from the laminate's principal direction (x-direction) to the layer's warp (1) direction. In the case of the laminate shown on the right hand side of Figure 1, this would be considered a 0°/90°/0° laminate since the outer plies are aligned in the laminate's principal direction while the inner ply is aligned 90° to the x-direction and aligned with the y-direction.

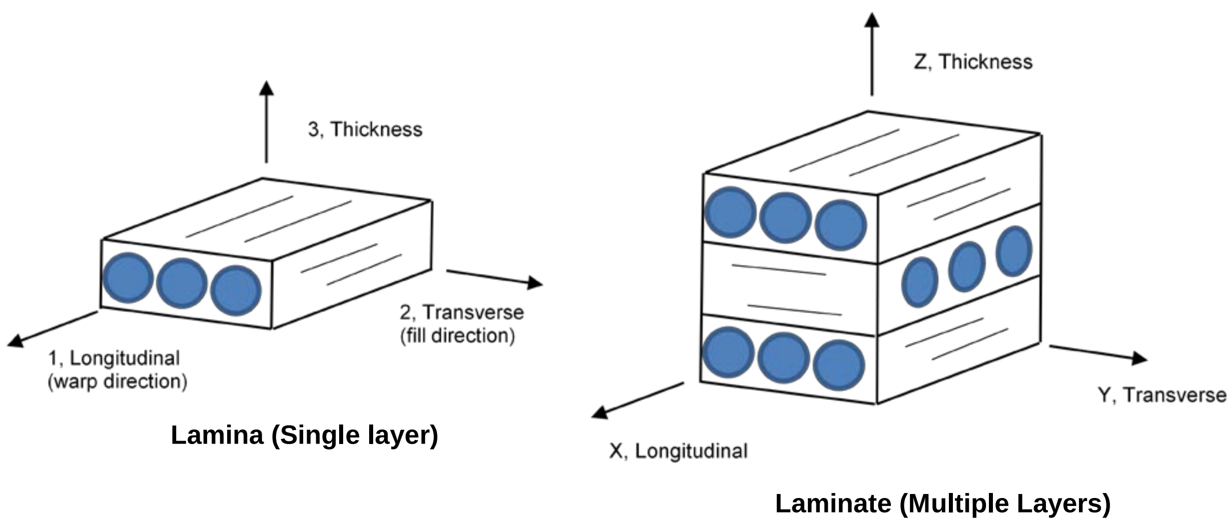


Figure 1. Lamina and Laminate Material Notation

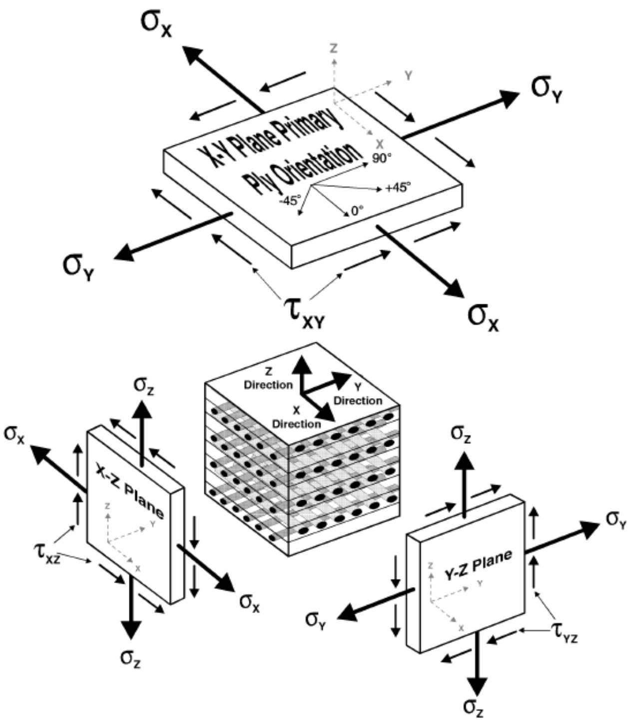
Physical and mechanical properties should be characterized for each single skin and sandwich laminate used in the design of the naval composite structures. This report focuses on the composite material test plans that are required for the development of the material properties of the single skin or composite face sheets of the composite sandwich structure. The testing should be performed on articles that are constructed using the exact manufacturing process, resins (including catalysts, additives, etc.), and fiber reinforcements that will be used in the fielded structure. The test articles should be fabricated in the same environment, using the same process, materials and same trained personnel as the fielded structure. Any changes or modifications to these listed items must be documented and may require the laminate to be re-characterized.

The fabrics used in the construction of marine composites are often made from large tows/rovings. This results in unit-cell sizes, which are large and often on the order of the gage section of the test coupons required by the ASTM standards. These tests assume that the gage section of the test specimen is large compared to the unit-cell size, which typically results in a uniform state of strain within the gage section of the test coupon. When the unit-cell size is large compared to the test gage section, the test results may not be representative of the larger laminate section that the test sample is intended to represent. Care should be taken when selecting test gage sections, so that two or more unit cells are represented in the test gage section if possible.

Due to the anisotropic nature of composite materials, it is typically necessary to perform mechanical testing along the two main orthogonal principal axes of the laminate (X and Y) to develop baseline material mechanical properties. The Z axis engineering properties should also be tested for laminates in which thickness effects need to be considered. A summary of the nomenclature used to capture the stiffness, strength and Poisson's Ratio test results in 3-planes, taken from Reference 5, is shown in Figure 2.

Approach

In FY10, Code 655 received funding to develop the Composite Materials Database, which can be referenced by Code 65 personnel who perform modeling and simulation activities in support of current and future Navy platforms. As published technical reports were gathered for incorporation into the database, it was discovered that every program seemed to perform testing differently and that not all important information about the composite material was always published in the report. Therefore, it became apparent that Code 65 should adopt standard reporting criteria to ensure that material property information was complete for future applications.



Stiffness	X	Longitudinal	Tensile Modulus E_X^T	Compressive Modulus E_X^C
	Y	Transverse	Tensile Modulus E_Y^T	Compressive Modulus E_Y^C
	Z	Thickness	Tensile Modulus E_Z^T	Compressive Modulus E_Z^C
	XY	Longitudinal/ Transverse	Shear Modulus G_{XY}	
	XZ	Longitudinal/ Thickness	Shear Modulus G_{XZ}	
	YZ	Transverse/ Thickness	Shear Modulus G_{YZ}	
Strength	X	Longitudinal	Tensile Strength $\sigma_X^{T\,ult}$	Compressive Strength $\sigma_X^{C\,ult}$
	Y	Transverse	Tensile Strength $\sigma_Y^{T\,ult}$	Compressive Strength $\sigma_Y^{C\,ult}$
	Z	Thickness	Tensile Strength $\sigma_Z^{T\,ult}$	Compressive Strength $\sigma_Z^{C\,ult}$
	XY	Longitudinal/ Transverse	Shear Strength τ_{XY}^{ult}	
	XZ	Longitudinal/ Thickness	Shear Strength τ_{XZ}^{ult}	
	YZ	Transverse/ Thickness	Shear Strength τ_{YZ}^{ult}	

Poisson's Ratio	XY (major)	υ_{XY}^T	υ_{XY}^C
	YX (minor)	υ_{YX}^T	υ_{YX}^C
	ZX	υ_{ZX}^T	υ_{ZX}^C
	YZ	υ_{YZ}^T	υ_{YZ}^C

Figure 2. Mechanical Property Nomenclature for Laminate Composite Materials[5]

This report was compiled to introduce the Composite Materials Database Template (CMDT) and develop a baseline standardized system for performing materials screening and design allowable testing for general composite materials use on future programs. The report is meant to be a starting point, which can be tailored to meet the specific needs of every program. In addition to this report, which presents general guidelines for the development of material design allowables for composite structures, a very comprehensive report entitled *Best Practices for Composite Non-Pressure Hull Submarine Structure Based on Findings and Lessons Learned from the Composite Advanced Sail Program for the USS* Virginia *(SSN 774) Class*[6] was published to document the specific materials testing guidelines that were developed for composite non-pressure hull submarine structures.

Composite Material Database Template

A cross-section of Code 65 personnel that perform modeling and simulation (M&S) activities were polled to determine a baseline set of composite material properties that are typically used in these M&S operations. Similarly, composite materials subject matter experts were consulted to determine what composite material constituents and processing should be included in the database. Based on feedback from these two groups of people, a standardized Composite Materials Database Template (CMDT) was developed, which contains the composite properties most relevant for use in design, as well as the most important aspects that capture the pedigree of the material. The current version of the template is a Microsoft Excel file, which contains several worksheet tabs into which material property data can be entered. A printed version of the CMDT is given in Appendix A. A listing of the tabs within the CMDT is given in Table 1.

Table 1. Composite Materials Database Template Worksheet Tabs

Tab Location	Name	Figure in Appendix A
1A/1B	Mean Properties / B-Basis Properties*	A-1, A-2 **
2	Material Description	A-3
3	Constitutive Properties	A-4
4	Tension	A-5
5	Compression	A-6
6	Shear	A-7
7	Notched Laminate Properties	A-8
8	Fracture	A-9
9	Extra Testing	A-10
10	Expansion Coefficients	A-11
11	Thermal Properties	A-12
12	Electrical Properties	A-13
13	Flammability Properties	A-14

* Summary tabs compiled through inputs on Tabs 2 through 13.
** Also Figure 3 and Figure 4.

The material properties for a given composite material lamina/laminate system are entered into Tabs 2 through 13 of the Excel worksheet, and the data are then duplicated in Tab 1A/1B to create a two-page summary of mean properties (Figure 3 and Figure 4), which can be used as the standardized entry of the material into the Composite Materials Database (CMD). This template will be used to compile design data from historical composite material programs. Additionally, the template will be used in the future to add new composite material design data to the CMD. Information entered in Tabs 3 through 13 will be material properties generated from standardized tests; whereas, Tab 2 will contain descriptive information on the composite material pedigree (fiber, resin, manufacturing method, manufacturer, date, etc.), along with the lists of any reports or other reference documentation that can be used to trace the data.

CMDb Template (Change to Material ID)						
		Summary of Mean Properties				
Material Description						
Matrix	what resin					
Fiber	what kind of base fiber used					
Fabric	uni, stitched, weave, woven roving, textile form, tape, prepreg					
Laminate Schedule	[0]10 [0]14 [0]36					
Manufacturing Method	what method was used					
Manufacturer	who manufactured the material					
Date of Manufacture	2006					
Testing Facility/Date	2007					
Program of Record	AHM&ST					
Reference	NSWCCD-65-TR-20??/??					
Data Type Available	screening, mean, B18, B30					
Physical Properties	**Test Method**		**Units**			
Density	density	den	*lbs/in^3*			
Void Content	Burn Off	Fvfw				
Fiber Volume Fraction (weight)	Burn Off	Fvfw				
Fiber Volume Fraction (volume)		Fvfv				
Moisture Absorption (Weight Gain %)	moisture	M				
Per Ply Thickness (single lamina)	Average	ppthick	*in/ply*			
Standard Mechanical Properties	**Test Method**	**RTD**	**CTD**	**ETW**	**ETD**	**Units**
Tensile Modulus, E1t	T0	E1T	0	0	0	*msi*
Tensile Strength, F1T		F1T	0	0	0	*ksi*
Tensile Strain to Failure, ε1T		ue1T	0	0	0	*microstrain*
υ 12		nu12t	0	0	0	
Tensile Modulus, E2T	T90	E2T	0	0	0	*msi*
Tensile Strength, F2T		F2T	0	0	0	*ksi*
Tensile Strain to Failure, ε2T		ue2T	0	0	0	*microstrain*
υ 21		nu21t	0	0	0	
Compressive Modulus, E1C	C0	E1C	0	0	0	*msi*
Compression Strength, F1C		F1C	0	0	0	*ksi*
Compressive Strain to Failure, ε1C		ue1c	0	0	0	*microstrain*
υ 12		nu12c	0	0	0	
Compressive Modulus, E2C	C90	E2c	0	0	0	*msi*
Compression Strength, F2C		F2c	0	0	0	*ksi*
Compressive Strain to Failure, ε2C		ue2c	0	0	0	*microstrain*
υ 21		nu21c	0	0	0	
Shear Modulus, G12	IPS	G12	0	0	0	*msi*
In-Plane Shear Strength, τ12		F12	0	0	0	*ksi*
Shear Strain to Failure, γ12		Ga12	0	0	0	*microstrain*
Open Hole Tensile Strength	OHT	OHT	0	0	0	*ksi*
Open Hole Compression Strength	OHC	OHC	0	0	0	*ksi*
Bearing Strength	Bearing	PB	0	0	c	*ksi*
Interlaminar Mechanical Properties	**Test Method**	**RTD**	**CTD**	**ETW**	**ETD**	**Units**
Interlaminar Shear Modulus, G13	ILS-1	G13	0	0	0	*msi*
Interlaminar Shear Strength, τ13		F13	0	0	0	*ksi*
Interlaminar Shear Strain to Failure, γ13		Ga13	0	0	0	*microstrain*
Interlaminar Shear Modulus, G23	ILS-2	G23	0	0	0	*msi*
Interlaminar Shear Strength, τ23		F23	0	0	0	*ksi*
Interlaminar Shear Strain to Failure, γ23		Ga23	0	0	0	*microstrain*
Interlaminar Tensile Modulus, E3T	ILT	E3t	0	0	0	*msi*
Interlaminar Tensile Strength, F3T		F3t	0	0	0	*ksi*
Interlaminar Tensile Strain to Failure, ε3T		ue3T	0	0	0	*microstrain*
Interlaminar Compressive Modulus, E3C	ILC	E3c	0	0	0	*msi*
Interlaminar Comporessive Strength, F3C		F3c	0	0	0	*ksi*
Interlaminar Compressive Strain to Failure, ε3C		ue3c	0	0	0	*microstrain*
υ 13						
υ 23						
υ 31 (Tension, Compression)		31T, 31c	,	,	,	
υ 32 (Tension, Compression)		32T, 32c	,	,	,	
Fracture Toughness	**Test Method**	**RTD**	**CTD**	**ETW**	**ETD**	**Units**
Mode I Fracture Toughness						
Non Linear Onset	DCB	nloG1c	0	0	0	*in-lbs/in^2*
Onset (Crack Gage)		oG1c	0	0	0	*in-lbs/in^2*
Propagation @ Crack Growth of 1/4"		pG1c	0	0	0	*in-lbs/in^2*
Steady State		ssG1c	0	0	0	*in-lbs/in^2*
Mode II Fracture Toughness						
Non Linear Onset	ENF	nloG2c	0	0	0	*in-lbs/in^2*
Maximum		maxG2c	0	0	0	*in-lbs/in^2*
Mixed Mode Bending Ratios	MMB	9				

Figure 3. Composite Materials Database - Summary of Mean Properties (Page 1)

Thermal Properties	**Test Method**		**Units**			
Thermal Conductivity	ASTM D5930	TC	*W/(m -°K)*			
Specific Heat	ASTM E2716	c	*Joules/(g-°K)*			
Glass Transition Temperature, Tg	ASTM D7028	Tg	*°F*			
Electrical Properties	**Test Method**		**Units**			
Dielectric Constant		0				
Resistivity		0				
Loss Tangent		0				
Flammability Properties	**Test Method**		**Units**			
Flammability Properties (Tmax)	ASTM D7309	0	*°F*			
Smoke Generation	ASTM E662	0	*in-lbs*			
Concentration of Gases	ASTM E800	0				
Extras to be cited in Comments Section	**Test Method**	**RTD**	**Units**			
Compression After Impact						
Impact Energy, Compression Strength	ASTM D7136/D7137	25, Fcai	ft-lbs/sec, ksi			
Impact Energy, Compression Strength		50, fcai1	ft-lbs/sec, ksi			
Impact Energy, Compression Strength		83, fcai2	ft-lbs/sec, ksi			
Impact Energy, Compression Strength		100, fcai3	ft-lbs/sec, ksi			
		RTD	**CTD**	**ETW**	**ETD**	
Flexural Modulus, Ef	Flex	Ff	FfCTD	Ff	FfETD	*msi*
Flexural Strength, Ff		Ef	Ef	EfETW	Ef	*ksi*
Coefficients of Expansion	**Test Method**		**Units**			
Coefficient of Thermal Expansion, α1	TE-1	alpha1	*per °F*			
Coefficient of Thermal Expansion, α2	TE-2	alpha2	*per °F*			
Coefficient of Thermal Expansion, α3	TE-3	alpha3	*per °F*			
Coefficient of Moisture Expansion, β1	ME-1	M1	*per %Moisture*			
Coefficient of Moisture Expansion, β2	ME-2	M2	*per %Moisture*			
Coefficient of Moisture Expansion, β3	ME-3	M3	*per %Moisture*			
Processing Data						
Resin Formulation	Sample resin formulation 0.2% CoNap, 0.2% 2,4-P, 0.05% DMAA, 1.5% Triganox, Two Part Epoxy 100:25 A:B					
Additional References:						
Documentation List	Other reports on the same or similar material					

Figure 4. Composite Materials Database - Summary of Mean Properties (Page 2)

It is not expected that each composite material in the CMD will have a complete CMDT. This is especially true for historical composite materials programs. The values from the tests that have been performed will be entered and remaining cells left blank. In general, it is expected that most composite programs will have generated material properties from screening tests where the mean/average of ten (10) or fewer samples are reported, and, therefore a "Mean Properties" summary tab will be generated for the CMD. In the case where more extensive testing is performed, which will be explained in more detail later in this report, a "B-Basis" material summary tab will also be generated for the material for inclusion in the CMD. Depending on the interest of the program, other materials tests related to the thermal and electrical properties as well as fire, smoke and toxicity properties also have placeholders within the CMDT for future use.

Material Description

The purpose of the Material Description tab (shown in Appendix A) within the CMDT is to capture as much information as possible about the pedigree of the composite material that was tested. There are numerous combinations of resin, reinforcements and manufacturing techniques that can be used to fabricate composite materials. The material properties and characteristics of the composite material can vary widely and can, to some extent, be tailored to meet specific design objectives. Selection of the fiber, the resin system and manufacturing process has a direct impact on the strength, stiffness, weight and cost of the structure. The following section will provide some basic additional guidance for the information that is required on the Material Description tab of the CMDT. More detailed information in this area can be found in the *Composite Materials Handbook* (Reference 2).

Manufacturer

If known, the manufacturer of the composite material should be entered into the CMDT. This may be a company, university, or a government laboratory. As much information as possible should be noted for reference purposes.

Manufacturing Method

Numerous methods have been developed to manufacture composite materials. Typically, the selection of the manufacturing technique depends on the selection of the fiber, matrix, core, overall design of composite structure, desired mechanical properties, and cost. Some examples of the different types of methods available include, (1) hand layup, (2) autoclave prepreg, (3) filament winding, (4) resin transfer molding (RTM), (5) vacuum assisted resin transfer molding (VARTM), (6) pultrusion, (7) out of autoclave prepreg, (8) compression molding and (9) injection molding. It is very important to capture as much information as possible about the manufacturing method used to fabricate the composite material, as well as any specific processing steps that might have been used to fabricate the composite material tested.

The two low-cost manufacturing techniques that are generally considered for naval application are VARTM and pultrusion. In the VARTM process, dry fabric pre-forms and core materials are placed on a tool surface under vacuum and the resin is pulled into the dry fabric. This process is somewhat limited to resins that have the desired viscosity to flow adequately into the preform and cure at room temperature. Increased mechanical properties can usually be obtained through post-cure of the part at elevated temperature. Pultrusion, similar to extrusion, is limited to parts that have the same cross section along the length of the part. In this case, dry fibers are pulled through a resin bath, along with the desired core, into a heated die of the desired cross section. Recent developments have also shown that edge features such as tongue and groove like features can also be incorporated into the dies to aid in joining of panels. Since the dies are heated in the pultrusion process, increased mechanical performance of the composite can be obtained without a post cure.

Matrix

In this section, the type of polymer that is used for the matrix component of the composite material should be listed. This section should include as much information about the matrix system as possible. At a minimum, it should include the generic type of matrix resin system such as vinyl ester, epoxy, polyester, phenolic, etc. If possible, it should also include the manufacturer and trade name of the specific resin system used, as well as any batch material information available, such as lot number, batch date or date of resin manufacture. Epoxy and vinyl ester resin are the two most common matrices that are typically selected for medium to high performance naval composites. These materials come in several grades depending on the manufacturing requirements and ultimate durability requirements of the material system. For example, resins can be purchased with additives for increased fire resistance or impact toughness.

Resin Formulation

This section should include as much information as possible regarding the resin formulation used to make the part. This is especially important in liquid molding processes where the ratio of catalyst, gel time retarder, accelerator and other components can be changed to vary the gel time or other requirements. It should also be noted in systems that are multi-component, such as two-part epoxy, what the mix ratio is of the two components.

Gel Time

In this section, the time that the resin takes to gel should be noted. In general, gel is defined as the point at which the resin is no longer capable of flowing through the fiber preform.

Batches

This section should note the number of batches that are represented in material property data in the report. The definition of a batch of material typically refers to a quantity of homogeneous resin (base resin and curing agent) prepared in one operation with traceability to individual component batches as defined by the resin manufacturer combined with a specific manufacturing set up and run. For example, in the case of a VARTM manufacturing method, for panels to be considered from a separate batch, they must be infused separately with separately measured and mixed resins.

Fiber

In this section, the specific fiber that is used in the fabrication of the part should be noted. As in previous sections, as much information as possible should be recorded in the CMDT. At a minimum, this should include the fiber type such as E-Glass, S-Glass, Carbon, Kevlar, etc. Typically, the baseline fiber would have a coating/finish/sizing applied for a variety of reasons. These terms tend to be used somewhat interchangeably in industry to denote something is applied to the fiber surface after fabrication. In general, they are applied to the single fiber, but may also be applied to a group of fibers (tow, roving, yarn). The selection of coating/finish/sizing can significantly affect the material properties. In some cases, coupling agents can be applied to make a fiber compatible or incompatible with the surrounding matrix. In the case of a compatible system, the fiber to matrix bond will be good/strong; whereas, an incompatible system will be bad/weak. In structural composite materials applications, a compatible system is typically favored; whereas, in a ballistic composite material application an incompatible sizing may be favored so that the fiber to matrix bond breaks first to dissipate more energy. More detailed information regarding fibers and fiber forms can be found in Reference 2.

Fabric

In this section, the type of fabric that is used to make the composite part should be noted as well as the manufacturer. Typically, once the fibers are fabricated, due to their small size (<30 μm in diameter), they grouped together into strands/rovings/tows/yarns. The terminology varies depending on the type of fiber. See Reference 2 for more detailed information. Different numbers of fibers can be grouped together such as a 3K, 6K or 9K carbon fiber tow examples. These groups of fibers are then used to make different types of fabrics. They can be woven together into different weaves such as plain weave, 3x1 twill, 8 harness satin, etc. They can also be stitched together with polyester/nylon string to form unidirectional fabric. Glass strands can be group together to form yarns and sometimes twisted as they are weaved into fabrics. As much information as possible should be noted about the fabric; it has a significant effect on the overall composite fiber volume fraction and subsequent fiber dominated mechanical properties.

Laminate Schedule

In this section, the layup of the composite shall be noted. In most cases, the composite layup should be balanced and symmetric to allow for uniform reaction of the composite material under loading. In some cases, a specialized layup that is unbalanced and/or unsymmetric may be warranted to yield a specific atypical material reaction, such as twisting under load. It is very important that the composite material layup is noted in the CMDT, as it has a significant effect on the fiber dominated mechanical properties.

Cure Schedule

In this section, as much information as possible should be noted about the cure/post cure of the composite material that is being tested. Like the fabric and composite layup, the temperature history of a composite material can significantly affect the mechanical properties. Typically, when performing mechanical testing on composite materials, it is desirable to perform the testing on material in the state that will best represent the lifetime operations state of the material. A composite part that will be fielded into a marine environment is expected to undergo significant amount of solar heating during its lifetime with exposure up to 175°F for a topside composite material application. This exposure will, in effect, post cure a composite part that was originally manufactured in a room temperature process. It is therefore sometimes beneficial to “artificially age” a newly manufactured room temperature composite material before mechanical testing by holding the material at an elevated temperature to accelerate the curing process to be able to generate properties that are close to the expected in-service values. Some room temperature cured vinyl ester based composite materials have used a 4-hour post cure at 160°F to simulate this operational lifetime environment.

Manufacturing Date

In this section, the approximate date of fabrication of the composite materials shall be noted.

Testing Facility/Date

In this section, the facility that performed the mechanical testing shall be noted, as well as the approximate date that the testing was performed.

Program of Record

In this section, the program that generated the data shall be noted. This may include RDT&E programs that are funded through ONR or internal NSWCCD funds, acquisition programs, SBIR programs, etc.

Reference

In this section, the reference that was used to obtain the data that was entered into the CMDT shall be noted. Some examples of references shall be NSWCCD reports, contractor reports, conference papers, etc. Whenever possible, a PDF file shall also be included with the data entry and a hyperlink provided in the file so that a user could look for more detailed information about the data entry. If possible it should also be noted if this data that was entered is company proprietary or is public releasable data. **In general, the data that will be entered**

into the database is company proprietary; it cannot be shared with other DoD contractors and is for Navy internal use only.

Data Type Available

In this section, the type of data that is entered into the CMDT shall be noted. In general, the data class will be either screening/mean, B-basis (B18 or B30) depending on how many samples were tested to generate the data. Additional information about the different types of methods used to statistically treat the data from different batches/panels can be found in Reference 2.

Additional References

In this section, any additional references on this composite material shall be noted.

Notes

In this section, any additional information that is deemed important to capture regarding the composite material shall be noted.

Material Property Screening Test Matrix

In some cases, it is desirable to do a “quick” material property characterization to see how a “new” composite material of interest compares to ones that have been used in the past. A “new” composite material could be one where there is a change in the constitutive materials, or simply a change in the resin chemistry or manufacturing process. In this case, it is recommended to do a series of baseline tests to determine the average mechanical properties of the material, as well as some baseline tests that look at the quality of the material and environmental durability of the as-manufactured material. A summary of the recommended materials screening tests are shown in Table 2 with a ranking of test priorities. The higher priority tests should be completed first with the lower priority tests performed as warranted by the specific requirements of the application.

Typically, the first test listed for tension and compression would be chosen for the materials screening. The second test listed would be the preferred test if all other considerations are equal. The tests listed under the shear test type all have limitations on composite laminate layup schedule and thicknesses. One or more of these tests should be chosen, depending on the detailed requirements of the test. All these tests should be performed at room temperature conditions. The quality inspection tests are focused on ensuring that the material has the fiber volume fraction and void content that is typical of the layup and manufacturing process. In addition to mechanical property and quality inspection tests, it might also be desirable to get a first glance at the potential environmental durability of the composite material through tests that look at exposure to moisture and temperature. More detailed summaries of all the tests denoted in Table 2 are given in the following sections.

Table 2. Screening Material Properties Test Matrix

Priority	Test Type	ASTM	Reference Number	Properties	Minimum Sample Quantity	
					0°	90°
1	Quality Inspection	D792	7	Density	5	5
		D2584	8	Fiber volume fraction (glass)	5	5
		D3171	9	Fiber volume fraction (carbon)	5	5
		D2734	10	Void content	5	5
	Tension	D638, D3039	11, 12	Tensile strength, modulus, Poisson's Ratio and strain to failure	5	5
	Compression	D695, D6641	13, 14	Compressive strength, modulus, Poisson's Ratio and strain to failure	5	5
2	Shear	D5379, D7078	15, 16	Shear strength, modulus and strain to failure	5	5
	Interlaminar Shear	D2344	17	Short beam shear strength	5	5
		D7291	18	Through thickness "flatwise" tension strength and modulus	5	5
3	Environmental Durability	D570	19	Moisture absorption	5	5
		D7028	20	Glass transition temperature	5	5

Quality Inspection

Typically, the first tests that are performed on a new composite material would be those that evaluate the quality of the laminate to ensure that it is adequate to warrant further evaluation of the composite materials with mechanical tests. The basic tests that can be performed quickly on a small amount of material are used to determine the composite density, fiber volume fraction, and void content of the composite material. The following ASTM standards can be used to perform the quality inspection.

Density

ASTM D792, *Standard Test Methods for Density and Specific Gravity*.[7] This test is used to determine the specific gravity (relative density) and density of solid plastics in forms such as sheets, rods, tubes or molded items. Test Method A is typically used for laminated composites. The process requires the weighing of a 1- to 50-gram specimen of varying geometry in water. Sinkers can be used for plastics that are lighter than water. When dealing with composite specimens, care should be taken to smooth the edges of the specimen so that air bubbles are not entrapped when the specimen is placed underwater. The size/weight of the specimen can be variable and is limited only by the laboratory facilities available to perform the testing. This method uses the Archimedes Principle to determine the density of the composite. This test method is suitable for unreinforced and reinforced plastics that are wet by, but not otherwise affected by water.

Fiber Volume Fraction

ASTM D2584, *Standard Test Method for Ignition Loss of Cured Reinforced Resins*.[8] This test method covers the determination of the ignition loss of cured reinforced resins and is colloquially known as the "burnoff" method. This test method calls for a small sample (~5 g, 1 inch square), to be weighed, placed in a suitable receptacle and placed in an oven, which is heated to 1050°F (565°C) until such time that the resin is reduced to ash leaving behind any materials (such as glass fibers) that are not affected by the extreme temperature. It is then assumed that the ignition loss or the weight loss can be considered the weight of the resin for the sample. This test method cannot be used for samples that contain reinforcing materials that lose weight under the temperature exposure (e.g., carbon fiber) or resins that do not decompose to volatile materials released by ignition.

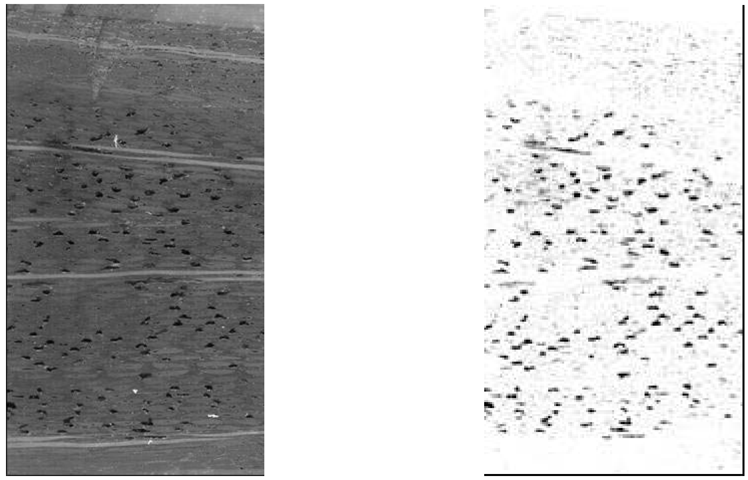
ASTM D3171, *Standard Test Methods for Constituent Content of Composite Materials*.[9] This test uses several methods to determine the constituent content of composite materials. Method I describes seven methods to remove the matrix either through digestion or ignition, leaving the reinforcement unaffected. The amount of loss is once again attributed solely to the resin allowing for the calculation of the percent resin/fiber content. Combined with the density results of ASTM D792, this method can be used to determine the void content within the composite material.

Void Content

ASTM D2734, *Standard Test Methods for Void Content of Reinforced Plastics*.[10] This test provides three different methods for determining the void content of reinforced composite materials. It is based on a comparison of the theoretical density and measured experimental density. This method is typically used in conjunction with ASTM D792, and ASTM D2584 or ASTM D3171. At very low void contents, or in cases where the resin does not totally volatize, the calculations of this method can yield non-real negative void volume contents.

Alternative Fiber Volume Fraction/Void Content

In the cases where one is unable to use the methods outlined in ASTM D2584 or ASTM D3171 to remove the resin from the composite material to determine the fiber volume fraction and/or void content, one can perform an optical inspection of the composite to determine a local fiber volume fraction and/or void content. In this case, a specimen is cut perpendicular to the fiber direction to expose the desired cross section. The sample is then polished using standard metallographic specimen preparation techniques such that the areas of interest (voids/fibers) can easily be seen under the desired magnification. An example of an area that was used to determine the void content of a thick section carbon fiber reinforced composite is shown in Figure 5. This figure was captured using a scanner set to a high resolution. It has been found that the use of a scanner for large composite specimens, that do not need high magnification, is a simple way to capture a high resolution image. In this case, one can see the elliptical carbon fiber tows of the 0° layers and some off-axis and 90° layers. A computer graphics program such as Adobe Photoshop™ or Corel Photopaint™ can then be used to perform a threshold analysis on the image which leaves only the void content in black. The software's histogram function can then be used to determine the number of black pixels in the area and therefore an areal/volume fraction. This technique was used on Figure 5 and the threshold image which yielded a 5.8% void fraction is shown. This technique can also be used to determine the local fiber volume fraction. More information on photomicrographic procedures for determining fiber volume fraction can be found in Reference 21.

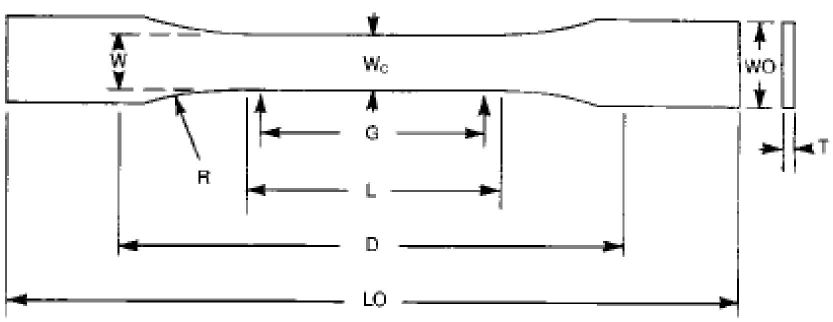


Optical Scan of Carbon Fiber Composite and Computer-Generated Image of Void Areas (5.8% void volume fraction)

Figure 5. Optical Scan of Composite Material Used to Determine Void Volume Fraction

Tension Tests

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*.[11] This test is used to determine the tensile properties (strength, elastic modulus, strain to failure and Poisson's Ratio) of unreinforced and reinforced plastics in the form of a standard dumbbell-shaped test specimen. Typically, for composite materials within the thickness rage of 0.28 to 0.55 inches, a Type III specimen is called out by the ASTM standard as shown in Figure 6. The ASTM D3039 standard is preferred for determining the tensile properties of resin-matrix composites reinforced with oriented continuous or discontinuous high modulus (>3 Msi) fibers.

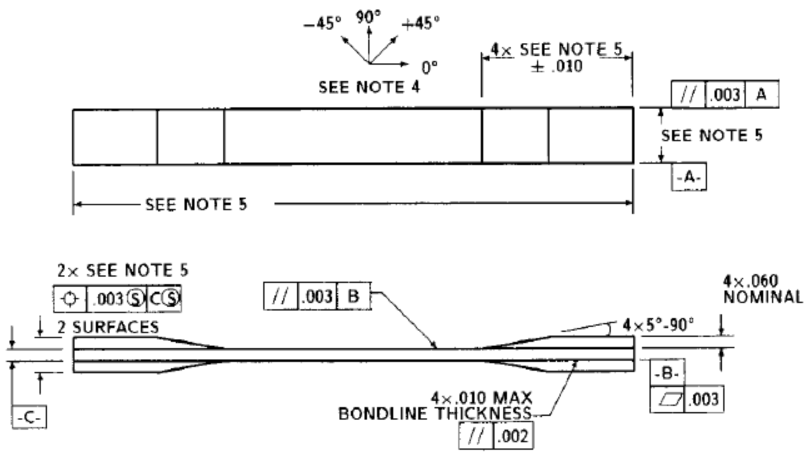


T	= 0.28-0.55 inch, incl.
W	= 0.75 inch
L	= 2.25 inch
WO	= 1.13 inch
LO	= 9.7 inch
G	= 2.00 inch
D	= 4.5 inch
R	= 3.00 inch

Figure 6. ASTM D638 Tensile Test Sample Configuration[11]

ASTM D3039/30309M, *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*.[12] This test is used to determine the in-plane tensile properties (strength, elastic modulus, strain to failure and Poisson's Ratio) of polymer matrix composite materials reinforced by high modulus fibers. The laminate must be balanced and symmetric with respect to the test direction. The standard contains several tables to determine the exact specimen geometry that should be used for the material being evaluated based mainly on fiber orientation and material thickness. A baseline drawing of the test specimen geometry is shown in Figure 7.

Tabs are not required, but may be necessary to ensure that the tensile failure occurs within the gage length of the test specimen. Detailed information regarding tab design (length, width, and bevel angle) can also be found in the ASTM D3039/D3039M standard. For example a tabbed tensile test specimen for a quasi-isotropic carbon fiber reinforced vinyl ester composite material is 10 inches long, 1 inch wide, and 0.25 inch thick with 0.125 inch thick G-10 tab material, whichis 2 inches long with a 5-90° bevel angle.



Note 4:

Ply orientation tolerance relative to -A- within ±0.5°.

Note 5:

Values to be provided for the following, subject to any ranges shown in the fields of the drawing; material, lay-up, ply orientation reference relative to -A-, overall length, gage length, coupon thickness, tab material, tab thickness, tab length, tab bevel angle, tab adhesive.

Figure 7. ASTM D3039/D3039M Tensile Test Sample Configuration[12]

Compression Tests

ASTM D695, *Standard Test Method for Compressive Properties of Rigid Plastics*.[13] This test is used to determine the compressive properties (strength, elastic modulus, strain to failure and Poisson's Ratio) of unreinforced and reinforced rigid plastics, including high modulus composites when loaded in compression. For materials greater than 0.125 inch thick, the specimen geometry shall be 0.5 inch wide and of sufficient length such that the length to thickness ratio falls within 11 to 16:1. For materials less that 0.125 inch thick, the specimen geometry is shown in Figure 8.

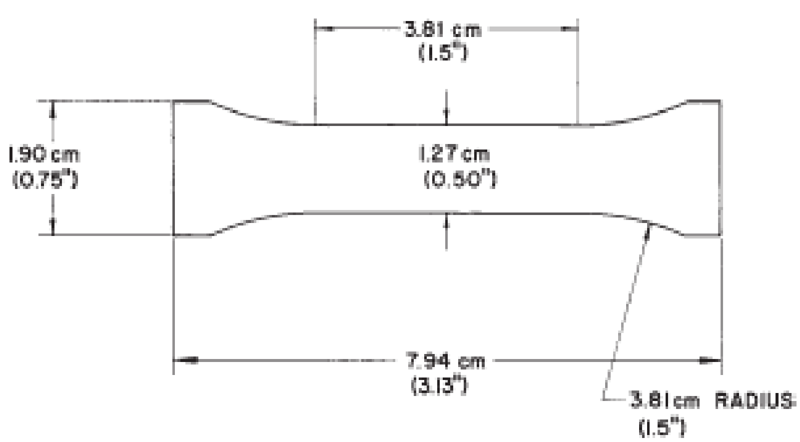
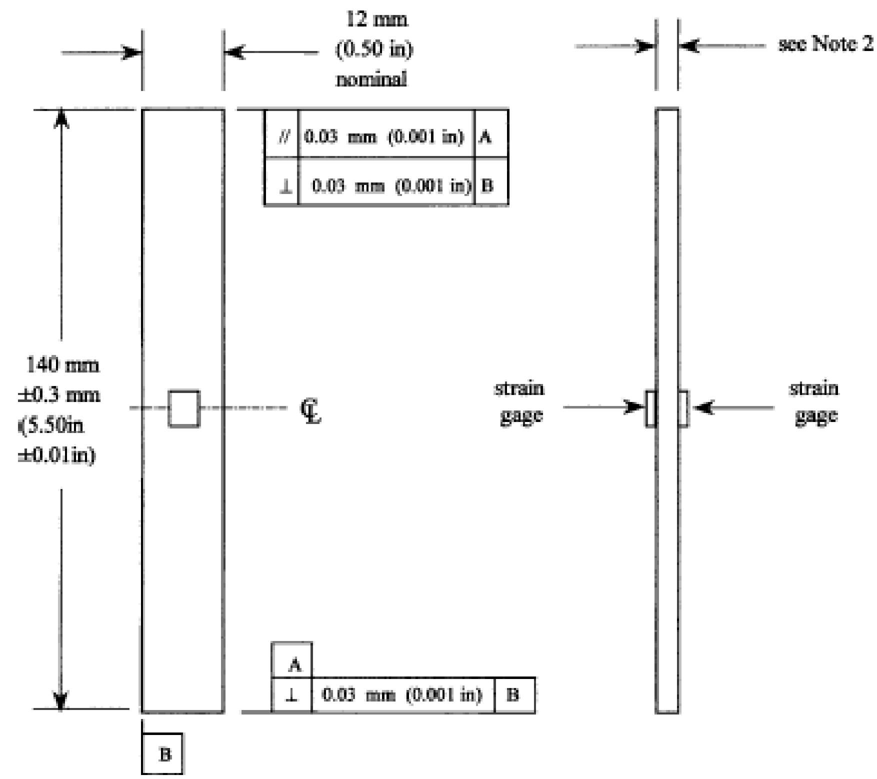


Figure 8. ASTM D695 Compression Test Sample Configuration for Materials less than 3.2 mm (0.125 inch) Thick[13]

ASTM D6641, *Standard Test Method for Determining the Compression Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture*.[14] This test method can be used to determine the compressive strength and stiffness properties of polymer matrix composite materials using a combined loading compression (CLC) or comparable test fixture. The compressive force is introduced into the specimen by combined end- and shear-loading. In comparison, the test method ASTM D695 is pure end-loading. The composite laminate must be balanced and symmetric and contain at least one 0° ply. Unidirectional composites can be tested to determine unidirectional compressive modulus and Poisson's Ratio, but not compression strength. The laminate is limited to 50% 0° plies for determining the compression strength due to the untabbed nature of the standard specimen. The standard specimen geometry is shown in Figure 9.



Note 1:

The specimen ends must be parallel to each other within 0.03mm (0.001 in) and also perpendicular to the longitudinal axis of the specimen with 0.03 mm (0.001 in).

Note 2:

Nominal specimen thickness can be varied, but must be uniform. Thickness irregularities (for example, thickness taper or surface imperfections) shall not exceed 0.03 mm (0.001 in) across the specimen width or 0.06 mm (0.002 in) along the specimen length.

Note 3:

The faces of the specimen may be lapped slightly to remove any local surface imperfections and irregularities, thus providing flatter surfaces for more uniform gripping by the fixture.

Figure 9. ASTM D 6641 Combined Loading Compression Test Sample Configuration[14]

In Plane Shear Tests

ASTM D5379, *Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method*.[15] This test method determines the in-plane shear modulus, shear strength and shear strain of composite materials reinforced with high modulus fibers. There are several limitations to the composite material layup, so that a desired failure mode occurs during the test. (1) Laminates composed only of unidirectional fibers must have the fibers oriented perpendicular or parallel to the loading axis. (2) Laminates composed of woven fabric must have the warp direction oriented either parallel or perpendicular to the loading direction. (3) Laminates composed of unidirectional fibers containing equal numbers of plies oriented at 0° and 90° in a balanced and symmetric stacking sequence must have the 0° plies orientated either perpendicular or parallel to the loading axis. (4) Short fiber reinforced composites can be tested as long as the majority of the fibers are randomly distributed. The test specimen geometry and test fixture schematic are shown in Figure 10. One of the advantages of this test method is its ability to be used to determine the material shear properties in a variety of different material planes by machining the specimen at different orientations. An example of the 6 different test orientations of a unidirectional composite is shown in Figure 11.

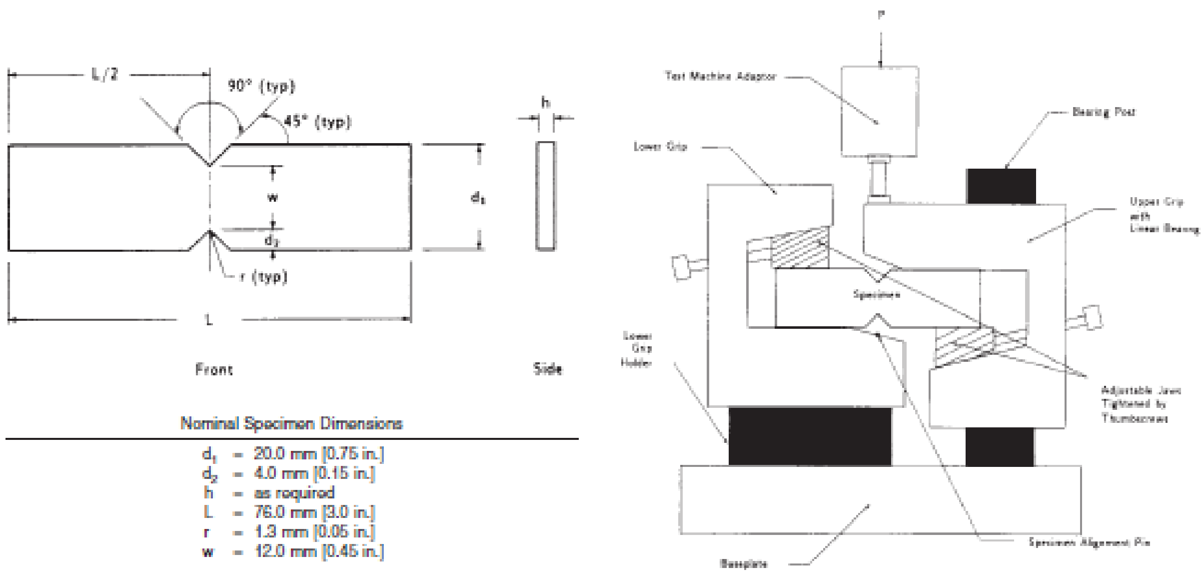


Figure 10. V-Notched Beam Test Coupon and Fixture Schematics[15]

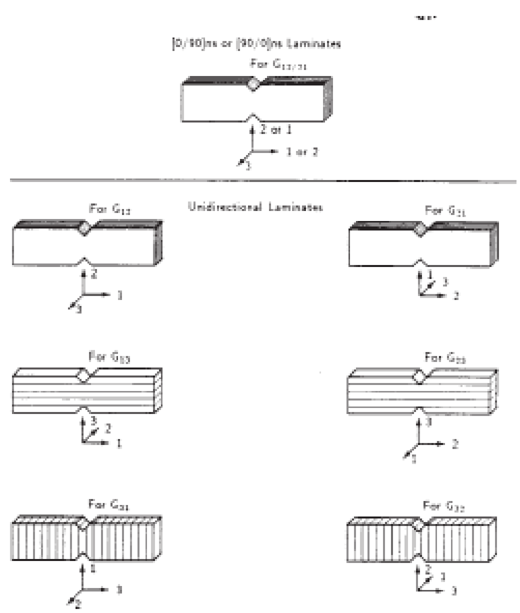
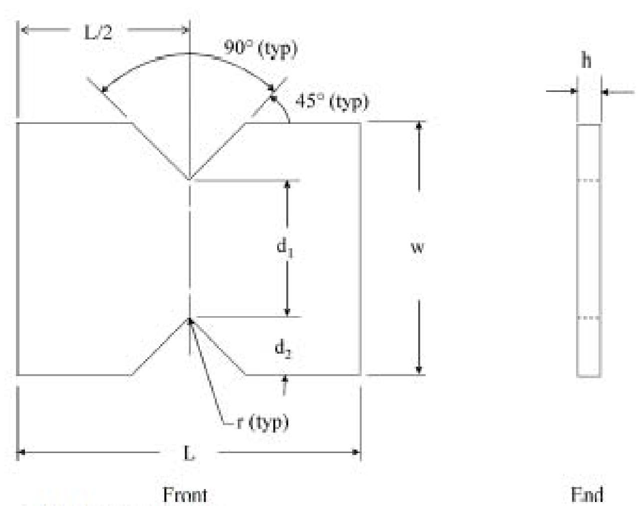
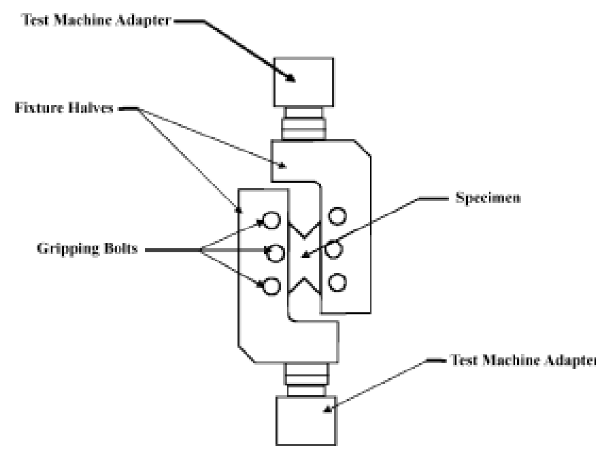


Figure 11. Orientation of Material Plane for Unidirectional V-Notched Test Coupon[15]

ASTM D7078, *Standard Test Method for Shear Properties of Composite Materials by the V-Notched Rail Shear*.[16] This test method determines the in-plane shear modulus, shear strength and shear strain of composite materials reinforced with high modulus fibers by clamping the ends of the V-notched specimen between two pairs of loading rails. When loaded in tension, the rails induce shear forces into the specimen through the specimen faces. If necessary, this mechanism of shear loading allows higher shear force to be applied to the specimen than ASTM D5379, which is loaded through its top and bottom edges. The test specimen geometry and test fixture schematic are shown in Figure 12. Like the ASTM D5379 standard, the D7078 method has limitations on the composite layups that can be tested to ensure a valid failure mode, but it will allow you to test specimens in many of the orientations shown in Figure 11. This standard calls out specific test analysis methods that will allow for testing of composites with ±45° layers within the composite layup.





(b) Assembled V-Notched Rail Shear Apparatus

Nominal Specimen Dimensions:

d_1 = 1.20 inch (31.0 mm)

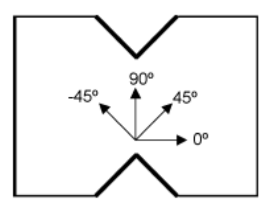
d_2 = 0.50 inch (12.7 mm

h = as required

L = 3.0 inch (76.0 mm)

R = 0.05 inch (1.3 mm)

W = 2.20 inch (56.0 mm)



(c) Fiber Orientations in V-Notched Shear Specimen

(a) Specimen Schematic

Figure 12. ASTM D7078 Testing Details[16]

Interlaminar Shear Tests

ASTM D2344, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*.[17] This test method determines the short beam strength of high-modulus fiber reinforced composite materials. The test specimen configuration, as shown in Figure 13, is a short beam that is typically machined from a curved or a flat laminate up to 0.25 in thick. The composite materials must be balanced and symmetric with respect to the longitudinal axis of the beam. Typical test sample geometry is a 0.25-in thick, 1.5-inch long and 0.5-inch wide rectangular prism. For alternate geometries, the guidelines are that the specimen length is 6 times the thickness and the specimen width is 2 times the thickness. The specimens are loaded in a three-point bend configuration with the span to depth ratio of 4. Typical failure modes observed during short beam shear testing are shown in Figure 14.

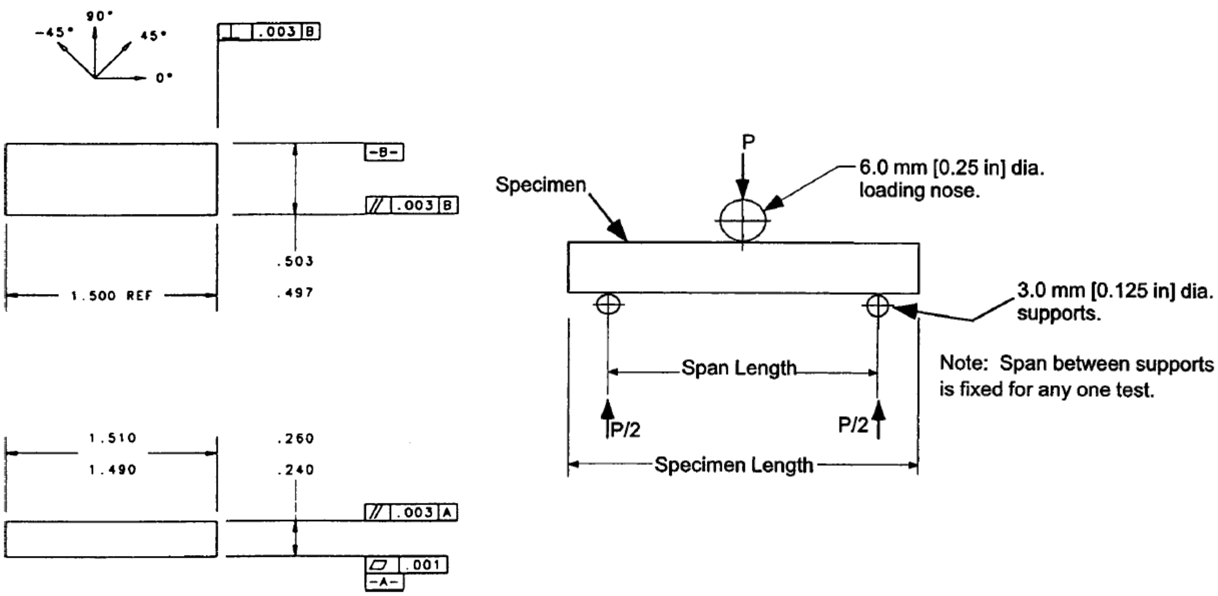


Figure 13. ASTM D2344 Short Beam Shear Test Coupon and Fixture Schematics[17]

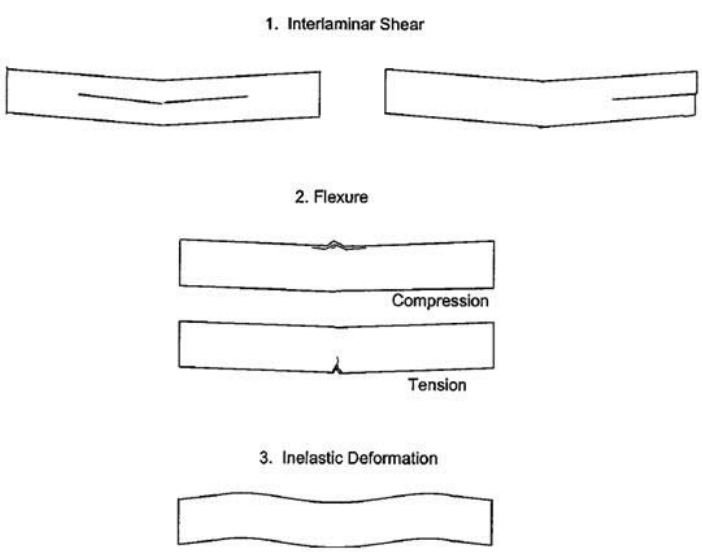


Figure 14. ASTM D2344 Short Beam Shear Test Typical Failure Modes[17]

ASTM D7291, *Standard Test Method for Through-Thickness "Flatwise" Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material*.[18] This method is used to determine the through-thickness "flatwise" tensile strength and elastic modulus of fiber reinforced polymer matrix composite materials. Typical test coupon geometries are shown in Figure 15. The composite material is adhesively bonded to thick metallic endtabs, which are used to apply a tensile force normal to the plane of the composite laminate. The test is considered valid only when failure occurs completely within the composite laminate. Specimens can be instrumented with strain gages to determine modulus values. The nominal specimen diameter is 1 inch. For through thickness failure strength measurement, the minimum specimen thickness is 0.1 inch. When measuring strains, the minimum thickness is 0.25 in. The reduced gage specimen geometry is typically used for materials that exhibit through thickness strength that approaches the bond strength of the adhesive and are the preferred geometry of specimens that are at least 1 inch thick.

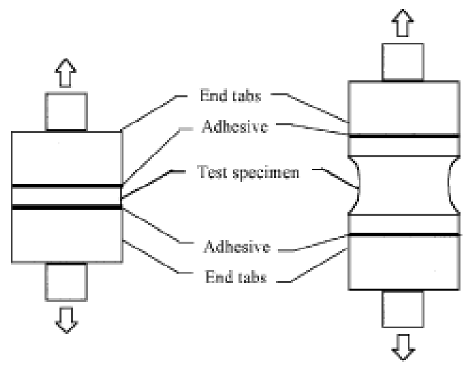


Figure 15. Straight Sided Cylindrical and Reduced Gage Section "Spool" Test Specimens[18]

Environmental Durability

The mechanical tests outlined in the previous section are all typically performed at room temperature of 70±10°F with the moisture condition in the as-received or as-manufactured condition to provide baseline materials properties. In reality, the composite materials can be fielded into a variety of different environments with different hot/cold and wet/dry conditions. Therefore, it is sometimes useful to get a quick look at how the composite material will behave when exposed to moisture and elevated temperatures. This can be accomplished by performing the following two tests that determine the equilibrium moisture content and glass transition temperature of the composite material.

ASTM D570, *Standard Test Method for Water Absorption for Plastics*.[19] This test method can be used to determine the relative rate of absorption of water by plastics when immersed in water. This method can be used for all different types of plastics, including reinforced polymer matrix composites. The methodology presented in Section 7.4, Long Term Immersion, can also be used to determine long-term moisture uptake behavior for materials exposed to different hot/wet environmental conditions. Typically, a 50°C temperature exposure, with 80% relative humidity has been used as the typical long-term hot/wet conditioning for surface ship topside composite structure applications. It has been found in the past that higher moisture equilibrium content tends to lead to a greater degradation in room temperature material properties upon hot/wet exposure.

ASTM D7028, *Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis*.[20] This test method covers the procedure to determine the dry (or wet) glass transition temperature (Tg) of polymer matrix composites using a dynamic mechanical analyzer (DMA) under the flexural oscillation mode. The glass transition temperature is dependent on the physical property measured, the measuring apparatus and experimental parameters used to perform the test. The Tg determined from this test (DMA Tg) may not be the same as that reported by another measurement technique such as differential scanning calorimetry (DSC). Following ASTM D7078, a small flat rectangular strip of composite laminate is placed in the DMA equipment and oscillated at a nominal frequency of 1 Hz, while the specimen is heated at a rate of 5°C/min. The same heating rate should be used for both dry and wet specimens to allow for a direct comparison between the two. If not testing a wet specimen, greater precision can be accomplished using a 2°C/min or less heating rate. Test apparatus and test parameters should be reported along with measured Tg. The temperature at which a significant drop in the storage modulus (E') begins is assigned as DMA Tg. Typically, a drop in the storage modulus material property can be related to a drop in the elastic modulus material property. Therefore, one would desire the Tg of a composite material to be greater than the highest operating temperature of a composite structure to ensure that there is no drop in elastic material properties when the structure is exposed to elevated temperatures.

Material Property Allowables Generation

Once it has been determined that a new composite material will be used in the design of a composite structure, it is necessary to develop a materials test plan to measure the allowables used in the design. The procedure for establishing material properties for composite systems is illustrated in Figure 16. Composite material strength properties can depend on the operating conditions under which the composite is exposed. Therefore, the first step is to define a set of end-use conditions for the material system. These include the anticipated environmental conditions in which the system will operate, as well as the expected service life of the composite system. All structural systems aboard a U.S. Navy vessel, whether interior or exterior, are assumed to operate in a "wet" environment.[3,5] As a guideline, some previous environmental conditions that have been used in the past for composites programs have been summarized in Table 3. More detailed requirements can be found in Reference 3 and Reference 5. It is important to document in the notes section of the Composite Materials Database Template (CMDT), the environmental conditioning performed on the test specimens prior to testing, as well as the conditions of the testing environment itself.

In order to generate accurate mechanical properties of conditioned samples, care should be taken to ensure that the materials are stabilized at the conditioned state and minimal time elapses between their removal from a conditioning chamber and placement in a test chamber. In cases where this is not possible, it should be documented in the notes section of the CMDT. For example, one note could state that "Samples were conditioned in a hot/wet environment at 122°F and 80% relative humidity, removed for no more than 10 minutes before being placed in a test chamber at 122°F for testing." Due to test equipment constraints, it is not always possible to test the samples at the same conditions to which they were environmentally conditioned. Care should be taken to document the environmental conditioning as much as possible, as well as the testing conditions when generating material property allowables.

Base Material System

(Define In-Service Operating Conditions)

Temperature Extremes

Moisture/Humidity Conditions

↓

Material Strength Testing

(Recommended Approach)

Testing for Strength at Extreme Conditions

Used to estimate reduction factors

- **Room Temperature, Dry**
- **Room Temperature, Wet**
- **Elevated Temperature, Dry**
- **Elevated Temperature, Wet**
- **Static and Fatigue**

↓

Material Allowables

- **Account for Material Variability (B-Basis)**
- **Environmental Degradation**
- **Endurance**

Figure 16. Methodology for Establishing Material Allowables[3]

Methodology

The materials test program must also be designed to capture the statistical variability in actual composite properties, both manufactured and at the end of service life. Detailed explanations of several methods to do this are provided in MIL-HDBK-17-1E.[2] Typically, the "B-basis" method has been used in the past in NAVSEA composite structures programs. The B-basis method can be used to determine the property at which 90 percent of the population of the data is expected to fall within a 95 percent confidence level.

Table 3. Examples of Environmental Conditioning

Condition	Level
Room temperature dry (RTD)	74°F
Elevated temperature (ET)	175°F
Cold temperature (CT)	-65°F,-20°F
Hot/wet (HW or ETW)	122°F/80%RH
Wet (W)	Immersed in relevant fluid

Source: Reference 5

For a composite material property allowable, several batches of material must be characterized to establish the statistical B-basis material allowable. The definition of a batch of material typically refers to a quantity of homogeneous resin (base resin and curing agent) prepared in one operation with traceability to individual component batches, as defined by the resin manufacturer, combined with a specific manufacturing setup and run. In the case of a VARTM manufacturing method, for panels to be considered from a separate batch, they must be infused with separately measured and mixed resins. Each panel from each batch must be layed-up at different times and infused at separate times under separate vacuum bags. The minimum requirement for the materials design allowable generation is shown in Figure 17. The the B-basis value is developed using 3 batches of material, 2 panels from each batch, and 3 test coupon specimens from each panel. The test needs to be completed at the room temperature dry condition, as well as at each temperature/moisture condition identified as representative of the composite materials potential operating environment. If a bi-directional (or unbalanced) fabric is proposed, material properties shall be determined for both the warp (0°) and fill (90°) directions. For unidirectional reinforcement materials, both fiber direction and transverse properties must be characterized. For example, if a new composite material of interest were a 0_{10} composite laminate composed of 24-oz woven roving fabric material made with the warps aligned, with environmental conditions of interest of the RTD, ETD, CTD and ETW (Table 3), then for each material property of interest, there would be a total of 4 × 18 = 72 samples tested in the 0° and 4 × 18 = 72 samples tested in the 90° direction.

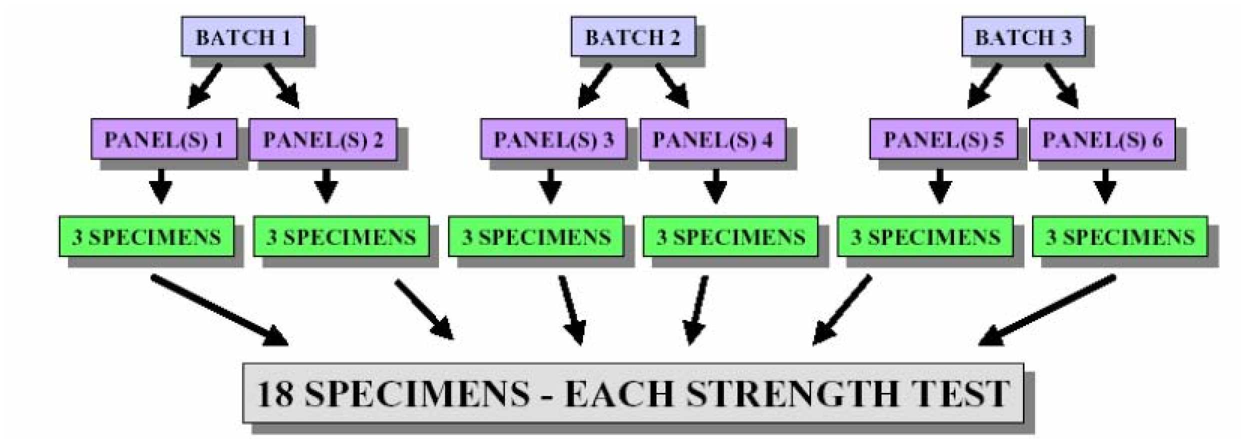


Figure 17. Minimum Material Test Program for B-Basis Material Allowable[5]

Materials Allowable Mechanical Property Test Matrix

Once the methodology to determine the statistical variation of composite materials, presented in the previous section, is well understood, the next step would be to determine the material properties of interest for design purposes to which this methodology should be applied. As discussed earlier, a cross-section of Code 65 personnel, who perform modeling and simulation (M&S) activities, was polled to develop the CMDT, which can be used to capture all the material properties that are typically used in these M&S operations.

Based on the CMPT, Table 4 and Table 5 were developed to show the specific tests and specimen counts that are necessary to develop the B-basis allowables for a new composite material. A ranking of the priorities of the tests are also given in these tables. The higher priority tests should be performed first with the lower priority tests performed as warranted by the specific requirements of the application. The CMPT can be used to capture the results of both materials screening tests, as presented in the previous section, as well as B-basis allowables. Notations are made on the individual worksheets to denote whether the date is average screening data or B-basis allowable data. More detailed summaries of all the tests denoted in Table 4 and Table 5 are given in the following section.

Table 4. Material Allowable Mechanical Properties Test Matrix

Priority	Test Type	ASTM	Reference Number	Properties	Specimen Count B-Basis (RTD only)*	
					0°	90°
1	Quality Inspection	D792	7	Density	18 (3/6)^	18 (3/6)
		D2584	8	Fiber volume fraction (glass)	18 (3/6)	18 (3/6)
		D3171	9	Fiber volume fraction (carbon)	18 (3/6)	18 (3/6)
		D2734	10	Void content	18 (3/6)	18 (3/6)
	Tension	D638, D3039	11, 12	Tensile strength, modulus, Poisson's Ratio and strain to failure	18 (3/6)	18 (3/6)
	Compression	D695, D6641	13, 14	Compressive strength, modulus, Poisson's Ratio and strain to failure	18 (3/6)	18 (3/6)
2	Shear	D5379, D7078	15, 16	Shear strength, modulus and strain to failure	18 (3/6)	18 (3/6)
	Interlaminar Shear	D2344	17	Short beam shear strength	18 (3/6)	18 (3/6)
		D7291	18	Through thickness "flatwise" tension strength and modulus	18 (3/6)	18 (3/6)
3	Open Hole	D5766, D6484	22, 23	Tension Compression	18 (3/6)	18 (3/6)
	Bearing	D5961	24	Bearing strength	18 (3/6)	18 (3/6)
	Fracture Toughness	D5528	25	Mode I fracture toughness (double cantilever beam - DCB)	18 (3/6)	18 (3/6)
		Draft ASTM WK22949, NSWCCD TR-2008/29	26, 27	Mode II fracture toughness (end notch flexure - ENF)	18 (3/6)	18 (3/6)
		D6671	28	Mode I-II fracture toughness (mixed mode bending - MMB)	18 (3/6)	18 (3/6)
	Damage Resistance	D7136, D7137	29, 30	Compression strength after impact	18 (3/6)	18 (3/6)
	Flexural	D7264	31	Flexural stiffness and strength	18 (3/6)	18 (3/6)

^ (3/6) – Denotes 3 samples taken from 6 panels (3 batches) as in Figure 17.
* Additional tests required to cover all the environmental operating conditions.
+ Test can be performed at various impact energy levels.

Table 5. Additional Material Properties Test Matrix

Priority	Test Type	ASTM	Reference Number	Properties
4	Thermal Properties	E2585, E1952	32, 33	Thermal diffusivity/conductivity
		E1269, E2716	34, 35	Specific heat
		D7028	20	Glass transition temperature
		E228, E831	36, 37	Coefficient of thermal expansion
	Fire Smoke and Toxicity	E84, E162	38, 39	Surface flammability Surface flammability (radiant panel)
		E662	40	Smoke generation
		E1354	41	Heat and smoke release rates
		E800	42	Concentration of gases
	Moisture	D570, D5229	19, 43	Equilibrium exposed moisture content
	Electrical Properties	various		Dielectric constant
		D257	44	Resistivity
		various		Loss tangent

Quality Inspection

As with the screening test matrix, the first tests performed on a new composite material would typically be those that evaluate the quality of the laminate. This ensures further mechanical tests of the composite materials are warranted. The same tests listed in the screening test matrix section would be used to determine the quality of the composite material for design material allowables development. However, a significant quantity of additional specimens would be tested to determine the statistical variation of these properties due to batch-to-batch variation. Typically, the specimen guidelines presented in Figure 17, where there are 3 samples each taken from a total of 6 panels, can be used for most applications. However, Reference 6 increases the specimen quantity to 5 from each panel as the best practice for non-pressure hull submarine composite applications. The CMPT also calls out a cured ply thickness as a material property of interest that needs to be recorded.

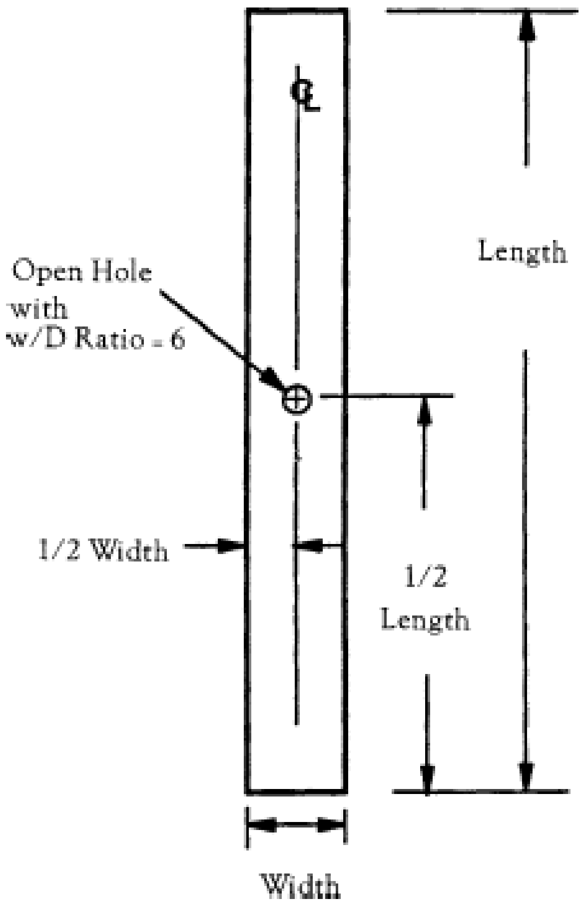
Tension, Compression, and Shear Tests

All the tension, compression and shear material property tests have been explained in greater detail in the Material Property Screening Test Matrix Section, beginning on Page 11. The specimen count that is needed to determine the B-basis allowables are shown in Table 4. The tension and compression tests, along with the quality inspection tests, are considered a priority Level 1 test; whereas, the shear tests are considered a priority Level 2 test.

Open Hole Tension and Compression

In applications where the composite material will have a hole drilled into it for joining and/or attachment purposes, it is important to understand how the composite material behaves with the hole present. Therefore, two different tests can be performed to determine the effect that the hole has on the tensile and compression strength of the composite. These tests are considered priority Level 3 tests, since they depend on the application.

ASTM D5766, *Standard Test Method for Open Hole Tensile Strength of Polymer Matrix Composite Laminates*.[22] This test method determines the open hole tensile strength of polymer matrix composite materials. The laminates must be balanced and symmetric. The baseline specimen geometry is shown in Figure 18, and the mechanical testing is performed in accordance with ASTM D3039.[12]



Where:

Length	**= 8 to 12 inches (200 to 300 mm)**
Width	**= 1.5 ± 0.05 inch (36±1 mm)**
Hole	**= 0.25 ± 0.003 inches (6 ± 0.06 mm) diameter**

Figure 18. ASTM D5766 Test Specimen Schematic[22]

ASTM D6484, *Standard Test Method for Open Hole Compression Strength of Polymer Matrix Composite Laminates*.[23] This test method determines the open hole compressive strength of polymer matrix composite materials. The laminates must be balanced and symmetric. The baseline specimen geometry and the test fixture assembly that is used to perform the test are shown in Figure 19.

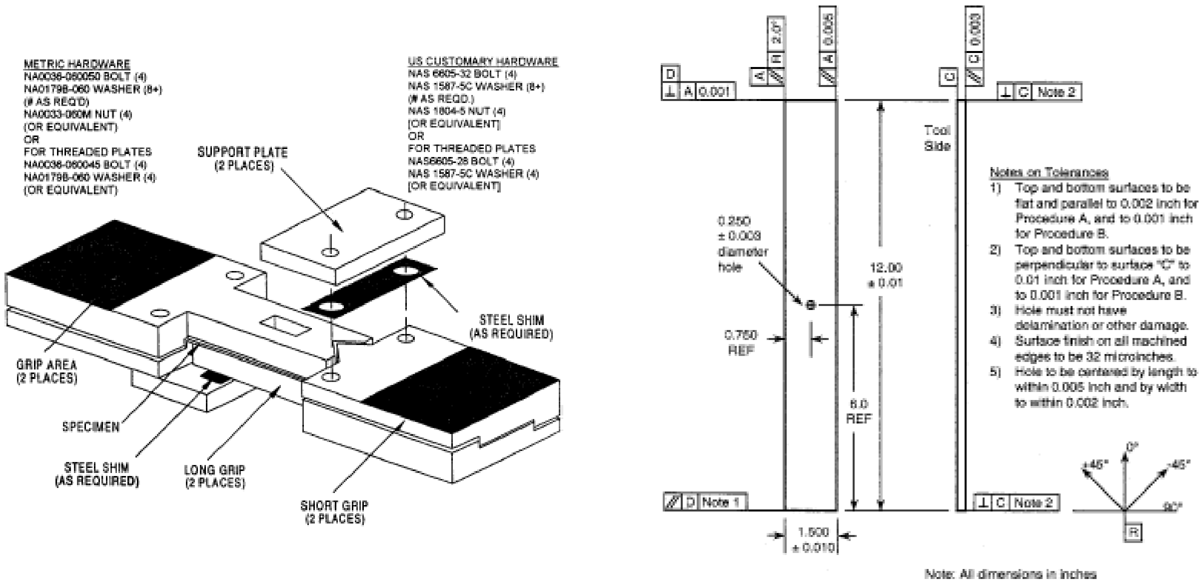
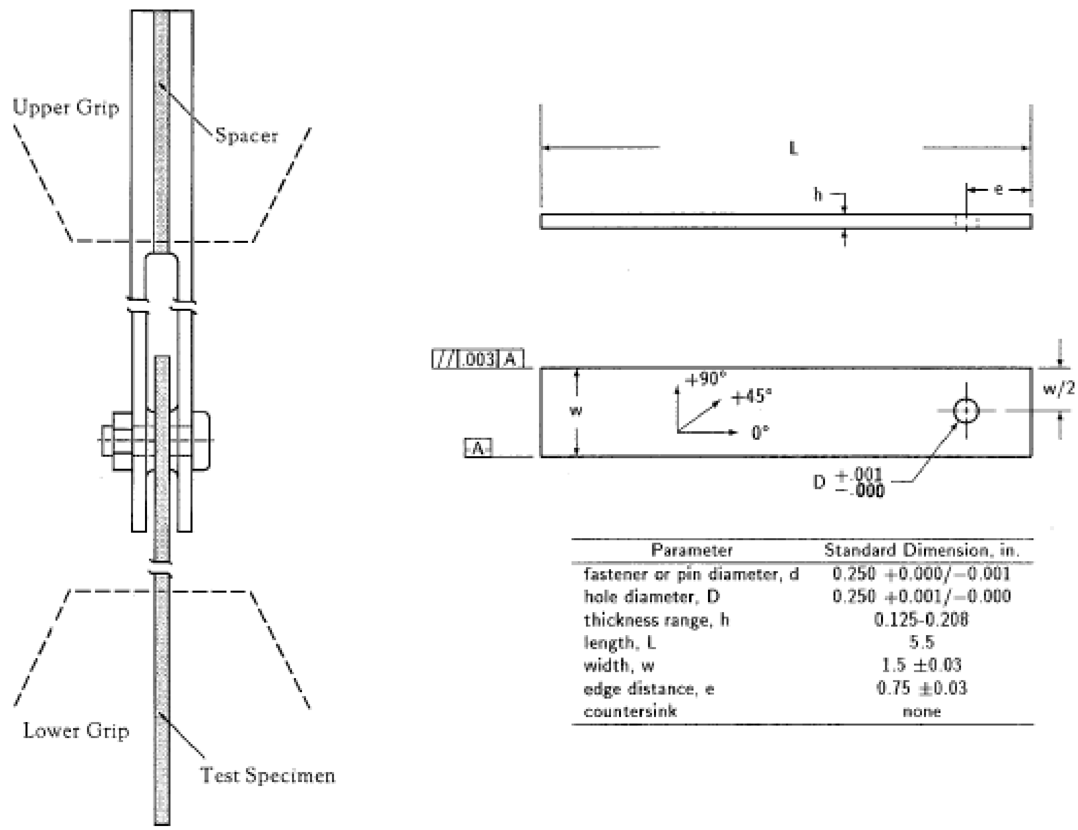


Figure 19. ASTM D6484 Test Support Fixture Assembly (left) and Open Hole Compression Test Specimen Geometry (right)[23]

Bearing Strength

ASTM D5961, *Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates*.[24] This test method determines the bearing response of polymer matrix composite materials when loaded in either double-shear (Procedure A) tensile loading or single shear (Procedure B) tensile or compressive loading. The laminates must be balanced and symmetric. The baseline specimen geometry and the test fixture assembly used to perform the test according to Procedure A are shown in Figure 20.



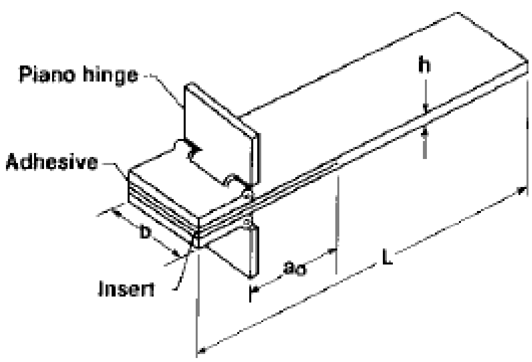
Parameter	Standard Dimension, in.
fastener or pin diameter, d	0.250 +0.000/−0.001
hole diameter, D	0.250 +0.001/−0.000
thickness range, h	0.125-0.208
length, L	5.5
width, w	1.5 ±0.03
edge distance, e	0.75 ±0.03
countersink	none

Figure 20. ASTM D5961 Test Fixture Assembly (left) and Double Shear Test Specimen Geometry (right)[24]

Fracture Toughness

The Mode I, Mode II or Mixed Mode I/II fracture toughness can be determined using a series of standardized tests. These tests are considered priority Level 3 tests, since they depend on the application whether or not they will be required for the specific application.

ASTM D5528, *Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites*.[25] This test method determines the opening Mode I interlaminar toughness, G_{Ic}, of polymer matrix composite materials using the Double Cantilever Beam (DCB) method. The laminates must contain an even number of plies with unidirectional fibers aligned along the length of the DCB specimen. The baseline specimen geometry is shown in Figure 21. For materials with low flexural modulus or high interlaminar fracture toughness, it may be necessary to increase the number of plies (laminate thickness) to avoid large deflections of the specimen arms. The testing protocol that has been developed for Navy application of this ASTM test standard has been documented in Reference 27. Ithighlights the use of crack gages and the Modified Beam Theory (MBT) method within the standard to determine the 4 different fracture toughness values that can be determined as the crack progresses through the specimen. These tests tend to have significant variability in the results; and, as such, Reference 27 recommends performing 10 tests when determining design values.

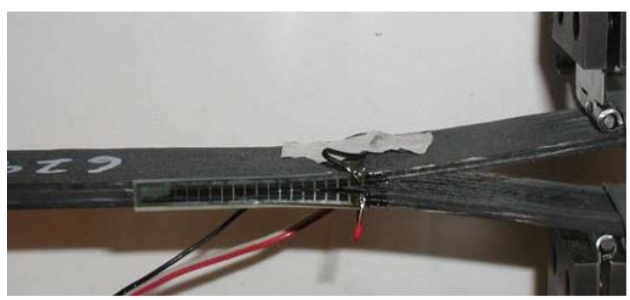


B = 0.08 to 1inches (20 to 25 mm)

L = 5 inches (125 mm)

a_o = ~2.5 inches

h = 0.12 to 0.2 inches (3 to 5 mm)



Specimen under load with crack gage

Figure 21. ASTM D5528 Test Specimen Geometry[25] (left) and Specimen under Loading with Crack Gage (right)

ASTM WK22949, *New Test Method for Determination of the Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites Using the End-Notched Flexure (ENF) Test*.[26] This test method is currently under development within the ASTM D30 committee, and it is anticipated that it will be released as a new standard in the near future. The details of this method to determine the Mode II Interlaminar Fracture Toughness using the End-Notched Flexure (ENF) test can be found in Reference 27. A schematic of the ENF test geometry is shown in Figure 22. The overall sample is similar to the DCB specimen with an overall length of 8 inches and width of 1 inch. The insert length is typically on the order of 2.25 inches. The Mode II fracture toughness is determined by performing a series of tests on a sample and varying the distance between the end of the insert and the top loading point in the three-point bend test configuration.

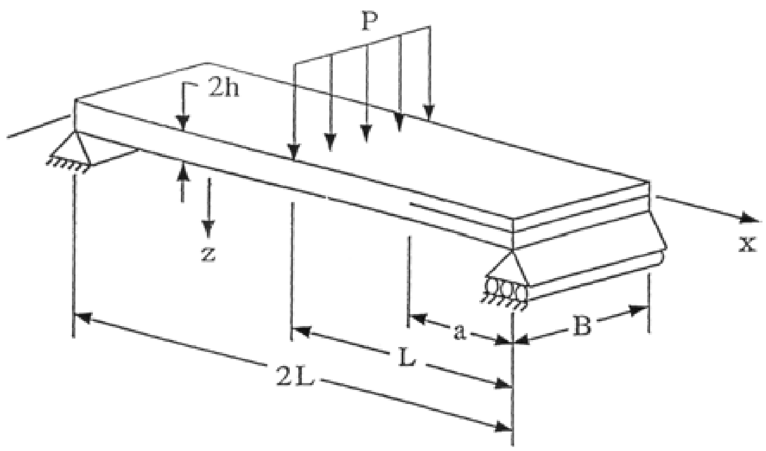


Figure 22. ASTM WK22949 End Notched Flexure Testing Schematic[27]

ASTM D6671, *Standard Test Method for Mixed Mode I- Mode II Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites*.[28] This test method describes the determination of the interlaminar fracture toughness, G_c, of fiber reinforced composite materials at various Mode I to Mode II loading ratios using the mixed mode bending (MMB) test apparatus. The composite materials must contain an even number of plies and must have unidirectional fibers aligned with the length of the specimen. The MMB sample is similar to the DCB and ENF samples with an insert length of 2 inches and specimen length of 5.5 inches and about 1 inch wide. The schematic of the test set up is shown in Figure 23. The length of the lever, c, in the fixture can be varied to vary the ratio of the Mode I/Mode II fracture toughness.

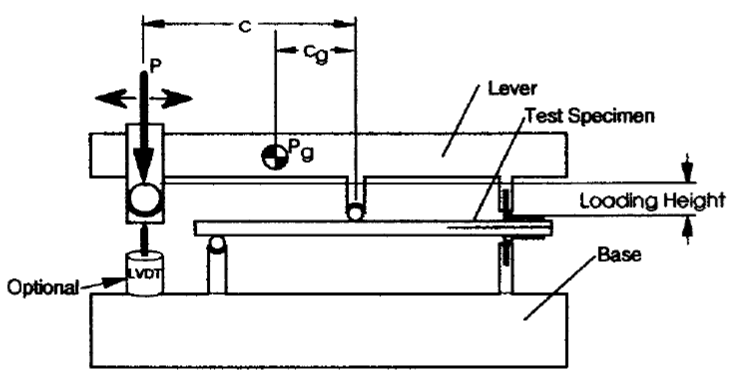


Figure 23. ASTM D6671 Mixed Mode Bending Fracture Toughness Testing Schematic[28]

Damage Resistance

In applications that might be subject to impact events, it is desirable to determine the damage resistance of composite materials. One way that this is accomplished is by determining the residual compression strength of a composite material after it is subjected to a specific level of energy impact. If the rate of strength degradation is required, a series of tests can be performed at a variety of impact energy levels and the residual strength determined over the range of impact energies tested.

ASTM D7136, *Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event*,[29] and **ASTM D7137**, *Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates*.[30] This test sequence is commonly referred to as the Compression after Impact (CAI) method. In this combination of methods, a 4-inch by 6-inch flat rectangular composite plate is subject to an out-of-plane, concentrated impact using a drop-weight device with a hemispherical impactor as shown in Figure 24. After the completion of ASTM D7136, the extent of damage is documented, and then the sample is placed in the compression test support, as shown in Figure 24, to perform the testing according to ASTM D7137. Composite laminates need to be balanced and symmetric with respect to the test direction. The target thickness of the specimens is 0.2 inches. Alternate thicknesses can be used, as long as an acceptable failure mode occurs within the specimen, and there is no evidence of off-axis bending during the testing. This can be determined by the use of strain gages on either side of the specimen during the loading process. The use of strain gages will also allow for the determination of an effective material modulus using the slope of the stress-strain curve well prior to the ultimate strength load level.

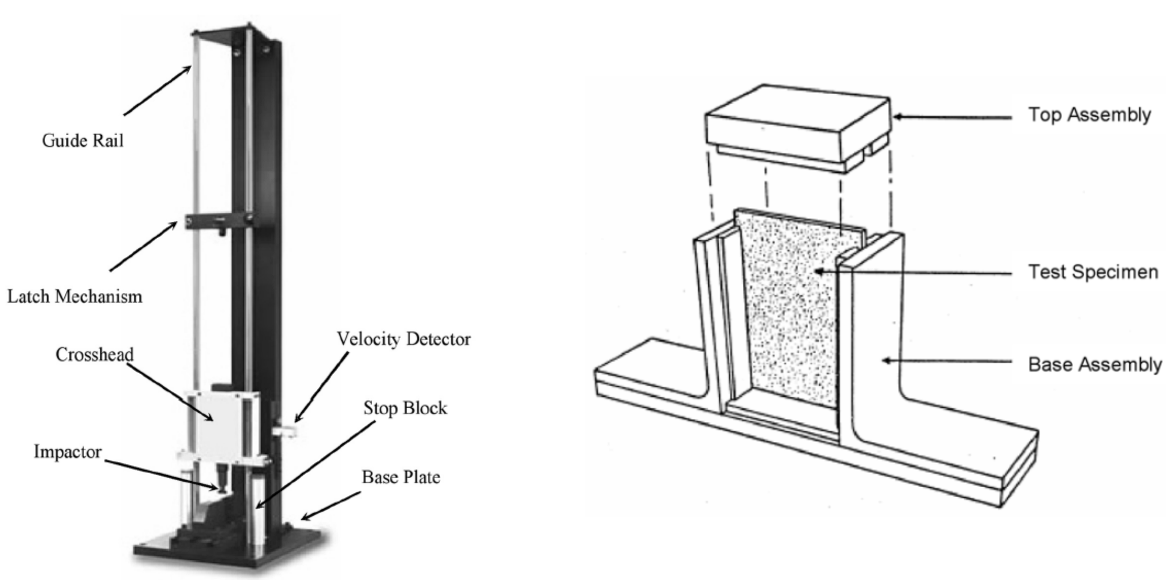


Figure 24. ASTM D7136 Impact Device[29] (left) and ASTM D7137 Test Support Fixture[30] (right)

Flexural Properties

ASTM D7264, *Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials*.[31] This test method can be used to determine the flexural stiffness and strength of polymer matrix composites using either three-point loading (Procedure A) or four-point loading (Procedure B) on a simply supported beam as shown in Figure 25. For flexural strength, the standard support span-to-thickness ratio of 32:1 is chosen, so that failure occurs at the outer surface of the specimens due only to the bending moment. The standard thickness is 0.16 inch, width is 0.5 inch and the length is about 20% longer than the support span. For fabric reinforced composite materials, the width should be at least 2 unit cells. Alternate span-to-depth ratios, can be used and should be noted in the test report. Strength results from different span-to-depth ratio testing cannot be compared, since the ratio of the compressive/tensile strength to out of plane shear strength will vary. See Note 2 of ASTM D7264[31] for a more detailed explanation.

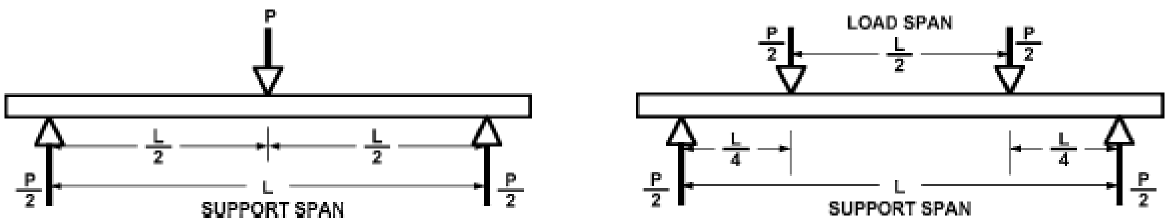


Figure 25. ASTM D 7264 Flexural Loading Configurations, Three Point Bending (left) and Four Point Bending (right)[31]

Thermal Properties

Depending on the application, it might be desirable to better understand the thermal properties of the composite material. The CMPT has been populated with four placeholders for the thermal properties of thermal diffusivity/conductivity, specific heat, coefficient of thermal expansion and glass transition temperature. For the majority of applications, only the glass transition temperature is determined as explained in the screening section of this document. In some cases the other properties can be estimated using standard rule of mixtures techniques.

Fire, Smoke and Toxicity

Typically when considering composite materials for uses in structural Naval applications, the fire, smoke and toxicity requirements are specified in a detailed fashion in the Design Data Sheet 078-1, Composite Materials, Surface Ships, Topside Structural and Other Topside Applications – Fire Performance Requirements[45] and MIL-STD-2031, Fire and Toxicity Test Methods and Qualification Procedure for Composite Material Systems Used in Hull, Machinery and Structural Applications Inside Naval Submarines.[46] The CMPT has been populated with three of the standard tests that are called out in these test specifications. These are standard tests are Surface Flammability (ASTM E84/ASTM E162),[38,39] Optical Density/Smoke Generation (ASTM E662[40]/ASTM E1354) and Concentration of Gases (ASTM E800).[42] A brief description of each of these tests is given below.

ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*.[38] The purpose of this test is to determine the relative burning behavior of the material by observing the flame spread along the specimen. The test is conducted with the specimen in the ceiling position with the surface to be evaluated exposed to the ignition source. Flame spread and smoke developed index are reported after this test. Test specimens are typically 20 to

24 inches wide and 24 ft or less in length. The DDS-078-1[45] general requirements for composite materials applications are a maximum flame spread index of 25 and maximum smoke developed index of 15. There are specific applications called out in this specification that list more detailed surface flammability requirements.

ASTM E162, *Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source*.[39] This is a small-scale laboratory test method for measuring the surface flammability of materials that employs a radiant heat source consisting of 12- by 18-inch panel in front of which an inclined 6- by 18-inch specimen of the material is placed. The results of this test are a flame spread factor and the radiant panel index.

ASTM E662, *Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials*.[40] This test determines the specific optical density of smoke generated by solid materials and assemblies mounted in the vertical direction. A nominally 3-inch by 3-inch specimen is mounted within a holder which exposes an area to an electrically heated radiant energy producing a 2.5 W/m^2 irradiance level for the non-flaming condition of the test. The flaming condition of the test uses a six-tube burner in addition to the radiant heater. During the testing, the specimens are exposed to the flaming and non-flaming condition within a closed chamber. A photometric system is used to measure the varying light transmission as smoke accumulates. The light transmission is then used to calculate the specific optical density of smoke generated during the time period to reach a maximum value.

ASTM E1354, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*.[41] This fire test standard provides guidance for measuring the response of materials exposed to controlled levels of radiant heating with or without an external heater. This test method is used to determine the ignitability, heat release rates, mass loss rates, effective heat of combustion, and visible smoke development of materials and products. Specimens are exposed to initial heat fluxes in the range of 0 to 100 kW/m^2. An electrical spark is used if external ignition is required. This test method was developed for use in material and product evaluations, so specimens are typically portions of an end-use product or the various components in an end-use product.

ASTM E800, *Standard Guide for Measurement of Gases Present or Generated During Fires*.[42] This guide presents the analytical methods for the measurement and sampling considerations of carbon monoxide, carbon dioxide, oxygen, nitrogen oxides, sulfur oxides, carbonyl sulfide, hydrogen cyanide, aldehydes, and hydrocarbons. The measurement techniques can be used to determine concentration of a specific gas in the total sample taken, and do not determine the total amount of gases that would be generated by a specimen during the conduction of a fire test. Typically, the concentrations of CO, HCl, and HCN are reported along with other concentrations of gases that are included in the Immediately Hazardous to Life and Health (IDLH) concentrations of fire gases published by the National Institute of Occupational Safety and Health (NIOSH)[47].

Moisture

In addition to ASTM D570,[19] which can be used to determine the response of a composite material to moisture, ASTM D5229[43] can be used to provide a more rigorous approach, and can be used with fluids other than water to determine the absorption or desorption properties of a material.

ASTM D5229, *Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials*.[43] This test method can be used to determine the absorption and desorption properties in the through thickness direction of flat or curved panels. Several different procedures are available to determine the single phase Fickian diffusion material properties with constant moisture absorption properties through the thickness of the material. A reinforced polymer matrix composite material tested below its glass-transition temperature typically meets this requirement, although two phase matrices such as toughened epoxies may require a multi-phase moisture absorption model.

Electrical Properties

Depending on the application, it might be desirable to better understand the electrical properties of a composite material. This is especially the case in applications where the composite material is used for a radome or other application where the electrical signature of the material is used in the design. The CMPT has been populated with three placeholders for the electrical properties of dielectric constant, resistivity and loss tangent. For the majority of composite structural applications, the electrical properties are not needed in the design.

Conclusions

The goal of this report is to establish guidelines for the development of materials tests plans to generate composite material properties (screening and design allowables) for inclusion in the Code 65 Composite Materials Database and use in modeling and simulation activities for future NAVSEA composite material applications. These guidelines have been developed based on current and previous modeling and simulation activities in Code 65, NSWC Carderock on submarine, surface ship, air craft carrier and expeditionary vehicle platforms. The Code 65 Composite Materials Database Template (CMDT), reproduced as Appendix A, has been introduced; it includes the tests that are generally used to determine the properties of composite materials.

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Appendix A
Composite Materials Database Template with Excel Entry Tabs

Page

Composite Materials Database Template

Summary of Mean Properties

Material Description

Matrix	what resin
Fiber	what kind of base fiber used
Fabric	uni, stitched, weave, woven roving, textile form, tape, prepreg
Laminate Schedule	[0]10 [0]14 [0]36
Manufacturing Method	what method was used
Manufacturer	who manufactured the material
Date of Manufacture	2006
Testing Facility/Date	2007
Program of Record	AHM&ST
Reference	NSWCCD-65-TR-20??/??
Data Type Available	screening, mean, B18, B30

Physical Properties	Test Method		Units
Density	ASTM D792		
Void Content	ASTM 2734		
Fiber Volume Fraction (weight)	ASTM D2584/D3171		
Fiber Volume Fraction (volume)			
Moisture Absorption (Weight Gain %)	ASTM D590		
Per Ply Thickness (single lamina)	Average		*in/ply*

Standard Mechanical Properties	Test Method	RTD	CTD	ETW	ETD	Units
Tensile Modulus, E1t	Tension					*msi*
Tensile Strength, F1T						*ksi*
Tensile Strain to Failure, ε1T						*microstrain*
υ 12						
Tensile Modulus, E2T	Tension					*msi*
Tensile Strength, F2T						*ksi*
Tensile Strain to Failure, ε2T						*microstrain*
υ 21						
Compressive Modulus, E1C	Compression					*msi*
Compression Strength, F1C						*ksi*
Compressive Strain to Failure, ε1C						*microstrain*
υ 12						
Compressive Modulus, E2C	Compression					*msi*
Compression Strength, F2C						*ksi*
Compressive Strain to Failure, ε2C						*microstrain*
υ 21						
Shear Modulus, G12	IPS					*msi*
In-Plane Shear Strength, τ12						*ksi*
Shear Strain to Failure, γ12						*microstrain*
Open Hole Tensile Strength	OHT					*ksi*
Open Hole Compression Strength	OHC					*ksi*
Bearing Strength	Bearing					*ksi*

Interlaminar Mechanical Properties	Test Method	RTD	CTD	ETW	ETD	Units
Interlaminar Shear Modulus, G13	ILS-1					*msi*
Interlaminar Shear Strength, τ13						*ksi*
Interlaminar Shear Strain to Failure, γ13						*microstrain*
Interlaminar Shear Modulus, G23	ILS-2					*msi*
Interlaminar Shear Strength, τ23						*ksi*
Interlaminar Shear Strain to Failure, γ23						*microstrain*
Interlaminar Tensile Modulus, E3T	ILT					*msi*
Interlaminar Tensile Strength, F3T						*ksi*
Interlaminar Tensile Strain to Failure, ε3T						*microstrain*
Interlaminar Compressive Modulus, E3C	ILC					*msi*
Interlaminar Comporessive Strength, F3C						*ksi*
Interlaminar Compressive Strain to Failure, ε3C						*microstrain*
υ 13						
υ 23						
υ 31 (Tension, Compression)						
υ 32 (Tension, Compression)						

Fracture Toughness	Test Method	RTD	CTD	ETW	ETD	Units
Mode I Fracture Toughness	DCB					
Non Linear Onset						*in-lbs/in^2*
Onset (Crack Gage)						*in-lbs/in^2*
Propagation @ Crack Growth of 1/4"						*in-lbs/in^2*
Steady State						*in-lbs/in^2*
Mode II Fracture Toughness	ENF					
Non Linear Onset						*in-lbs/in^2*
Maximum						*in-lbs/in^2*
Mixed Mode Bending Ratios	MMB					

Figure A-1. Composite Materials Database Template - Mean Properties Tab (Page 1)

Composite Materials Database Template

Summary of Mean Properties

Material Description						
Matrix	what resin					
Fiber	what kind of base fiber used					
Fabric	uni, stitched, weave, woven roving, textile form, tape, prepreg					
Laminate Schedule	[0]10 [0]14 [0]36					
Manufacturing Method	what method was used					
Manufacturer	who manufactured the material					
Date of Manufacture	2006					
Testing Facility/Date	2007					
Program of Record	AHM&ST					
Reference	NSWCCD-65-TR-20??/??					
Data Type Available	screening, mean, B18, B30					
Thermal Properties	**Test Method**		**Units**			
Thermal Conductivity	ASTM D5930/D2585		*W/(m - °K)*			
Specific Heat	ASTM E2716		*Joules/(g- °K)*			
Glass Transition Temperature, Tg	ASTM D7028		*°F*			
Electrical Properties	**Test Method**		**Units**			
Dielectric Constant		0				
Resistivity		0				
Loss Tangent		0				
Flammability Properties	**Test Method**		**Units**			
Surface Flammability	ASTM E84	0				
Smoke Generation	ASTM E662	0				
Concentration of Gases	ASTM E800	0				
Extras to be cited in Comments Section	**Test Method**	**RTD**	**Units**			
Compression After Impact						
Impact Energy, Compression Strength	ASTM D7136/D7137		ft-lbs/sec, ksi			
Impact Energy, Compression Strength			ft-lbs/sec, ksi			
Impact Energy, Compression Strength			ft-lbs/sec, ksi			
Impact Energy, Compression Strength			ft-lbs/sec, ksi			
		RTD	**CTD**	**ETW**	**ETD**	
Flexural Modulus, Ef	Flex					*msi*
Flexural Strength, Ff						*ksi*
Coefficients of Expansion	**Test Method**		**Units**			
Coefficient of Thermal Expansion, α1			*per °F*			
Coefficient of Thermal Expansion, α2			*per °F*			
Coefficient of Thermal Expansion, α3			*per °F*			
Coefficient of Moisture Expansion, β1			*per %Moisture*			
Coefficient of Moisture Expansion, β2			*per %Moisture*			
Coefficient of Moisture Expansion, β3			*per %Moisture*			
Processing Data						
Resin Formulation	Sample resin formulation 0.2% CoNap, 0.2% 2,4-P, 0.05% DMAA, 1.5% Triganox, Two Part Epoxy 100:25 A:B					
Additional References:						
Documentation List	Other reports on the same or similar material					

Figure A-2. Composite Materials Database Template - Mean Properties Tab (Page 2)

Manufacturer	who manufactured the material
Manufacturing Method	what method was used
Matrix	what resin
Resin Formulation	Sample resin formulation 0.2% CoNap, 0.2% 2,4-P, 0.05% DMAA, 1.5% Triganox, Two Part Epoxy 100:25 A:B
Gel Time	Sample gel time 2.5 hrs
Batches	How many resin batches made
Fiber	what kind of base fiber used
Fabric	uni, stitched, weave, woven roving, textile form, tape, prepreg
Laminate Schedule	[0]10 [0]14 [0]36
Cure Schedule	temperature/time ramp, autoclave pressure, room temperature
Manufacturing Date	2006
Test Facility/Date	2007
Program of Record	AHM&ST
Reference	NSWCCD-65-TR-20??/??
Data Type Available	screening, mean, B18, B30
Additional References	Other reports on the same or similar material
Notes:	

Figure A-3. Composite Materials Database Template - Material Description Tab

Fiber Volume Fraction		
	Test Method	Burn Off
	No. Batches	
Fvf (weight)	mean	Fvfw
	minimum	
	maximum	
	COV (%)	
	No. Specimens	
	Data Class	
Fvf (volume)	mean	Fvfv
	minimum	
	maximum	
	COV (%)	
	No. Specimens	
	Data Class	

Void Content		
	Test Method	Burn Off
	No. Batches	
VC (%)	mean	Fvfw
	minimum	
	maximum	
	COV (%)	
	No. Specimens	
	Data Class	

Density		
	Test Method	density
	No. Batches	
ρ (*lbs/in*^{3})	mean	den
	minimum	
	maximum	
	COV (%)	
	No. Specimens	
	Data Class	

Moisture Absorption		
	Test Method	moisture
	No. Batches	
M(%)	mean	M
	minimum	
	maximum	
	COV (%)	
	No. Specimens	
	Data Class	

Per Ply Thickness		
	Test Method	Average
ply t (*in*)	mean	ppthick
	minimum	
	maximum	

Figure A-4. Composite Materials Database Template - Constituent Properties Tab

		RTD	CTD	ETW	ETD
1-Direction Axial Tension					
	Test Method	T0			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{1T} (*ksi*)	mean	F1T			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_{1T} (*msi*)	mean	E1T			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
ν_{12}	mean	nu12t			
	COV (%)				
	No. Specimens				
	Data Class				
ε_{1T} ($\mu\varepsilon$)	mean	ue1T			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
2-Direction Transverse Tension					
	Test Method	T90			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{2T} (*ksi*)	mean	F2T			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_{2T} (*msi*)	mean	E2T			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
ν_{21}	mean	nu21t			
	COV (%)				
	No. Specimens				
	Data Class				
ε_{2T} ($\mu\varepsilon$)	mean	ue2T			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
3-Direction Interlaminar Tension					
	Test Method	ILT			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{3T} (*ksi*)	mean	F3t			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_{3T} (*msi*)	mean	E3t			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
ν_{31}	mean	31T			
	COV (%)				
	No. Specimens				
	Data Class				
ν_{32}	mean	32T			
	COV (%)				
	No. Specimens				
	Data Class				
ε_{3T} ($\mu\varepsilon$)	mean	ue3T			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

Figure A-5. Composite Materials Database Template - Tension Properties Tab

		RTD	CTD	ETW	ETD
1-Direction Axial Compression					
	Test Method	C0			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{1C} (*ksi*)	mean	F1C			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_{1C} (*msi*)	mean	E1C			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
ν_{12}	mean	nu12c			
	COV (%)				
	No. Specimens				
	Data Class				
ε_{1C} ($\mu\varepsilon$)	mean	ue1c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
2-Direction Transverse Compression					
	Test Method	C90			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{2C} (*ksi*)	mean	F2c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_{2C} (*msi*)	mean	E2c			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
ν_{21}	mean	nu21c			
	COV (%)				
	No. Specimens				
	Data Class				
ε_{2C} ($\mu\varepsilon$)	mean	ue2c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
3-Direction Interlaminar Compression					
	Test Method	ILC			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{3C} (*ksi*)	mean	F3c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_{3C} (*msi*)	mean	E3c			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
ν_{31}	mean	31c			
	COV (%)				
	No. Specimens				
	Data Class				
ν_{32}	mean	32c			
	COV (%)				
	No. Specimens				
	Data Class				
ε_{3C} ($\mu\varepsilon$)	mean	ue3c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

Figure A-6. Composite Materials Database Template - Compression Properties Tab

		RTD	CTD	ETW	ETD
1-2 Direction In-Plane Shear					
	Test Method	IPS			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{12} (*ksi*)	mean	F12			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
G_{12} (*msi*)	mean	G12			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
γ_{12} ($\mu\varepsilon$)	mean	Ga12			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

1-3 Direction Through-Thickness Shear					
	Test Method	ILS-1			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{13} (*ksi*)	mean	F13			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
G_{13} (*msi*)	mean	G13			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
γ_{13} ($\mu\varepsilon$)	mean	Ga13			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

2-3 Direction Through-Thickness Shear					
	Test Method	ILS-2			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{23} (*ksi*)	mean	F23			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
G_{23} (*msi*)	mean	G23			
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
γ_{23} ($\mu\varepsilon$)	mean	Ga23			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

Figure A-7. Composite Materials Database Template - Shear Properties Tab

		RTD	CTD	ETW	ETD
Open Hole Tension					
	Test Method	OHT			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{OHT} (*ksi*)	mean	OHT			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Open Hole Compression					
	Test Method	OHC			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_{OHC} (*ksi*)	mean	OHC			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Bearing Strength					
	Test Method	Bearing			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_B (*ksi*)	mean	PB			c
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

Figure A-8. Composite Materials Database Template - Notched Laminate Properties Tab

		RTD	CTD	ETW	ETD
Mode I (DCB) Fracture Toughness					
	Test Method	DCB			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
Non-Linear Onset G_{1C} (*in-lbs/in^2*)	mean	nloG1c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Onset G_{1C} (in-lbs/in^2)	mean	oG1c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Propagation G_{1C} (in-lbs/in^2) (@ 1/4 of crack growth)	mean	pG1c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Steady State G_{1C} (in-lbs/in^2)	mean	ssG1c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Mode II (ENF) Fracture Toughness					
	Test Method	ENF			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
Non-Linear Onset G_{2C} (*in-lbs/in^2*)	mean	nloG2c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
Maximum G_{2C} (in-lbs/in^2)	mean	maxG2c			
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

Mode I-II Mixed Mode Bending (MMB) Fracture Toughness										
	Test Method	MMB								
	No. Batches									
	Mix Ratios Tested (excluding 0 and 100%)	9								
	Environmental Condition	RTD								
	Mode Mix %	10	20	30	40	50	60	70	80	90
G_1 (*in-lbs/in^2*)	mean	nloG1c20	nloG1c21	nloG1c22	nloG1c23	nloG1c24	nloG1c25	nloG1c26	nloG1c27	nloG1c28
G_2 (in-lbs/in^2)	mean	oG1c20	oG1c21	oG1c22	oG1c23	oG1c24	oG1c25	oG1c26	oG1c27	oG1c28
G (in-lbs/in^2)	mean	pG1c20	pG1c21	pG1c22	pG1c23	pG1c24	pG1c25	pG1c26	pG1c27	pG1c28
G_2/G	mean	ssG1c20	ssG1c21	ssG1c22	ssG1c23	ssG1c24	ssG1c25	ssG1c26	ssG1c27	ssG1c28
	COV (%)									
	No. Specimens									
	Data Class									

Figure A-9. Composite Materials Database Template - Fracture Properties Tab

		RTD	CTD	ETW	ETD
Flexural Bend Testing					
	Test Method	Flex			
	No. Batches				
	Temperature (°F)				
	Environmental Condition (dry/wet)				
F_F (*ksi*)	mean	Ff	FfCTD	Ff	FfETD
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				
E_F (*msi*)	mean	Ef	Ef	EfETW	Ef
	minimum				
	maximum				
	COV (%)				
	No. Specimens				
	Data Class				
Compression After Impact Testing					
	Test Method	ASTM D7136/D7137			
	No. Batches				
	Impact Energy (Joules)	25	50	83	100
F_{CAI} (*ksi*)	mean	Fcai	fcai1	fcai2	fcai3
	minimum				
	maximum				
	COV (%)				
	B-Basis				
	No. Specimens				
	Data Class				

Figure A-10. Composite Materials Database Template - Extra Testing Tab

1-Direction Thermal Expansion		
	Test Method	TE-1
	No. Batches	
	mean	alpha1
	minimum	
	maximum	
α_1 (1/°F)	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	
2-Direction Thermal Expansion		
	Test Method	TE-2
	No. Batches	
	mean	alpha2
	minimum	
	maximum	
α_2 (1/°F)	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	
3-Direction Thermal Expansion		
	Test Method	TE-3
	No. Batches	
	mean	alpha3
	minimum	
	maximum	
α_3 (1/°F)	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	
1-Direction Moisture Expansion		
	Test Method	ME-1
	No. Batches	
	mean	M1
	minimum	
	maximum	
M_1 (1/°F)	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	
2-Direction Moisture Expansion		
	Test Method	ME-2
	No. Batches	
	mean	M2
	minimum	
	maximum	
M_2 (1/°F)	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	
3-Direction Moisture Expansion		
	Test Method	ME-3
	No. Batches	
	mean	M3
	minimum	
	maximum	
M_3 (1/°F)	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	

Figure A-11. Composite Materials Database Template - Expansion Tab

Thermal Conductivity		
	Test Method	ASTM D5930
	No. Batches	
λ (W/(m-°K)	mean	TC
	minimum	
	maximum	
	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	

Specific Heat		
	Test Method	ASTM E2716
	No. Batches	
c (Joules/(g-°K)	mean	c
	minimum	
	maximum	
	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	

Glass Transition Temperature		
	Test Method	ASTM D7028
	No. Batches	
T_g (°F)	mean	Tg
	minimum	
	maximum	
	COV (%)	
	B-Basis	
	No. Specimens	
	Data Class	

Figure A-12. Composite Materials Database Template - Thermal Properties Tab

Dielectric Constant	
Test Method	
No. Batches	
mean	
minimum	
maximum	
COV (%)	
B-Basis	
No. Specimens	
Data Class	

Resistivity	
Test Method	
No. Batches	
mean	
minimum	
maximum	
COV (%)	
B-Basis	
No. Specimens	
Data Class	

Loss Tangent	
Test Method	
No. Batches	
mean	
minimum	
maximum	
COV (%)	
B-Basis	
No. Specimens	
Data Class	

Figure A-13. Composite Materials Database Template - Electrical Properties Tab

Flammability	
Test Method	ASTM D7039
No. Batches	
mean	
minimum	
maximum	
COV (%)	
B-Basis	
No. Specimens	
Data Class	

Smoke Generation	
Test Method	ASTM E662
No. Batches	
mean	
minimum	
maximum	
COV (%)	
B-Basis	
No. Specimens	
Data Class	

Concentration of Gases	
Test Method	ASTM E800
No. Batches	
mean	
minimum	
maximum	
COV (%)	
B-Basis	
No. Specimens	
Data Class	

Figure A-14. Composite Materials Database Template - Flammability Properties Tab

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