CHAPTER 1 GENERAL INFORMATION

1.1 INTRODUCTION

The standardization of a statistically-based mechanical property data base, procedures used, and overall material guidelines for characterization of composite material systems is recognized as being beneficial to both manufacturers and governmental agencies. It is also recognized that a complete characterization of the capabilities of any engineering material system is primarily dependent on the inherent material physical and chemical composition which precede, and are independent of, specific applications. Therefore, at the material system characterization level, the data and guidelines contained in this handbook are applicable to military and commercial products and provide the technical basis for establishing statistically valid design values acceptable to certificating or procuring agencies.

This standardization handbook has been developed and is maintained as a joint effort of the Department of Defense and the Federal Aviation Administration. It is oriented toward the standardization of methods used to develop and analyze mechanical property data on current and emerging composite materials.

1.2 PURPOSE AND SCOPE OF VOLUME 2

A primary focus of this Handbook is guidance on the selection and use of composite materials. The data collected within this volume are presented to allow initial assessments of material adequacy for a particular application. It provides a common database that will allow significant reductions in the amount of validation data necessary to use the data for design purposes. This handbook cannot be cited as a DoD contractor requirement.

This handbook volume provides a standard source of statistically based mechanical property data for current and emerging polymeric matrix composite materials. Physical, chemical, and mechanical values of the composite constituents - the fibers, matrix material, and prepreg - are reported where applicable. Subsequent chapters include data summaries for the various composite systems. Individual chapters focus on particular type of reinforcement fiber. Strength and strain-to-failure properties are reported in terms of mean and A-values and/or B-values. The A and B statistical allowable values are determined by the procedures of Volume 1. Only mean values are reported for stiffnesses. Maximum and minimum data points, and coefficients of variation are reported for all data items.

The verification of the ability to attain equivalent statistical properties to the required level of risk (probability and confidence) is the responsibility of the user. The verification of the ability of a manufacturer to attain the same statistical properties should be performed as outlined in Volume 1, Chapter 2. The specific process to leverage the data in this volume is described in Volume 1, Section 2.3.7.

The source and context for much of the handbook data sets has historically come from experience with aerospace flight-critical structures. However, all transportation industries (aerospace, ground, rail, and marine), whether commercial or military, as well as other applications including civil infrastructure and general industrial products, will find the handbook useful. Incorporation of additional information related to broader applications is ongoing. Initial input has led to predominantly lamina mechanical properties of prepreg tape and fabric. The range of materials has expanded to cover resin transfer molded and repair materials. The range of properties covered has expanded to laminate mechanicals. Expansion of the ranges of both properties and material forms is expected to continue.

Statistically based strength properties are defined for each composite material system over the usable range of environment. The intent is to provide data at the upper and lower limits of the environmental range for a particular material. If intermediate environmental condition data are available, they are included to assist in defining the relationship over the environmental range. The statistically based strength data can be used as a starting point for establishing structural design allowables when stress and

strength analysis capabilities permit lamina and laminate level margin of safety checks. Depending on the application, some structural design allowables will have to be determined empirically at higher testing levels (element, sub-component, full-scale) as they may be dependent on design geometry and philosophies. Additional information and properties will be added to this Volume as they become available and are demonstrated to meet the handbook's criteria.

All statistical data included herein are based on test specimens only. Unless otherwise noted, test specimen dimensions conform to those specified for the particular test method that is used. Standard test methods are recommended in Volume 1. In Volume 2, data are limited to those obtained from recommended in Volume 1. The data contained in this volume may have been provided by more than one source. Where more than one source for data is used for a reported property, the variability of the data from source to source has been reviewed statistically in accordance with Volume 1, Chapters 2 and 8. If the variability has been sufficiently small for the data to be considered from the same population, the data sets are combined and treated as one data set. Where there are reasons for differences among the data sets, both data sets are presented (for example, Volume 2, Section 4.2.8).

The designer, manufacturer and all users are responsible for any translation of the data contained herein to other production sites, specimen dimensions, temperature, humidity, and other environmental conditions not specifically identified in this document. Issues not addressed in this document are scale-up effects and the influence of the selected test method on properties. In general, decisions concerning which properties to use for a specific application or design are the responsibility of the user and are outside the scope of this handbook. MIL-HDBK-17, Volume 3, addresses some of the relevant issues regarding design usage of the data in this volume. It is the responsibility of the handbook user to meet end use, customer and regulatory requirements.

An overview of the material, guidelines for its usage, and details of the statistical and technical analysis of the data are provided at the beginning of each section of Chapters 4 through 10. The format of all information in each data set is described in detail in Section 1.4. A more detailed description of fibers and/or matrix materials may be found in Volume 3, Chapter 2.

1.3 ORGANIZATION OF DATA IN HANDBOOK

The data in Volume 2 is divided into chapters of fiber properties, resin properties, and composite properties organized by fiber and then resin.

1.3.1 Fiber properties

Chapter 2 in Volume 2 will provide data for fiber properties. Sections are to be included for different types of fiber, e.g., glass fibers and carbon fibers. Fiber properties and methods for obtaining them are discussed in Volume 1, Chapter 3.

1.3.2 Matrix properties

Matrix or resin properties will be included in Chapter 3 which will be divided into sections according to the type of resin. For example, Section 3.2 will give data for epoxies and Section 3.3 will provide data for polyester resins. Resin properties and methods for obtaining them are presented in Volume 1, Chapter 4.

1.3.3 Composite properties

The remaining chapters of Volume 2 will provide data for prepreg, lamina, laminate, and joint properties. Methods for characterizing materials are discussed in Volume 1, Chapter 5, and properties and definitions for laminae and laminates are presented in Volume 1, Chapter 6. Properties for structural elements are presented in Volume 1, Chapter 7. The statistical methods used in determining these proper-

ties are discussed in Volume 1, Chapter 8. There will be individual chapters for each family of composites based on fiber type. For example, Chapter 4 describes carbon fiber composites.

1.4 PRESENTATION OF DATA

This section provides information on how the data are presented in this volume, both to help understand the data as presented and to ensure the data presentation is consistent. Information enclosed in {}'s represents data that should be included in a given field. Information that is not applicable or not available is omitted.

Each section is titled based on the following information.

{Fiber Commercial Name} {Filament Count}/{Matrix Commercial Name} {Tape/Weave Type/Weave Style} {Critical Processing Information}

Examples of the tape/weave type include unidirectional tape, plain weave, and five-harness satin weave. Weave styles are descriptive codes most commonly used for glass fabrics, such as 7781. Additional information is shown when it is necessary to discriminate between data sets. This includes material information such as glass surface finish or critical processing information, such as bleed or no-bleed. If a warning regarding data documentation is included for the data set, an asterisk follows the section title.

Each section contains three types of information (Figure 1.4). The data set description identifies the specific material system, provides selected supplier information, and discusses any anomalies which appeared during data sets. The summary data tables give an overview of property types and data classes included in the section. The individual data tables provide the details of data analysis. A separate individual data table is included for each test type, loading direction, and lay-up in the data set. The following describe the content and format for each of these subsections.

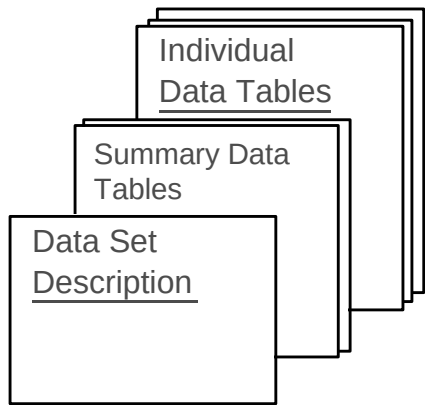


FIGURE 1.4 *Types of information in each data section.*

1.4.1 Data set description

The first page of each section presents general information.

Material Description:

Material - {Fiber Commercial Name} {Filament Count}/ {Matrix Commercial Name} for the material tested.

Form - Description of material tested including unidirectional tape or weave type, nominal fiber areal weight, typical cured resin content, typical cured ply thickness, sizing, tackifier or binder (class, form, manufacturer, and common name), and/or scrim fiber class and scrim fabric style as relevant. This information is specific to the data set that follows it.

Processing - Description of processing including information listed under Process Description in Volume 1, Table 2.5.6.

General Supplier Information: This section presents information often provided by the material supplier. There are no requirements for substantiation of this information.

Fiber: Often includes precursor, surface treatment, twist, filament count, typical tensile modulus or modulus family, and typical tensile strength.

Matrix: Often includes resin type, cure temperature family, description of characteristics.

Maximum Service Temperature: For dry and wet conditions.

Typical Applications: Brief description of applications. May be as generic as "general purpose structural applications" or more specific based on critical characteristics.

Data Analysis Summary: This section contains pertinent information from the statistical analysis of the data. If no other information is included in this section, no data analysis.

Testing: Often includes information on documented deviations from standard test method.

Outliers: Often includes information on the outliers observed, particularly after pooling batches, and their disposition (see Volume 1, Sections 2.5.8 and 2.4.4).

Batch Definition: Often includes information on independence of fiber and matrix lots used in the composite batches.

Batch-to-Batch Variability and Pooling of Data Sets: Often includes information on decision-making for pooling based on batch-to-batch variability. May also contain information on relative batch behavior, such as one batch consistently providing results different from other batches.

Additional Information: For any notes or comments to highlight other concerns by the Secretariat or Data Review working group during analysis and review of the data.

Processing Trace: When available, a processing trace will be presented. Included will be the processing history based on the specification including ramp rates and relative timing of the application of the various processing parameters.

Lay-Up Schematic: When available, a sketch of the processing lay-up will be presented. Included will be bagging, damming, bleeder material, and so on.

The remaining pages in each data section represent data analyzed by the Secretariat, evaluated by the Data Review working group, and approved by the Coordination Group. These data are presented in tables that are described in more detail below. Tables in each section are organized in the same order the properties are listed in the summary tables.

1.4.2 Summary tables

The format for the first page of summary information is shown in Table 1.4.2(a). Details for different portions of the figure are indexed to descriptions in the text by numbered circles.

❶ The first set of information in a data section is a summary table containing information on the materials, processing, etc. The box with a heavy border in the upper right-hand corner identifies the first summary table.

{Fiber Class}/{Matrix Class} {Nominal FAW} - {Tape/Weave Type}
{Fiber}/{Matrix}
Summary

This box contains the fiber/matrix class of the material, such as carbon/epoxy, identified using the material system codes in Section 1.5.1. With the fiber and matrix classes is the nominal fiber areal weight and the abbreviated tape/weave type. Abbreviations for tape and weave type include UT (unidirectional tape), PW (plain weave), or *n*HS (*n*-harness satin) The material identification is summarized by the fiber and matrix names.

❷ Material information is presented for the composite, the preconsolidation form, the fiber, and the matrix. Composite material identification, presented in the Material slot, is the same as the section title.

The preconsolidation Form description depends on the form type. For prepregs, the Form description includes

{Manufacturer} {Commercial Name} {Weave pattern} {Tape/Weave Type} prepreg

For prepregged fabric, information such as warp and fill fiber spacing is included when it is available. For RTM and wet fabric lay-up, the Form description includes

{Weaver} {Fabric Style if glass} {Weave Pattern}{tow/in x tow/in} {Fabric Sizing Identification} {Fabric Sizing Content}, {Tackifier} tackifier + {liquid/film} resin

If a binder is used, information on the binder replaces information on a tackifier.

Fiber identification includes {Manufacturer} {Commercial Name} {Filament Count} {Sizing} {Sizing Amount} {Twist} {[not] surface treated/surface treatment type}. Resin identification is presented as {Manufacturer} {Commercial Name}.

❸ Overall processing information is presented as Reinforcement Application Process (how the fiber/preform was put together) followed by Cure Process Type (how the part was cured/molded) from Table 1.4.2(b). Basic processing information for one or more processing steps, including the type of processing step (from Table 1.4.2(b), temperature, pressure, duration, and any other critical parameters, is presented. A more complete description may be provided in graphical form as part of the summary information (see Section 1.4.1).

❹ Glass transition temperature under dry and wet conditions is presented with the test method used to obtain these data (See Volume 1, Section 6.6.3). These may be nominal values obtained from the matrix supplier.

❺ Any warning for limited data documentation is presented on each page of data presentation. On the first page of the data section, a warning is shown below the material identification block.

❻ The block below the material identification block presents various dates relevant to the fabrication and testing of the material. The date of data submittal determines the data documentation requirements that were used for the data set (Volume 1, Section 2.5.6) and the date of analysis determines the statistical analysis that was used (Volume 1, Section 8.3). Ranges of dates are presented where appropriate, such as for a testing program that lasted several months.

❼ Lamina properties are summarized with the class of data provided for each property. The columns of the lamina property summary table define the environmental conditions. The first column contains room temperature ambient or dry data. Dry is used only if a drying procedure was used. Ambient refers to as-fabricated with subsequent storage in an ambient laboratory environment. The remaining columns are ordered from lowest to highest moisture content and within a given moisture content, from lowest to highest temperature. If there is enough space, a blank column separates the room temperature ambient/dry column from the other columns and each moisture condition from the others.

The rows of the lamina summary table identify the type test and direction. The basic mechanical properties are included in each summary table. If data are available, additional properties are appended in the following order:

SB strength, 31-plane	G_{Ic}	CTE 1-axis
SB strength, 23-plane	G_{IIc}	CTE 2-axis
		CTE 3-axis

❽ For each test type and direction, the symbol for each class of data for the strength, modulus, Poisson's ratio, and strain-to-failure is provided, in that order. The symbols are listed in Table 1.4.2(c). For example, if the entry under RTA and Tension, 1-axis is BI-S, there is room temperature ambient data for longitudinal tension strength, modulus, and strain-to-failure. The dash indicates that there are no Poisson's ratio data. The strength data are B30 (robust sampling), the modulus data are interim, and the strain-to-failure data are screening. Data classes are defined in Volume 1, Section 2.5.1, and summarized in Table 1.4.2(c). Certain test methods, for example, short beam strength, result only in screening data.

TABLE 1.4.2(a) *Summary table format,* first page.

MATERIAL:	{Fiber} {Filament-Count}/{Matrix} {Weave pattern} {Tape/Fabric} ❷	❶
FORM:	{input depends on type of preconsolidation form and processing}	
FIBER:	{Manufacturer} {Commercial Name} {Filament Count} {Sizing} {Twist}	MATRIX: {Manufacturer} {Commercial Name}
PROCESSING:	{Reinforcement Application}, {Mold Type} {Type of Processing Step}: {Temperature}, {Duration}, {Pressure} ❸	
T_g(dry):	XXX°F	T_g(wet): XXX°F T_g METHOD: {Method} ❹

*{Warning} ❺

Date of fiber manufacture	MM/YY	Date of testing	MM/YY
Date of resin manufacture	MM/YY	Date of data submittal	MM/YY
Date of prepreg manufacture	MM/YY	Date of analysis	MM/YY
Date of composite manufacture	MM/YY		❻

LAMINA PROPERTY SUMMARY ❼

	{RTA}		{Ambient/dry, coldest to hottest}					{Wet, coldest to hottest}		
Tension, 1-axis										
Tension, 2-axis										
Tension, 3-axis										
Compression, 1-axis										
Compression, 2-axis			The data class is noted for each type test/direction/ environmental-condition combination							
Compression, 3-axis										
Shear, 12-plane										
Shear, 23-plane										
Shear, 31-plane										
{Additional type test/direction}										

Classes of data in Strength/Modulus/Poisson's Ratio/Strain-to-Failure order: ❽
A = A75, a = A55, B = B30, b = B18, M = Mean, I =Interim, S = Screening, - = no data (See Table 1.4.2(c)).

TABLE 1.4.2(b) *Composite reinforcement application, cure process type, and processing step descriptions*.

Reinforcement Application Process	Cure Process Type	Type of Processing Step
automated fiber placement - tape automated fiber placement - towpreg automated fiber placement - wet automated lay-up - prepreg automated lay-up - wet hand lay-up - prepreg hand lay-up - wet preform - braid preform - weave spray wound - dry wound - wet wound - prepreg	compression molding diffusion bonding injection molding injection molding - vacuum assisted injection molding - reaction injection molding - liquid oven autoclave hydroclave trapped rubber pultrusion resin transfer molding VARTM [vacuum-assisted resin transfer molding] vacuum infiltration vapor deposition e-beam induction	age-harden anneal consolidate [pre-cure] cooldown cure - bleed cure - no bleed debulk densify injection isothermal dwell part insertion part removal postcure preform insertion preheat

TABLE 1.4.2(c) *MIL-HDBK-17 data classes and minimum sampling requirements*.

			Minimum Requirements	
Designation	Symbol	Description	Number of Batches	Number of Specimens
A75	A	A-basis – Robust Sampling	10	75
A55	a	A-basis – Reduced Sampling	5	55
B30	B	B-Basis – Robust Sampling	5	30
B18	b	B-Basis – Reduced Sampling	3	18
M	M	Mean	3	18
I	I	Interim	3	15
S	S	Screening	1	5

Continuing on the second page of summary information (Table 1.4.2(d)):

① Any warning is placed at the top of this page.

② The box at the top of the second page of summary information presents basic physical parameters for the data set. The first data column contains nominal values, typically specification information. This information may not match information directly applicable to this data set. For example, the nominal fiber volume according to the prepreg manufacturer may be one value, while the data are normalized to a different value based on Volume 1, Section 2.5.7, to provide consistency within the handbook. One or more of the nominal values can be calculated from other information if the values are not otherwise available. For example, if unavailable the nominal composite density will be calculated from nominal fiber density, matrix density, and fiber volume. In this case, a note describes the calculation. If the nominal fiber volume was not supplied by the data source, it was calculated based on resin content, fiber density and composite density, assuming void content is 0%.

③ The second data column presents the range of values for the data set submitted. These data may not correlate directly with each other. For example, fiber volume and fiber areal weight may be batch average measurements, while the cured ply thickness values are generally based on individual specimen measurements.

④ The last column presents the test method used to obtain these data. This information was not included in the early versions of data documentation requirements.

⑤ Laminate property data are summarized in the lower box in the same way as lamina property data are summarized on the previous page. Families of laminates are provided with properties listed below each laminate family. A laminate family is identified by square brackets surrounding a list of the ply orientations separated by commas. More specific lay-up information is included in the laminate summary table only if needed to differentiate among lay-ups. Specific lay-up information is provided in the detailed tables that follow. The type test and direction are included only if data are available and are based on Table 1.4.2(e).

Unless otherwise noted, the x-axis corresponds to the +0-direction of the laminate lay-up. Data included for this material are indicated by the data class symbol, identified in the footnote.

TABLE 1.4.2(d) *Summary table format,* second page.

{Warning} ①

		Nominal ②	As Submitted ③	Test Method ④
Fiber Density	(g/cm^3)	X.XX	{Minimum} - {Maximum}	{Method}
Resin Density	(g/cm^3)	X.XX	{Minimum} - {Maximum}	{Method}
Composite Density	(g/cm^3)	X.XX	{Minimum} - {Maximum}	{Method}
Fiber Areal Weight	(g/m^2)	XXX	{Minimum} - {Maximum}	{Method}
Fiber Volume	(%)	XX	{Minimum} - {Maximum}	{Method}
Ply Thickness	(in)	0.0XXX	{Minimum} - {Maximum}	{Method}

LAMINATE PROPERTY SUMMARY ⑤

	{RTA}		{Ambient/dry, coldest to hottest}					{Wet, coldest to hottest}		
{Laminate Family}										
{Type test/direction}										
.										
.										
.			The data class is noted							
{Laminate Family}			for each type test/direction/							
{Type test/direction}			environmental-condition combination							
.										
.										
.										

Classes of data in Strength/Modulus/Poisson's ratio/Strain-to-failure order
A = A75, a = A55, B = B30, b = B18, M = Mean, I =Interim, S = Screening, - = no data (See Table 1.4.2(c)).

TABLE 1.4.2(e) *Laminate type test and directions*

Type Test (in order)		Direction	
Tension	Filled Hole Tension (FHT)	x-axis	xy-plane
Compression	Filled Hole Compression (FHC)	y-axis	yz-plane
Shear	Compression After Impact (CAI)	z-axis	zx-plane
Open Hole Tension (OHT)	Bearing		
Open Hole Compression (OHC)	Bearing/Bypass		
	CTE		

1.4.3 Individual data tables - normalized data

The format for a data table containing normalized material property information is shown in Table 1.4.3(a). Requirements and procedures for normalization are found in Volume 1, Section 2.5.7 and 2.4.3.

❶ Warnings are shown on each page for data sets that do not meet the data documentation requirements. Many of the data sets were submitted before the establishment of the data documentation requirements. Data sets that do not meet the first version of data documentation requirements or the data documentation requirements that were current when the data were submitted will not be considered for B or A data classes.

❷ At the top right corner of each page is a box with a heavy border. This box contains information that identifies the data set, the type of test for which results are shown, specimen orientation, test conditions, and the classes of data. The tape/weave type abbreviations are described for the top right corner of the first summary page (circle-1), Specimen orientation is provided as a lay-up code with the loading direction used as the reference axis. For example, a unidirectional specimen is described as $[0]_n$ for 1-axis properties and $[90]_n$ for 2- axis properties. Lay-up codes are described in Section 1.6.

{Table Number}
{Fiber Class}/{Matrix Class} {FAW}-{Tape/Weave Type} - FAW, fiber areal weight
{Fiber Name}/{Matrix Name}
{Test Type}, {Direction}
{Lay-up}
{Test Temperature}/{Moisture Content} - repeated for each data column
{Data Classes } - includes symbols for all data classes on this page in descending order (from A75 to S).

❸ Material identification is provided for the composite material as

{Fiber} {Filament-Count}/{Matrix} {Tape/Weave Type} {Critical processing parameters}

This information should be the same as the section title and the material identification on the first page of the summary tables. The range of physical parameters, resin content, fiber volume, ply thickness, composite density, and void content, for the *cured* material are presented for the data on this particular page. The endpoints of these ranges may not correspond directly as fiber volume, resin content, and so on are generally available as a batch or panel average while the cured ply thickness values are usually based on individual specimen measurements.

❶ **TABLE 1.4.3** *Format for normalized property table.*

{Warning}

MATERIAL:	{Fiber} {Filament count}/{Matrix} {Tape/weave type} ❸			❷	
RESIN CONTENT:	XX.X - XX.X wt%	COMP: DENSITY:	X.XX-X.XX g/cm^3		
FIBER VOLUME:	XX.X - XX.X vol %	VOID CONTENT:	0.X to X.X %		
PLY THICKNESS:	0.0XXX - 0.0XXX in.				
TEST METHOD: ❹		MODULUS CALCULATION: ❺			
{Organization} {Number} {Date}		{Method}, XXXX - XXXX □□			
NORMALIZED BY:	{Method} ❻				

Temperature (°F) Moisture Content (%) Equilibrium at T, RH Source Code		❼				
		Normalized	Measured	Normalized	Measured	Normalized	Measured
F_1^{tu} ❽ (ksi)	Mean Minimum Maximum C.V.(%) B-value Distribution C_1 C_2 No. Specimens No. Batches Data Class	❾					
E_1^t (Msi)	Mean Minimum Maximum C.V.(%) No. Specimens No. Batches Data Class						
ν_{12}^t	Mean No. Specimens No. Batches Data Class						
ε_1^{tu} (με)	Mean Minimum Maximum C.V.(%) B-value Distribution C_1 C_2 No. Specimens No. Batches Data Class	Note that the strain values presented are “as measured” and may not be equivalent to stress divided by modulus (linear analysis)					

❿

❹ The test method is identified with the organization, number, and date. For compression after impact, the nominal impact energy level used for the test is appended to the test method, since alternate levels are often used. See Tables 1.4.5 - 1.4.7 for additional information that describes testing parameters for notched laminates, bearing, and bearing/bypass.

❺ The method of calculating the modulus is presented for mechanical property data. This includes the calculation method, and the location or range of measurements used for the calculation. Unless otherwise stated (in a footnote), the same method and range is used for Poisson's ratio.

❻ The normalization method is presented for data that have been normalized (See Volume 1, Section 2.4.3). The fiber volume to which the data are normalized is also included. This value is typically 60% for carbon-fiber-reinforced unidirectional material (tape) and 57% for carbon-fiber-reinforced fabric. The normalizing fiber volume for all glass-fiber-reinforced material is 50%. Types of normalization as entered are:

Normalized by fiber volume to XX% (0.0XXX in. CPT)
Normalized by specimen thickness and batch fiber volume to XX% (0.0XXX in. CPT)
Normalized by specimen thickness and batch fiber areal weight to XX% fiber volume (0.0XXX in. CPT)

Corresponding cured ply thickness (CPT) values, based on a nominal fiber areal weight, are included for reference for each method.

❼ At the top of each data column are the test conditions. Nominally dry conditions, for materials that are fabricated and stored under controlled conditions are noted. Wet conditions that are not conditioned to equilibrium are also noted. The source code provides a means for identifying data sets from the same source. No other source identification is provided.

❽ Specific properties are identified in the tables with symbols. These symbols are a combination of an initial letter with subscripts and super scripts added as appropriate. Components of the property symbols are shown in Table 1.4.3(b).

TABLE 1.4.3(b) *Components used to construct property symbols*.

Initial letter(s)	Test type superscripts	Property descriptor superscripts	Test direction subscripts
F - strength ε - strain E - modulus G - shear modulus, strain energy release rate υ - Poisson's ratio CTE - coefficient of thermal expansion	t - tension c - compression s - shear sbs - short beam strength oht - open hole tension ohc - open hole compression fht - filled hole tension cai - compression after impact br - bearing byp - bypass	u - ultimate y - yield	1, 2, 3 12, 23, 31 x, y, z, xy, yz, zx

Property symbols are created by combining these components with test type superscripts preceding property descriptor super scripts. Thus, the symbol for ultimate tensile strength in the 1 direction is F_1^{tu}. The property descriptor superscripts are only used for strength and strain. Exceptions to this rule are strain energy release rates, for example, G_{1c}, and bearing/bypass data where "byp" is used as a subscript for the bypass strength.

❾ Strength data and strain-to-failure data are presented in the handbook with a full set of statistical parameters. All statistical parameters are presented for normalized and as-measured strength data. All statistical parameters are presented for as-measured strain-to-failure data. Note that the strain values presented are “as measured” and may not be equivalent to stress divided by modulus (linear analyses). The normalized data column is listed first, followed by the measured data column. The data class using the designation from Table 1.4.2(c) is indicated for each property/condition combination. B-values are presented only for B and A data classes. A-basis values are presented for A data classes. The statistical distribution or method of analysis is presented. The constants, C_1 and C_2, correspond to the distribution as listed in Table 1.4.3 (c).

C_1 for the Weibull distribution and C_1 and C_2 for the Normal distribution have the same units as the property (e.g., ksi for strength and $\mu\varepsilon$ for strain). C_2 for the Weibull distribution and C_1 and C_2 for the Nonparametric method are dimensionless. For the Lognormal distribution, the units for C_1 and C_2 are log(property unit). For the ANOVA method, C_1 and C_2 are the square of the property units.

TABLE 1.4.3(c) *Distributions and associated constants.*

	C_1	C_2
Weibull	scale parameter	shape parameter
Normal	mean	standard deviation
Lognormal	mean of the natural log of the data	standard deviation of the natural log of the data
Nonparametric	rank	data point (rank)
ANOVA	tolerance limit factor	estimate of the population standard deviation

Modulus data are presented with only mean, minimum, maximum, coefficient of variation, batch size, sample size, and data class. Values are presented for both normalized and as-measured data. Where available, Poisson's ratio data are presented with batch size, sample size, and data class information.

❿ Footnotes are presented wherever additional information is pertinent. Information frequently presented in footnotes include conditioning parameters, reasons for not presenting B-values, and deviations from standard test methods.

1.4.4 Individual data tables - unnormalized data

Table 1.4.4 shows an example table for material properties that are not normalized. The basic table format and information are identical to the table format and information for normalized data. Only as-measured data are presented in each column of information. The statistical parameters are the same provided for normalized data.

1.4.5 Individual data tables - notched laminate data

Table 1.4.5 shows the format for notched laminate data, including data from open and filled hole tests. The numbered circles refer to the notes for Table 1.4.3(a) with the following additional information. Properties in the index box (upper right-hand corner) are abbreviated OHT (open hole tension), OHC (open hole compression), FHT (filled hole tension), and FHC (filled hole compression). The headers and data for fastener type, torque, hole clearance, and countersink angle & depth appear only for filled hole tests. The data are normalized according to Volume 1, Section 2.5.7, with the descriptions noted with Table 1.4.3(a). Symbols are described in Tables 1.4.3(b), Open hole tension in the x-axis direction is shown as an example.

1.4.6 Individual data tables - bearing data

Table 1.4.6 presents the format for bearing data. The numbered circles refer to the notes for Table 1.4.3(a) with the following additional information. The property in the index box (upper right-hand corner) is Bearing. The data are not normalized according to Volume 1, Section 2.5.7. Symbols are described in Tables 1.4.3(b). Bearing in the x-axis direction is shown as an example. Information on hole clearance, and countersink angle & depth appear as a footnote if applicable and available.

1.4.7 Individual data tables - bearing/bypass data

Table 1.4.7 shows the format for bearing/bypass data. The numbered circles refer to the notes for Table 1.4.3(a) with the following additional information. The property in the index box (upper right-hand corner) is Bearing/Bypass. The data are not normalized according to Volume 1, Section 2.5.7. If data are available for more than one bearing/bypass ratio, they are presented in columns ordered from lowest to highest ratio for each environment. Symbols are described in Tables 1.4.3(b). Tensile bypass and bearing in the x-axis direction are shown as an example. Information on hole clearance, and countersink angle & depth appear as a footnote if applicable and available.

❶ **TABLE 1.4.4** *Format for as-measured property table.*

{Warning}

MATERIAL: {Fiber} {Filament count}/{Matrix} {Tape/weave type} ❸						❷
RESIN CONTENT: XX - XX wt%		COMP: DENSITY: X.XX-X.XX g/cm^3				
FIBER VOLUME: XX - XX vol %		VOID CONTENT: 0.X to X.X %				
PLY THICKNESS: 0.0XXX - 0.0XXX in.						
TEST METHOD: ❹ {Organization} {Number} {Date}		MODULUS CALCULATION: ❺ {Method}, XXXX - XXXX με				
NORMALIZED BY: Not normalized ❻						
Temperature (°F) Moisture Content (%) Equilibrium at T, RH Source Code		❼				
	Mean Minimum Maximum C.V.(%)	❾				
F_2^{tu} ❽ (ksi)	B-value Distribution C_1 C_2					
	No. Specimens No. Batches Data Class					
	Mean Minimum Maximum C.V.(%)					
E_2^t (Msi)	No. Specimens No. Batches Data Class					
	Mean No. Specimens No. Batches Data Class					
ν_{21}^t						
	Mean Minimum Maximum C.V.(%)		Note that the strain values presented are "as measured" and may not be equivalent to stress divided by modulus (linear analysis)			
ε_2^{tu} (με)	B-value Distribution C_1 C_2					
	No. Specimens No. Batches Data Class					

❿

❶ **TABLE 1.4.5** *Format for notched laminate strength property table.*

{Warning}

MATERIAL: {Fiber} {Fil. Count} / {Matrix} {tape/weave type} ❸

RESIN CONTENT: XX-XX wt% COMP. DENSITY: 0.0XX-0.0XX lb/in^3
FIBER VOLUME: XX-XX % VOID CONTENT: X.X - X.X %
PLY THICKNESS: 0.00XX - 0.00XX in.

❷

❹

TEST METHOD: {Org. Method - Date}

SPECIMEN GEOMETRY: t = {thickness} in., w = {width} in., d = {diameter} in.
FASTENER TYPE: { } HOLE CLEARANCE: {if applicable}
TORQUE: { } COUNTERSINK ANGLE & DEPTH: {if applicable}

❻

NORMALIZED BY: {Method}

Temperature (°F) Moisture Content (%) Equilibrium at T,RH(°F, %) Source Code		❼				
		Normalized	Measured	Normalized	Measured	Normalized	Measured
❽	Mean Minimum Maximum C.V.(%)	❾					
F_x^{oht} (ksi)	B-value Distribution C_1 C_2						
	No. Specimens No. Batches Data Class						
F_x^{ohc} (ksi)	Mean Minimum Maximum C.V.(%)						
	B-value Distribution C_1 C_2						
	No. Specimens No. Batches Data Class						

❿

❶ **TABLE 1.4.6** *Format for bearing strength property table.*

{Warning}

MATERIAL: {Fiber} {Fil. Count} / {Matrix} {tape/weave type} ❸				❷
RESIN CONTENT: XX-XX wt%		COMP. DENSITY: 0.0XX-0.0XX lb/in^3		
FIBER VOLUME: XX-XX %		VOID CONTENT: X.X - X.X %		
PLY THICKNESS: 0.00XX - 0.00XX in.				
❹				
TEST METHOD: {Org. Method - Date}				
TYPE OF BEARING TEST: {single or double lap shear}				
JOINT CONFIGURATION				
Member 1 (t,w,lay-up): {thickness, width, lay-up }				
Member 2 (t,w,lay-up): {thickness, width, lay-up }				
FASTENER TYPE: { }		THICKNESS/DIAMETER: { }		
TORQUE: { }		EDGE DISTANCE RATIO: { }		
		PITCH DISTANCE RATIO: { }		
NORMALIZED BY: Not normalized ❻		YIELD STRAIN OFFSET: { }		
Temperature (°F) ❼				
Moisture Content (%)				
Equilibrium at T, RH (°F, %)				
Source Code				
❽	Mean ❾			
	Minimum			
	Maximum			
	C.V.(%)			
	B-value			
F_x^{bru}	Distribution			
(ksi)	C_1			
	C_2			
	No. Specimens			
	No. Batches			
	Data Class			
	Mean			
	Minimum			
	Maximum			
	C.V.(%)			
F_x^{bry}	B-value			
(ksi)	Distribution			
	C_1			
	C_2			
	No. Specimens			
	No. Batches			
	Data Class			

❿

❶ **TABLE 1.4.7** *Format for bearing/bypass property table.*

{Warning}

MATERIAL:	{Fiber} {Fil. Count} / {Matrix} {tape/weave type} ❸			❷
RESIN CONTENT:	XX-XX wt%	COMP. DENSITY:	0.0XX-0.0XX lb/in^3	
FIBER VOLUME:	XX-XX %	VOID CONTENT:	X.X - X.X %	
PLY THICKNESS:	0.00XX - 0.00XX in.			
TEST METHOD:	{Org. Method - Date} ❹			
JOINT CONFIGURATION				
Member 1 (t,w,lay-up):	{thickness, width, lay-up}			
Member 2 (t,w,lay-up):	{thickness, width, lay-up}			
FASTENER TYPE:	{ }	THICKNESS/DIAMETER:	{ }	
TORQUE:	{ }	EDGE DISTANCE RATIO:	{ }	
		PITCH DISTANCE RATIO:	{ }	
NORMALIZED BY:	Not normal-ized ❻			

Temperature (°F) Moisture Content (%) Equilibrium at T, RH (°F, %) Source Code		❼		
Bearing/Bypass Ratio				
F_x^{byp-tu} ❽ (ksi)	Mean Minimum Maximum C.V.(%)	❾		
F_x^{br} (ksi)	Mean Minimum Maximum C.V.(%) B-value Distribution C_1 C_2 No. Specimens No. Batches Data Class			

❿

1.5 MATERIALS SYSTEMS

1.5.1 Materials system codes

The materials systems codes which are used in the handbook consist of a fiber system code and a matrix material code separated by a virgule (/). The codes for the fiber and matrix materials appear in Tables 1.5.1(a) and (b).

TABLE 1.5.1(a) *Fiber system codes.*

AlO	Alumina
Ar	Aramid
B	Boron
C	Carbon
DGl	D-Glass
EGl	E-Glass
Gl	Glass
Gr	Graphite
Li	Lithium
PAN	Polyacrylonitrile
PBT	Polybenzothiazole
Q	Quartz
Si	Silicon
SiC	Silicon carbide
SGl	S-Glass
Ti	Titanium
W	Tungsten

TABLE 1.5.1(b) *Matrix material codes.*

BMI	Bismaleimide
CE	Cyanate Ester
EP	Epoxy
FC	Fluorocarbon
P	Phenolic
PAI	Polyamide-imide
PBI	Polybenzimidazole
PEEK	Polyetheretherketone
PEI	Polyetherimide
PES	Polyethersulfone
PI	Polyimide
PPS	Polyphenylene sulfide
PSU	Polysulfone
SI	Silicone
TPES	Thermoplastic polyester

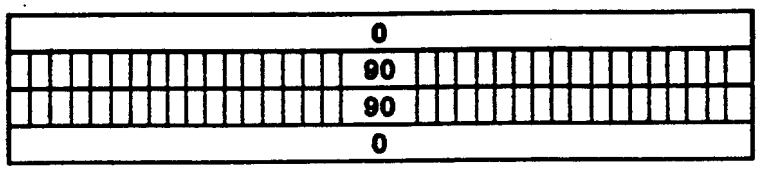
1.5.2 Index of materials

This section is reserved for future use.

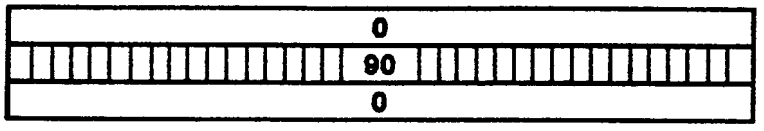
1.6 MATERIAL ORIENTATION CODES

1.6.1 Laminate orientation codes

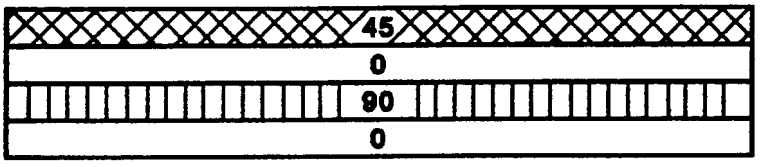
The purpose of a laminate orientation code is to provide a simple, easily understood method of describing the lay-up of a laminate. The laminate orientation code is based largely on the code used in the Advanced Composites Design Guide (Reference 1.6.1(a)). The following information and the examples in Figure 1.6.1 describe the laminate orientation code used in MIL-HDBK-17.



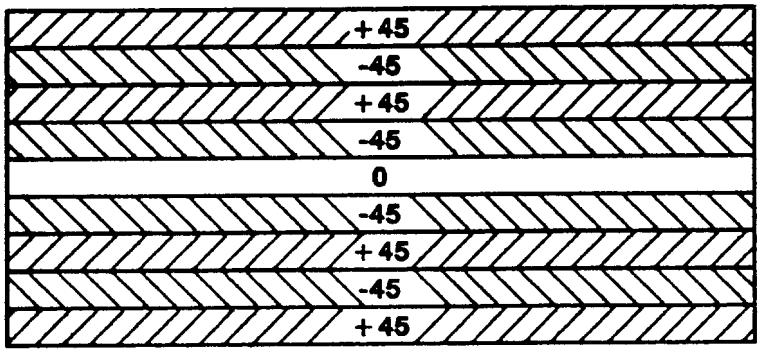
$[0/90]_s$



$[0/\overline{90}]_s$



$[45_f/0/90/0]$



$[(\pm 45)_2/\overline{0}]_s$

FIGURE 1.6.1 *Example laminate orientation codes.*

1. The orientation of each lamina with respect to the x-axis is indicated by the angle between the fiber direction and the x-axis. Positive angles are measured counter-clockwise from the x-axis when looking toward the lay-up surface (right-hand rule).

2. When indicating the lay-up of a weave, the angle is measured between the warp direction and the x-axis.

3. Orientations of successive laminae with different absolute values are separated by a virgule (/).

4. Two or more adjacent laminae with the same orientation are indicated by adding a subscript, to the angle of the first such lamina, equal to the number of repetitions of laminae with that orientation.

5. Laminae are listed in order from the first laid up to the last. Brackets are used to indicate the beginning and the end of the code.

6. A subscript of 's' is used if the first half of the lay-up is indicated and the second half is symmetric with the first. When a symmetric lay-up with an odd number of laminae is shown, the layer which is not repeated is indicated by overlining the angle of that lamina.

7. A repeated set of laminae are enclosed in parentheses and the number of repetitions of the set indicated by a subscript.

8. The convention used for indicating materials is no subscript for a tape ply and a subscript "f" for a weave.

9. The laminate code for a hybrid has the different materials contained in the laminate indicated by subscripts on the laminae.

10. Since the majority of computer programs do not permit the use of subscripts and superscripts, the following modifications are recommended based on ASTM Committee E-49 guidelines (Reference 1.6.1(b)).

    a. Subscript information will be preceded by a colon (:), e.g., [90/0:2/45]:s.
    b. A bar over a ply (designating a non-repeated ply in a symmetric laminate) should be indicated by a backslash (\) after the ply, e.g., [0/45/90\]:s.

1.6.2 Braiding orientation codes

This section is reserved for future use.

1.7 SYMBOLS, ABBREVIATIONS, AND SYSTEMS OF UNITS

This section defines the symbols and abbreviations which are used within MIL-HDBK-17 and describes the system of units which is maintained. Common usage is maintained where possible. References 1.7(a) - (c) served as primary sources for this information.

1.7.1 Symbols and abbreviations

The symbols and abbreviations used in this document are defined in this section with the exception of statistical symbols. These latter symbols are defined in Chapter 8. The lamina/laminate coordinate axes used for all properties and a summary of the mechanical property notation are shown in Figure 1.7.1.

- The symbols f and m, when used as either subscripts or superscripts, always denote fiber and matrix, respectively.

- The type of stress (for example, cy - compressive yield) is always used in the superscript position.

- Direction indicators (for example, x, y, z, 1, 2, 3, etc.) are always used in the subscript position.

- Ordinal indicators of laminae sequence (e.g., 1, 2, 3, etc.) are used in the superscript position and must be parenthesized to distinguish them from mathematical exponents.

- Other indicators may be used in either subscript or superscript position, as appropriate for clarity.

- Compound symbols (such as, basic symbols plus indicators) which deviate from these rules are shown in their specific form in the following list.

The following general symbols and abbreviations are considered standard for use in MIL-HDBK-17. Where exceptions are made, they are noted in the text and tables.

A - (1) area (m^2,in^2)
- (2) ratio of alternating stress to mean stress
- (3) A-basis for mechanical property values

a - (1) length dimension (mm,in)
- (2) acceleration (m/sec^2,ft/sec^2)
- (3) amplitude
- (4) crack or flaw dimension (mm,in)

B - (1) B-basis for mechanical property values
- (2) biaxial ratio

Btu - British thermal unit(s)

b - width dimension (mm,in), e.g., the width of a bearing or compressive panel normal to load, or breadth of beam cross-section

C - (1) specific heat (kJ/kg °C,Btu/lb °F)
- (2) Celsius

CF - centrifugal force (N,lbf)

CPF - crossply factor

CPT - cured ply thickness (mm, in.)

CG - (1) center of mass, "center of gravity"
- (2) area or volume centroid

$\mathit{\mathbb{C}}$ - centerline

c - column buckling end-fixity coefficient

$\bar{c}$ - honeycomb sandwich core depth (mm,in)

cpm - cycles per minute

D - (1) diameter (mm,in)
- (2) hole or fastener diameter (mm,in)
- (3) plate stiffness (N-m,lbf-in)

d - mathematical operator denoting differential

E - modulus of elasticity in tension, average ratio of stress to strain for stress below proportional limit (GPa,Msi)

E' - storage modulus (GPa,Msi)

E" - loss modulus (GPa,Msi)

E_c - modulus of elasticity in compression, average ratio of stress to strain for stress below proportional limit (GPa,Msi)

E_c' - modulus of elasticity of honeycomb core normal to sandwich plane (GPa,Msi)

E^{sec} - secant modulus (GPa,Msi)

E^{tan} - tangent modulus (GPa,Msi)

e - minimum distance from a hole center to the edge of the sheet (mm,in)

e/D - ratio of edge distance to hole diameter (bearing strength)

F - (1) stress (MPa,ksi)
- (2) Fahrenheit

F^b - bending stress (MPa,ksi)

F^{ccr} - crushing or crippling stress (upper limit of column stress for failure) (MPa,ksi)

F^{su} - ultimate stress in pure shear (this value represents the average shear stress over the cross-section) (MPa,ksi)

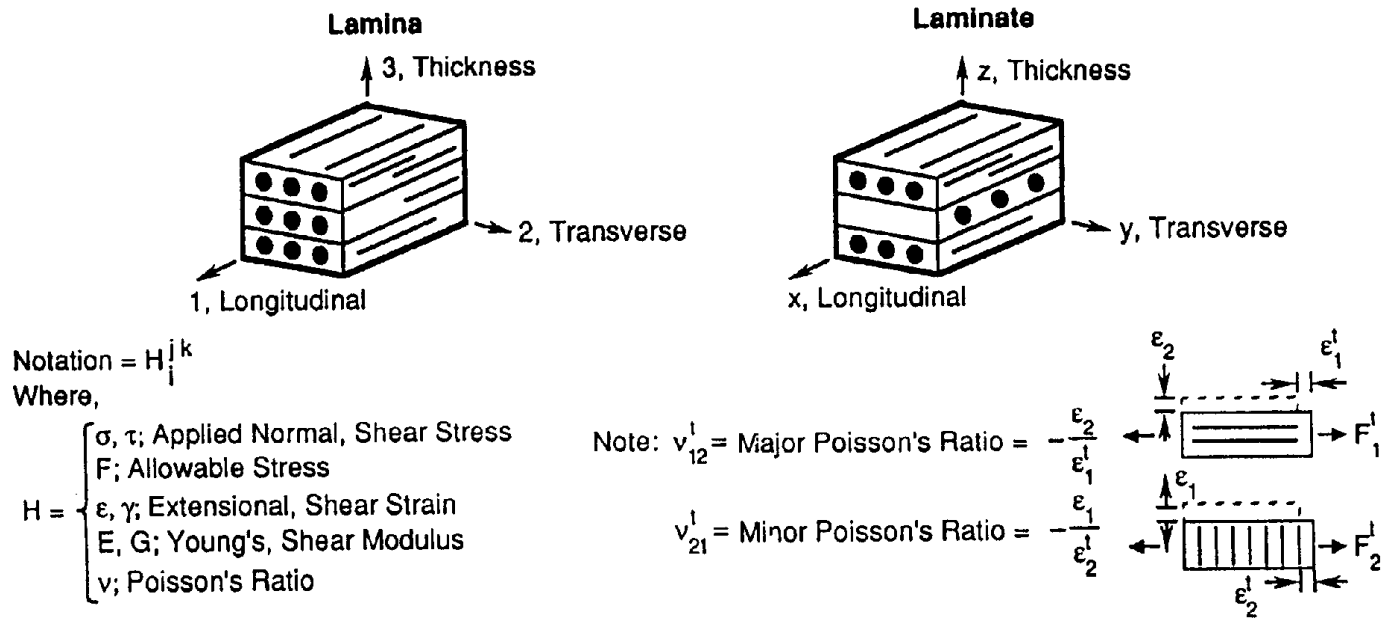


FIGURE 1.7.1 *Mechanical property notation.*

FAW - fiber areal weight (g/m^2, lb/in^2)
FV - fiber volume (%)
f - (1) internal (or calculated) stress (MPa,ksi)
- (2) stress applied to the gross flawed section (MPa,ksi)
- (3) creep stress (MPa,ksi)
f^c - internal (or calculated) compressive stress (MPa,ksi)
f_c - (1) maximum stress at fracture (MPa,ksi)
- (2) gross stress limit (for screening elastic fracture data (MPa,ksi)
ft - foot, feet
G - modulus of rigidity (shear modulus) (GPa,Msi)
GPa - gigapascal(s)
g - (1) gram(s)
- (2) acceleration due to gravity (m/s^2,ft/s^2)
H/C - honeycomb (sandwich)
h - height dimension (mm,in) e.g. the height of a beam cross-section
hr - hour(s)
I - area moment of inertia (mm^4,in^4)
i - slope (due to bending) of neutral plane in a beam, in radians
in. - inch(es)
J - (1) torsion constant (= I_p for round tubes) (m^4,in^4)
- (2) Joule
K - (1) Kelvin
- (2) stress intensity factor (MPa/m,ksi/in)
- (3) coefficient of thermal conductivity (W/m °C, $Btu/ft^2/hr/in/°F$)
- (4) correction factor
- (5) dielectric constant
K_{app} - apparent plane strain fracture toughness or residual strength (MPa/m,ksi/in)
K_c - critical plane strain fracture toughness, a measure of fracture toughness at point of crack growth instability (MPa/m,ksi/in)
K_{Ic} - plane strain fracture toughness (MPa/m,ksi/in)
K_N - empirically calculated fatigue notch factor
K_s - plate or cylinder shear buckling coefficient
K_t - (1) theoretical elastic stress concentration factor
- (2) t_w/c ratio in H/C sandwich
Kv - dielectric strength (KV/mm, V/mil)
K_x,K_y - plate or cylinder compressive buckling coefficient
k - strain at unit stress (m/m,in/in)
L - cylinder, beam, or column length (mm,in)
L' - effective column length (mm,in)
lb - pound
M - applied moment or couple (N-m,in-lbf)
Mg - megagram(s)
MPa - megapascal(s)
MS - military standard
M.S. - margin of safety
MW - molecular weight
MWD - molecular weight distribution
m - (1) mass (kg,lb)
- (2) number of half wave lengths
- (3) metre
- (4) slope
N - (1) number of fatigue cycles to failure
- (2) number of laminae in a laminate
- (3) distributed in-plane forces on a panel (lbf/in)
- (4) Newton
- (5) normalized

NA - neutral axis
n - (1) number of times in a set
- (2) number of half or total wavelengths
- (3) number of fatigue cycles endured
P - (1) applied load (N,lbf)
- (2) exposure parameter
- (3) probability
- (4) specific resistance (Ω)
P^u - test ultimate load, (N,lb per fastener)
P^y - test yield load, (N,lb per fastener)
p - normal pressure (Pa,psi)
psi - pounds per square inch
Q - area static moment of a cross-section (mm^3,in^3)
q - shear flow (N/m,lbf/in)
R - (1) algebraic ratio of minimum load to maximum load in cyclic loading
- (2) reduced ratio
RA - reduction of area
RH - relative humidity
RMS - root-mean-square
RT - room temperature
r - (1) radius (mm,in)
- (2) root radius (mm,in)
- (3) reduced ratio (regression analysis)
S - (1) shear force (N,lbf)
- (2) nominal stress in fatigue (MPa,ksi)
- (3) S-basis for mechanical property values
S_a - stress amplitude in fatigue (MPa,ksi)
S_e - fatigue limit (MPa,ksi)
S_m - mean stress in fatigue (MPa,ksi)
S_{max} - highest algebraic value of stress in the stress cycle (MPa,ksi)
S_{min} - lowest algebraic value of stress in the stress cycle (MPa,ksi)
S_R - algebraic difference between the minimum and maximum stresses in one cycle (MPa,ksi)
S.F. - safety factor
s - (1) arc length (mm,in)
- (2) H/C sandwich cell size (mm,in)
T - (1) temperature (°C,°F)
- (2) applied torsional moment (N-m,in-lbf)
T_d - thermal decomposition temperature (°C,°F)
T_F - exposure temperature (°C,°F)
T_g - glass transition temperature(°C,°F)
T_m - melting temperature (°C,°F)
t - (1) thickness (mm,in)
- (2) exposure time (s)
- (3) elapsed time (s)
V - (1) volume (mm^3,in^3)
- (2) shear force (N,lbf)
W - (1) weight (N,lbf)
- (2) width (mm,in)
- (3) Watt
x - distance along a coordinate axis
Y - nondimensional factor relating component geometry and flaw size
y - (1) deflection (due to bending) of elastic curve of a beam (mm,in)
- (2) distance from neutral axis to given point
- (3) distance along a coordinate axis
Z - section modulus, I/y (mm^3,in^3)
α - coefficient of thermal expansion (m/m/°C,in/in/°F)

γ - shear strain (m/m,in/in)
Δ - difference (used as prefix to quantitative symbols)
δ - elongation or deflection (mm,in)
ε^e - strain (m/m,in/in)
ε^p - elastic strain (m/m,in/in)
ε - plastic strain (m/m,in/in)
μ - permeability
η - plasticity reduction factor
$[\eta]$ - intrinsic viscosity
η^* - dynamic complex viscosity
ν - Poisson's ratio
ρ - (1) density (kg/m^3,lb/in^3)
- (2) radius of gyration (mm,in)
ρ_c' - H/C sandwich core density (kg/m^3,lb/in^3)
Σ - total, summation
σ - standard deviation
σ_{ij}, τ_{ij} - stress in j direction on surface whose outer normal is in i direction (i, j = 1, 2, 3 or x, y, z) (MPa,ksi)
T - applied shear stress (MPa,ksi)
ω - angular velocity (radians/s)
∞ - infinity

1.7.1.1 Constituent properties

The following symbols apply specifically to the constituent properties of a typical composite material.

E^f - Young's modulus of filament material (MPa,ksi)
E^m - Young's modulus of matrix material (MPa,ksi)
E_x^g - Young's modulus of impregnated glass scrim cloth in the filament direction or in the warp direction of a fabric (MPa,ksi)
E_y^g - Young's modulus of impregnated glass scrim cloth transverse to the filament direction or to the warp direction in a fabric (MPa,ksi)
G^f - shear modulus of filament material (MPa,ksi)
G^m - shear modulus of matrix (MPa,ksi)
G_{xy}^g - shear modulus of impregnated glass scrim cloth (MPa,ksi)
G_{cx}' - shear modulus of sandwich core along X-axis (MPa,ksi)
G_{cy}' - shear modulus of sandwich core along Y-axis (MPa,ksi)
ℓ - filament length (mm,in)
α^f - coefficient of thermal expansion for filament material (m/m/°C,in/in/°F)
α^m - coefficient of thermal expansion for matrix material (m/m/°C,in/in/°F)
α_x^g - coefficient of thermal expansion of impregnated glass scrim cloth in the filament direction or in the warp direction of a fabric (m/m/°C,in/in/°F)
α_y^g - coefficient of thermal expansion of impregnated glass scrim cloth transverse to the filament direction or to the warp direction in a fabric (m/m/°C,in/in/°F)
ν^f - Poisson's ratio of filament material
ν^m - Poisson's ratio of matrix material
ν_{xy}^g - glass scrim cloth Poisson's ratio relating to contraction in the transverse (or fill) direction as a result of extension in the longitudinal (or warp) direction

ν_{yx}^{g} - glass scrim cloth Poisson's ratio relating to contraction in the longitudinal (or warp) direction as a result of extension in the transverse (or fill) direction
σ - applied axial stress at a point, as used in micromechanics analysis (MPa,ksi)
τ - applied shear stress at a point, as used in micromechanics analysis (MPa,ksi)

1.7.1.2 Laminae and laminates

The following symbols, abbreviations, and notations apply to composite laminae and laminates. At the present time the focus in MIL-HDBK-17 is on laminae properties. However, commonly used nomenclature for both laminae and laminates are included here to avoid potential confusion.

A_{ij} (i,j = 1,2,6) - extensional rigidities (N/m,lbf/in)
B_{ij} (i,j = 1,2,6) - coupling matrix (N,lbf)
C_{ij} (i,j = 1,2,6) - elements of stiffness matrix (Pa,psi)
D_x, D_y - flexural rigidities (N-m,lbf-in)
D_{xy} - twisting rigidity (N-m,lbf-in)
D_{ij} (i,j = 1,2,6) - flexural rigidities (N-m,lbf-in)
E_1 - Young's modulus of lamina parallel to filament or warp direction (GPa,Msi)
E_2 - Young's modulus of lamina transverse to filament or warp direction (GPa,Msi)
E_x - Young's modulus of laminate along x reference axis (GPa,Msi)
E_y - Young's modulus of laminate along y reference axis (GPa,Msi)
G_{12} - shear modulus of lamina in 12 plane (GPa,Msi)
G_{xy} - shear modulus of laminate in xy reference plane (GPa,Msi)
h_i - thickness of i^{th} ply or lamina (mm,in)
M_x, M_y, M_{xy} - bending and twisting moment components (N-m/m, in-lbf/in in plate and shell analysis)
n_f - number of filaments per unit length per lamina
Q_x, Q_y - shear force parallel to z axis of sections of a plate perpendicular to x and y axes, respectively (N/m,lbf/in)
Q_{ij} (i,j = 1,2,6) - reduced stiffness matrix (Pa,psi)
u_x, u_y, u_z - components of the displacement vector (mm,in)
u_x^o, u_y^o, u_z^o - components of the displacement vector at the laminate's midsurface (mm,in)
V_v - void content (% by volume)
V_f - filament content or fiber volume (% by volume)
V_g - glass scrim cloth content (% by volume)
V_m - matrix content (% by volume)
V_x, V_y - edge or support shear force (N/m,lbf/in)
W_f - filament content (% by weight)
W_g - glass scrim cloth content (% by weight)
W_m - matrix content (% by weight)
W_s - weight of laminate per unit surface area (N/m^2,lbf/in^2)
α_1 - lamina coefficient of thermal expansion along 1 axis (m/m/°C,in/in/°F)
α_2 - lamina coefficient of thermal expansion along 2 axis (m/m/°C,in/in/°F)
α_x - laminate coefficient of thermal expansion along general reference x axis (m/m/°C, in/in/°F)
α_y - laminate coefficient of thermal expansion along general reference y axis (m/m/°C, in/in/°F)
α_{xy} - laminate shear distortion coefficient of thermal expansion (m/m/°C,in/in/°F)
θ - angular orientation of a lamina in a laminate, i.e., angle between 1 and x axes (°)
λ_{xy} - product of ν_{xy} and ν_{yx}
ν_{12} - Poisson's ratio relating contraction in the 2 direction as a result of extension in the 1 direction[1]

[1]The convention for Poisson's ratio should be checked before comparing different sources as different conventions are used.

ν_{21} - Poisson's ratio relating contraction in the 1 direction as a result of extension in the 2 direction[1]

ν_{xy} - Poisson's ratio relating contraction in the y direction as a result of extension in the x direction[1]

ν_{yx} - Poisson's ratio relating contraction in the x direction as a result of extension in the y direction[1]

ρ_c - density of a single lamina (kg/m^3,lb/in^3)

$\overline{\rho}_c$ - density of a laminate (kg/m^3,lb/in^3)

ϕ - (1) general angular coordinate, (°)
- (2) angle between x and load axes in off-axis loading (°)

1.7.1.3 Subscripts

The following subscript notations are considered standard in MIL-HDBK-17.

1, 2, 3 - laminae natural orthogonal coordinates (1 is filament or warp direction)
A - axial
a - (1) adhesive
- (2) alternating
app - apparent
byp - bypass
c - composite system, specific filament/matrix composition. Composite as a whole, contrasted to individual constituents. Also, sandwich core when used in conjunction with prime (')
- (4) critical
cf - centrifugal force
e - fatigue or endurance
eff - effective
eq - equivalent
f - filament
g - glass scrim cloth
H - hoop
i - i^{th} position in a sequence
L - lateral
m - (1) matrix
- (2) mean
max - maximum
min - minimum
n - (1) n^{th} (last) position in a sequence
- (2) normal
p - polar
s - symmetric
st - stiffener
T - transverse
t - value of parameter at time t
x, y, z - general coordinate system
$\sum$ - total, or summation
o - initial or reference datum
( ) - format for indicating specific, temperature associated with term in parentheses. RT - room temperature (21°C,70°F); all other temperatures in °F unless specified.

1.7.1.4 Superscripts

The following superscript notations are considered standard in MIL-HDBK-17.

b - bending

br - bearing
c - (1) compression
- (2) creep
cc - compressive crippling
cr - compressive buckling
e - elastic
f - filament
flex - flexure
g - glass scrim cloth
is - interlaminar shear
(i) - i^{th} ply or lamina
lim - limit, used to indicate limit loading
m - matrix
ohc - open hole compression
oht - open hole tension
p - plastic
pl - proportional limit
rup - rupture
s - shear
scr - shear buckling
sec - secant (modulus)
so - offset shear
T - temperature or thermal
t - tension
tan - tangent (modulus)
u - ultimate
y - yield
' - secondary (modulus), or denotes properties of H/C core when used with subscript c
CAI - compression after impact

1.7.1.5 Acronyms

The following acronyms are used in MIL-HDBK-17.

AA - atomic absorption
AES - Auger electron spectroscopy
AIA - Aerospace Industries Association
AlO - alumina
ANOVA - analysis of variance
Ar - aramid
ARL - US Army Research Laboratory - Materials Directorate
ASTM - American Society for Testing and Materials
B - boron
BMI - bismaleimide
BVID - barely visible impact damage
C - carbon
CAI - compression after impact
CCA - composite cylinder assemblage
CE - cyanate ester
CFRP - carbon fiber reinforced plastic
CLS - crack lap shear
CMCS - Composite Motorcase Subcommittee (JANNAF)
CPT - cured ply thickness
CTA - cold temperature ambient
CTD - cold temperature dry
CTE - coefficient of thermal expansion

CV - coefficient of variation
CVD - chemical vapor deposition!
DCB - double cantilever beam
DDA - dynamic dielectric analysis
DGl - D-glass
DLL - design limit load
DMA - dynamic mechanical analysis
DOD - Department of Defense
DSC - differential scanning calorimetry
DTA - differential thermal analysis
DTRC - David Taylor Research Center
EGl - E-glass
ENF - end notched flexure
EOL - end-of-life
EP - epoxy
ESCA - electron spectroscopy for chemical analysis
ESR - electron spin resonance
ETW - elevated temperature wet
FAA - Federal Aviation Administration
FC - fluorocarbon
FFF - field flow fractionation
FGRP - fiberglass reinforced plastic
FMECA - Failure Modes Effects Criticality Analysis
FOD - foreign object damage
FTIR - Fourier transform infrared spectroscopy
FWC - finite width correction factor
GC - gas chromatography
Gl - glass
Gr - graphite
GSCS - Generalized Self Consistent Scheme
HDT - heat distortion temperature
HPLC - high performance liquid chromatography
ICAP - inductively coupled plasma emission
IITRI - Illinois Institute of Technology Research Institute
IR - infrared spectroscopy
ISS - ion scattering spectroscopy
JANNAF - Joint Army, Navy, NASA, and Air Force
LC - liquid chromatography
Li - lithium
LPT - laminate plate theory
LSS - laminate stacking sequence
MMB - mixed mode bending
MOL - material operational limit
MS - mass spectroscopy
MSDS - material safety data sheet
MTBF - Mean Time Between Failure
NAS - National Aerospace Standard
NASA - National Aeronautics and Space Administration
NDI - nondestructive inspection
NMR - nuclear magnetic resonance
P - phenolic
PAI - polyamide-imide
PAN - polyacrylonitrile
PBI - polybenzimidazole
PBT - polybenzothiazole
PEEK - polyether ether ketone

PEI - polyetherimide
PES - polyethersulfone
PI - polyimide
PPS - polyphenylene sulfide
PSU - polysulfone
Q - quartz
RDS - rheological dynamic spectroscopy
RH - relative humidity
RT - room temperature
RTA - room temperature ambient
RTD - room temperature dry
RTM - resin transfer molding
SACMA - Suppliers of Advanced Composite Materials Association
SAE - Society of Automotive Engineers
SANS - small-angle neutron scattering spectroscopy
SEC - size-exclusion chromatography
SEM - scanning electron microscopy
SFC - supercritical fluid chromatography
Si - silicon
SI - International System of Units (Le Système International d'Unités)
SiC - silicon carbide
SGl - S-glass
SIMS - secondary ion mass spectroscopy
TBA - torsional braid analysis
TEM - transmission electron microscopy
TGA - thermogravimetric analysis
Ti - titanium
TLC - thin-layer chromatography
TMA - thermal mechanical analysis
TOS - thermal oxidative stability
TPES - thermoplastic polyester
TVM - transverse microcrack
UDC - unidirectional fiber composite
VNB - V-notched beam
W - tungsten
XPS - X-ray photoelectron spectroscopy

1.7.2 System of units

To comply with Department of Defense Instructive 5000.2, Part 6, Section M, "Use of the Metric System," dated February 23, 1991, the data in MIL-HDBK-17 are generally presented in both the International System of Units (SI units) and the U. S. Customary (English) system of units. ASTM E 380, Standard for Metric Practice, provides guidance for the application for SI units which are intended as a basis for world-wide standardization of measurement units (Reference 1.7.2(a)). Further guidelines on the use of the SI system of units and conversion factors are contained in the following publications (References 1.7.2(b) - (e)):

(1) DARCOM P 706-470, *Engineering Design Handbook: Metric Conversion Guide*, July 1976.

(2) NBS Special Publication 330, "The International System of Units (SI)," National Bureau of Standards, 1986 edition.

(3) NBS Letter Circular LC 1035, "Units and Systems of Weights and Measures, Their Origin, Development, and Present Status," National Bureau of Standards, November 1985.

(4) NASA Special Publication 7012, "The International System of Units Physical Constants and Conversion Factors", 1964.

English to SI conversion factors pertinent to MIL-HDBK-17 data are contained in Table 1.7.2.

TABLE 1.7.2 *English to SI conversion factors.*

To convert from	to	Multiply by
Btu (thermochemical)/in^2-s	watt/meter^2 (W/m^2)	1.634 246 E+06
Btu-in/(s-ft^2-°F)	W/(m K)	5.192 204 E+02
degree Fahrenheit	degree Celsius (°C)	T = (T - 32)/1.8
degree Fahrenheit	kelvin (K)	T = (T + 459.67)/1.8
foot	meter (m)	3.048 000 E-01
ft^2	m^2	9.290 304 E-02
foot/second	meter/second (m/s)	3.048 000 E-01
ft/s^2	m/s^2	3.048 000 E-01
inch	meter (m)	2.540 000 E-02
in.^{2}	meter^2 (m^2)	6.451 600 E-04
in.^{3}	m^3	1.638 706 E-05
kilogram-force (kgf)	newton (N)	9.806 650 E+00
kgf/m^2	pascal (Pa)	9.806 650 E+00
kip (1000 lbf)	newton (N)	4.448 222 E+03
ksi (kip/in^2)	MPa	6.894 757 E+00
lbf-in	N-m	1.129 848 E-01
lbf-ft	N-m	1.355 818 E+00
lbf/in^2 (psi)	pascal (Pa)	6.894 757 E+03
lb/in^2	gm/m^2	7.030 696 E+05
lb/in^3	kg/m^3	2.767 990 E+04
Msi (10^6 psi)	GPa	6.894 757 E+00
pound-force (lbf)	newton (N)	4.488 222 E+00
pound-mass (lb avoirdupois)	kilogram (kg)	4.535 924 E-01
torr	pascal (Pa)	1.333 22 E+02

* The letter "E" following the conversion factor stands for exponent and the two digits after the letter "E" indicate the power of 10 by which the number is to be multiplied.

1.8 DEFINITIONS

The following definitions are used within MIL-HDBK-17. This glossary of terms is not totally comprehensive but it does represent nearly all commonly used terms. Where exceptions are made, they are noted in the text and tables. For ease of identification the definitions have been organized alphabetically.

A-Basis (or A-Value) -- A statistically-based material property; a 95% lower confidence bound on the first percentile of a specified population of measurements. Also a 95% lower tolerance bound for the upper 99% of a specified population.

A-Stage -- An early stage in the reaction of thermosetting resins in which the material is still soluble in certain liquids and may be liquid or capable of becoming liquid upon heating. (Sometimes referred to as **resol**.)

Absorption -- A process in which one material (the absorbent) takes in or absorbs another (the absorbate).

Accelerator -- A material which, when mixed with a catalyzed resin, will speed up the chemical reaction between the catalyst and the resin.

Accuracy -- The degree of conformity of a measured or calculated value to some recognized standard or specified value. Accuracy involves the systematic error of an operation.

Addition Polymerization -- Polymerization by a repeated addition process in which monomers are linked together to form a polymer without splitting off of water or other simple molecules.

Adhesion -- The state in which two surfaces are held together at an interface by forces or interlocking action or both.

Adhesive -- A substance capable of holding two materials together by surface attachment. In the handbook, the term is used specifically to designate structural adhesives, those which produce attachments capable of transmitting significant structural loads.

ADK -- Notation used for the k-sample Anderson-Darling statistic, which is used to test the hypothesis that k batches have the same distribution.

Aliquot -- A small, representative portion of a larger sample.

Aging -- The effect, on materials, of exposure to an environment for a period of time; the process of exposing materials to an environment for an interval of time.

Ambient -- The surrounding environmental conditions such as pressure or temperature.

Anelasticity -- A characteristic exhibited by certain materials in which strain is a function of both stress and time, such that, while no permanent deformations are involved, a finite time is required to establish equilibrium between stress and strain in both the loading and unloading directions.

Angleply -- Same as **Crossply**.

Anisotropic -- Not isotropic; having mechanical and/or physical properties which vary with direction relative to natural reference axes inherent in the material.

Aramid -- A manufactured fiber in which the fiber-forming substance consisting of a long-chain synthetic aromatic polyamide in which at least 85% of the amide (-CONH-) linkages are attached directly to two aromatic rings.

Areal Weight of Fiber -- The weight of fiber per unit area of prepreg. This is often expressed as grams per square meter. See Table 1.7.2 for conversion factors.

Artificial Weathering -- Exposure to laboratory conditions which may be cyclic, involving changes in temperature, relative humidity, radiant energy and any other elements found in the atmosphere in various geographical areas.

Aspect Ratio -- In an essentially two-dimensional rectangular structure (e.g., a panel), the ratio of the long dimension to the short dimension. However, in compression loading, it is sometimes considered to

be the ratio of the load direction dimension to the transverse dimension. Also, in fiber micro-mechanics, it is referred to as the ratio of length to diameter.

Autoclave -- A closed vessel for producing an environment of fluid pressure, with or without heat, to an enclosed object which is undergoing a chemical reaction or other operation.

Autoclave Molding -- A process similar to the pressure bag technique. The lay-up is covered by a pressure bag, and the entire assembly is placed in an autoclave capable of providing heat and pressure for curing the part. The pressure bag is normally vented to the outside.

Axis of Braiding -- The direction in which the braided form progresses.

B-Basis (or B-Value) -- A statistically-based material property; a 95% lower confidence bound on the tenth percentile of a specified population of measurements. Also a 95% lower tolerance bound for the upper 90% of a specified population. (See Volume 1, Section 8.1.4)

B-Stage -- An intermediate stage in the reaction of a thermosetting resin in which the material softens when heated and swells when in contact with certain liquids but does not entirely fuse or dissolve. Materials are usually precured to this stage to facilitate handling and processing prior to final cure. (Sometimes referred to as **resitol**.)

Bag Molding -- A method of molding or laminating which involves the application of fluid pressure to a flexible material which transmits the pressure to the material being molded or bonded. Fluid pressure usually is applied by means of air, steam, water or vacuum.

Balanced Laminate -- A composite laminate in which all identical laminae at angles other than 0 degrees and 90 degrees occur only in ± pairs (not necessarily adjacent).

Batch (or Lot) -- For fibers and resins, a quantity of material formed during the same process and having identical characteristics throughout. For prepregs, laminae, and laminates, material made from one batch of fiber and one batch of resin.

Bearing Area -- The product of the pin diameter and the specimen thickness.

Bearing Load -- A compressive load on an interface.

Bearing Yield Strength -- The bearing stress at which a material exhibits a specified limiting deviation from the proportionality of bearing stress to bearing strain.

Bend Test -- A test of ductility by bending or folding, usually with steadily applied forces. In some instances the test may involve blows to a specimen having a cross section that is essentially uniform over a length several times as great as the largest dimension of the cross section.

Binder -- A bonding resin used to hold strands together in a mat or preform during manufacture of a molded object.

Binomial Random Variable -- The number of successes in independent trials where the probability of success is the same for each trial.

Birefringence -- The difference between the two principal refractive indices (of a fiber) or the ratio between the retardation and thickness of a material at a given point.

Bleeder Cloth -- A nonstructural layer of material used in the manufacture of composite parts to allow the escape of excess gas and resin during cure. The bleeder cloth is removed after the curing process and is not part of the final composite.

Bobbin -- A cylinder or slightly tapered barrel, with or without flanges, for holding tows, rovings, or yarns.

Bond -- The adhesion of one surface to another, with or without the use of an adhesive as a bonding agent.

Braid -- A system of three or more yarns which are interwoven in such a way that no two yarns are twisted around each other.

Braid Angle -- The acute angle measured from the axis of braiding.

Braid, Biaxial -- Braided fabric with two-yarn systems, one running in the $+\theta$ direction, the other in the $-\theta$ direction as measured from the axis of braiding.

Braid Count -- The number of braiding yarn crossings per inch measured along the axis of a braided fabric.

Braid, Diamond -- Braided fabric with an over one, under one weave pattern, (1 x 1).

Braid, Flat -- A narrow bias woven tape wherein each yarn is continuous and is intertwined with every other yarn in the system without being intertwined with itself.

Braid, Hercules -- A braided fabric with an over three, under three weave pattern, (3 x 3).

Braid, Jacquard -- A braided design made with the aid of a jacquard machine, which is a shedding mechanism by means of which a large number of ends may be controlled independently and complicated patterns produced.

Braid, Regular -- A braided fabric with an over two, under two weave pattern (2 x 2).

Braid, Square -- A braided pattern in which the yarns are formed into a square pattern.

Braid, Two-Dimensional -- Braided fabric with no braiding yarns in the through thickness direction.

Braid, Three-Dimensional -- Braided fabric with one or more braiding yarns in the through thickness direction.

Braid, Triaxial -- A biaxial braided fabric with laid in yarns running in the axis of braiding.

Braiding -- A textile process where two or more strands, yarns or tapes are intertwined in the bias direction to form an integrated structure.

Broadgoods -- A term loosely applied to prepreg material greater than about 12 inches in width, usually furnished by suppliers in continuous rolls. The term is currently used to designate both collimated uniaxial tape and woven fabric prepregs.

Buckling (Composite) -- A mode of structural response characterized by an out-of-plane material deflection due to compressive action on the structural element involved. In advanced composites, buckling may take the form not only of conventional general instability and local instability but also a micro-instability of individual fibers.

Bundle -- A general term for a collection of essentially parallel filaments or fibers.

C-Stage -- The final stage of the curing reaction of a thermosetting resin in which the material has become practically infusable and insoluble. (Normally considered fully cured and sometimes referred to as **resite**.)

Capstan -- A friction type take-up device which moves braided fabric away from the fell. The speed of which determines the braid angle.

Carbon Fibers -- Fibers produced by the pyrolysis of organic precursor fibers such as rayon, polyacrylonitrile (PAN), and pitch in an inert atmosphere. The term is often used interchangeably with "graphite"; however, carbon fibers and graphite fibers differ in the temperature at which the fibers are made and heat-treated, and the amount of carbon produced. Carbon fibers typically are carbonized at about 2400°F (1300°C) and assay at 93 to 95% carbon, while graphite fibers are graphitized at 3450 to 5450°F (1900 to 3000°C) and assay at more than 99% elemental carbon.

Carrier -- A mechanism for carrying a package of yarn through the braid weaving motion. A typical carrier consists of a bobbin spindle, a track follower, and a tensioning device.

Caul Plates -- Smooth metal plates, free of surface defects, the same size and shape as a composite lay-up, used immediately in contact with the lay-up during the curing process to transmit normal pressure and to provide a smooth surface on the finished laminate.

Censoring -- Data is right (left) censored at M, if, whenever an observation is less than or equal to M (greater than or equal to M), the actual value of the observation is recorded. If the observation exceeds (is less than) M, the observation is recorded as M.

Chain-Growth Polymerization -- One of the two principal polymerization mechanisms. In chain-growth polymerization, the reactive groups are continuously regenerated during the growth process. Once started, the polymer molecule grows rapidly by a chain of reactions emanating from a particular reactive initiator which may be a free radical, cation or anion.

Chromatogram -- A plot of detector response against peak volume of solution (eluate) emerging from the system for each of the constituents which have been separated.

Circuit -- One complete traverse of the fiber feed mechanism of a winding machine; one complete traverse of a winding band from one arbitrary point along the winding path to another point on a plane through the starting point and perpendicular to the axis.

Cocuring -- The act of curing a composite laminate and simultaneously bonding it to some other prepared surface during the same cure cycle (see **Secondary Bonding**).

Coefficient of Linear Thermal Expansion -- The change in length per unit length resulting from a one-degree rise in temperature.

Coefficient of Variation -- The ratio of the population (or sample) standard deviation to the population (or sample) mean.

Collimated -- Rendered parallel.

Compatible -- The ability of different resin systems to be processed in contact with each other without degradation of end product properties. (See **Compatible**, Volume 1, Section 8.1.4)

Composite Class -- As used in the handbook, a major subdivision of composite construction in which the class is defined by the fiber system and the matrix class, e.g., organic-matrix filamentary laminate.

Composite Material -- Composites are considered to be combinations of materials differing in composition or form on a macroscale. The constituents retain their identities in the composite; that is, they do not dissolve or otherwise merge completely into each other although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another.

Compound -- An intimate mixture of polymer or polymers with all the materials necessary for the finished product.

Condensation Polymerization -- This is a special type of step-growth polymerization characterized by the formation of water or other simple molecules during the stepwise addition of reactive groups.

Confidence Coefficient -- See **Confidence Interval**.

Confidence Interval -- A confidence interval is defined by a statement of one of the following forms:

(1) $P\{a<\theta\} \# 1-\alpha$
(2) $P\{\theta<b\} \# 1-\alpha$
(3) $P\{a<\theta<b\} \# 1-\alpha$

where $1-\alpha$ is called the confidence coefficient. A statement of type (1) or (2) is called a one-sided confidence interval and a statement of type (3) is called a two-sided confidence interval. In (1) a is a lower confidence limit and in (2) b is an upper confidence limit. With probability at least $1-\alpha$, the confidence interval will contain the parameter θ.

Constituent -- In general, an element of a larger grouping. In advanced composites, the principal constituents are the fibers and the matrix.

Continuous Filament -- A yarn or strand in which the individual filaments are substantially the same length as the strand.

Coupling Agent -- Any chemical substance designed to react with both the reinforcement and matrix phases of a composite material to form or promote a stronger bond at the interface. Coupling agents are applied to the reinforcement phase from an aqueous or organic solution or from a gas phase, or added to the matrix as an integral blend.

Coverage -- The measure of the fraction of surface area covered by the braid.

Crazing -- Apparent fine cracks at or under the surface of an organic matrix.

Creel -- A framework arranged to hold tows, rovings, or yarns so that many ends can be withdrawn smoothly and evenly without tangling.

Creep -- The time dependent part of strain resulting from an applied stress.

Creep, Rate Of -- The slope of the creep-time curve at a given time.

Crimp -- The undulations induced into a braided fabric via the braiding process.

Crimp Angle -- The maximum acute angle of a single braided yarn's direction measured from the average axis of tow.

Crimp Exchange -- The process by which a system of braided yarns reaches equilibrium when put under tension or compression.

Critical Value(s) -- When testing a one-sided statistical hypothesis, a critical value is the value such that, if the test statistic is greater than (less than) the critical value, the hypothesis is rejected. When testing a two-sided statistical hypothesis, two critical values are determined. If the test statistic is either less than the smaller critical value or greater than the larger critical value, then the hypothesis is rejected. In both cases, the critical value chosen depends on the desired risk (often 0.05) of rejecting the hypothesis when it is true.

Crossply -- Any filamentary laminate which is not uniaxial. Same as Angleply. In some references, the term crossply is used to designate only those laminates in which the laminae are at right angles to one another, while the term angleply is used for all others. In the handbook, the two terms are used synonymously. The reservation of a separate terminology for only one of several basic orientations is unwarranted because a laminate orientation code is used.

Cumulative Distribution Function -- See Volume 1, Section 8.1.4.

Cure -- To change the properties of a thermosetting resin irreversibly by chemical reaction, i.e., condensation, ring closure, or addition. Cure may be accomplished by addition of curing (cross-linking) agents, with or without catalyst, and with or without heat. Cure may occur also by addition, such as occurs with anhydride cures for epoxy resin systems.

Cure Cycle -- The schedule of time periods at specified conditions to which a reacting thermosetting material is subjected in order to reach a specified property level.

Cure Stress -- A residual internal stress produced during the curing cycle of composite structures. Normally, these stresses originate when different components of a lay-up have different thermal coefficients of expansion.

Debond -- A deliberate separation of a bonded joint or interface, usually for repair or rework purposes. (See **Disbond, Unbond**).

Deformation -- The change in shape of a specimen caused by the application of a load or force.

Degradation -- A deleterious change in chemical structure, physical properties or appearance.

Delamination -- The separation of the layers of material in a laminate. This may be local or may cover a large area of the laminate. It may occur at any time in the cure or subsequent life of the laminate and may arise from a wide variety of causes.

Denier -- A direct numbering system for expressing linear density, equal to the mass in grams per 9000 meters of yarn, filament, fiber, or other textile strand.

Density -- The mass per unit volume.

Desorption -- A process in which an absorbed or adsorbed material is released from another material. Desorption is the reverse of absorption, adsorption, or both.

Deviation -- Variation from a specified dimension or requirement, usually defining the upper and lower limits.

Dielectric Constant -- The ratio of the capacity of a condenser having a dielectric constant between the plates to that of the same condenser when the dielectric is replaced by a vacuum; a measure of the electrical charge stored per unit volume at unit potential.

Dielectric Strength -- The average potential per unit thickness at which failure of the dielectric material occurs.

Disbond -- An area within a bonded interface between two adherends in which an adhesion failure or separation has occurred. It may occur at any time during the life of the structure and may arise from a wide variety of causes. Also, colloquially, an area of separation between two laminae in the finished laminate (in this case the term "delamination" is normally preferred.) (See **Debond, Unbond, Delamination**.)

Distribution -- A formula which gives the probability that a value will fall within prescribed limits. (See **Normal**, **Weibull**, and **Lognormal Distributions**, also Volume 1, Section 8.1.4).

Dry -- a material condition of moisture equilibrium with a surrounding environment at 5% or lower relative humidity.

Dry Fiber Area -- Area of fiber not totally encapsulated by resin.

Ductility -- The ability of a material to deform plastically before fracturing.

Elasticity -- The property of a material which allows it to recover its original size and shape immediately after removal of the force causing deformation.

Elongation -- The increase in gage length or extension of a specimen during a tension test, usually expressed as a percentage of the original gage length.

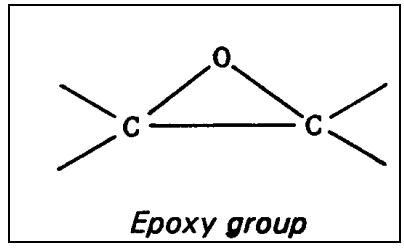
Eluate -- The liquid emerging from a column (in liquid chromatography).

Eluent -- The mobile phase used to sweep or elute the sample (solute) components into, through, and out of the column.

End -- A single fiber, strand, roving or yarn being or already incorporated into a product. An end may be an individual warp yarn or cord in a woven fabric. In referring to aramid and glass fibers, an end is usually an untwisted bundle of continuous filaments.

Epoxy Equivalent Weight -- The number of grams of resin which contain one chemical equivalent of the epoxy group.

Epoxy Resin -- Resins which may be of widely different structures but are characterized by the presence of the epoxy group. (The epoxy or epoxide group is usually present as a glycidyl ether, glycidyl amine, or as part of an aliphatic ring system. The aromatic type epoxy resins are normally used in composites.)



Epoxy group

Extensometer -- A device for measuring linear strain.

F-Distribution -- See Volume 1, Section 8.1.4.

Fabric, Nonwoven -- A textile structure produced by bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, thermal, or solvent means, and combinations thereof.

Fabric, Woven -- A generic material construction consisting of interlaced yarns or fibers, usually a planar structure. Specifically, as used in this handbook, a cloth woven in an established weave pattern from advanced fiber yarns and used as the fibrous constituent in an advanced composite lamina. In a fabric lamina, the warp direction is considered the longitudinal direction, analogous to the filament direction in a filamentary lamina.

Fell -- The point of braid formation, which is defined as the point at which the yarns in a braid system cease movement relative to each other.

Fiber -- A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament. It is a general term for a filament of finite length. A unit of matter, either natural or manmade, which forms the basic element of fabrics and other textile structures.

Fiber Content -- The amount of fiber present in a composite. This is usually expressed as a percentage volume fraction or weight fraction of the composite.

Fiber Count -- The number of fibers per unit width of ply present in a specified section of a composite.

Fiber Direction -- The orientation or alignment of the longitudinal axis of the fiber with respect to a stated reference axis.

Fiber System -- The type and arrangement of fibrous material which comprises the fiber constituent of an advanced composite. Examples of fiber systems are collimated filaments or filament yarns, woven fabric, randomly oriented short-fiber ribbons, random fiber mats, whiskers, etc.

Fiber Volume (Fraction) -- See fiber content.

Filament -- The smallest unit of a fibrous material. The basic units formed during spinning and which are gathered into strands of fiber, (for use in composites). Filaments usually are of extreme length and of very small diameter. Filaments normally are not used individually. Some textile filaments can function as a yarn when they are of sufficient strength and flexibility.

Filamentary Composite -- A composite material reinforced with continuous fibers.

Filament winding -- See **Winding.**

Filament Wound -- Pertaining to an object created by the filament winding method of fabrication.

Fill (Filling) -- In a woven fabric, the yarn running from selvage to selvage at right angles to the warp.

Filler -- A relatively inert substance added to a material to alter its physical, mechanical, thermal, electrical, and other properties or to lower cost. Sometimes the term is used specifically to mean particulate additives.

Finish (or Size System) -- A material, with which filaments are treated, which contains a coupling agent to improve the bond between the filament surface and the resin matrix in a composite material. In addition, finishes often contain ingredients which provide lubricity to the filament surface, preventing abrasive damage during handling, and a binder which promotes strand integrity and facilitates packing of the filaments.

Fixed Effect -- A systematic shift in a measured quantity due to a particular level change of a treatment or condition. (See Volume 1, Section 8.1.4.)

Flash -- Excess material which forms at the parting line of a mold or die, or which is extruded from a closed mold.

Former Plate -- A die attached to a braiding machine which helps to locate the fell.

Fracture Ductility -- The true plastic strain at fracture.

Gage Length -- the original length of that portion of the specimen over which strain or change of length is determined.

Gel -- The initial jelly-like solid phase that develops during formation of a resin from a liquid. Also, a semi-solid system consisting of a network of solid aggregates in which liquid is held.

Gel Coat -- A quick-setting resin used in molding processes to provide an improved surface for the composite; it is the first resin applied to the mold after the mold-release agent.

Gel Point -- The stage at which a liquid begins to exhibit pseudo-elastic properties. (This can be seen from the inflection point on a viscosity-time plot.)

Gel Time -- The period of time from a pre-determined starting point to the onset of gelation (gel point) as defined by a specific test method.

Glass -- An inorganic product of fusion which has cooled to a rigid condition without crystallizing. In the handbook, all reference to glass will be to the fibrous form as used in filaments, woven fabric, yarns, mats, chopped fibers, etc.

Glass Cloth -- Conventionally-woven glass fiber material (see **Scrim**).

Glass Fibers -- A fiber spun from an inorganic product of fusion which has cooled to a rigid condition without crystallizing.

Glass Transition -- The reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one.

Glass Transition Temperature -- The approximate midpoint of the temperature range over which the glass transition takes place.

Graphite Fibers -- See **Carbon Fibers**.

Greige -- Fabric that has received no finish.

Hand Lay-up -- A process in which components are applied either to a mold or a working surface, and the successive plies are built up and worked by hand.

Hardness -- Resistance to deformation; usually measured by indention. Types of standard tests include Brinell, Rockwell, Knoop, and Vickers.

Heat Cleaned -- Glass or other fibers which have been exposed to elevated temperatures to remove preliminary sizings or binders which are not compatible with the resin system to be applied.

Heterogeneous -- Descriptive term for a material consisting of dissimilar constituents separately identifiable; a medium consisting of regions of unlike properties separated by internal boundaries. (Note that all nonhomogeneous materials are not necessarily heterogeneous).

Homogeneous -- Descriptive term for a material of uniform composition throughout; a medium which has no internal physical boundaries; a material whose properties are constant at every point, in other words, constant with respect to spatial coordinates (but not necessarily with respect to directional coordinates).

Horizontal Shear -- Sometimes used to indicate interlaminar shear. This is not an approved term for use in this handbook.

Humidity, Relative -- The ratio of the pressure of water vapor present to the pressure of saturated water vapor at the same temperature.

Hybrid -- A composite laminate comprised of laminae of two or more composite material systems. Or, a combination of two or more different fibers such as carbon and glass or carbon and aramid into a structure (tapes, fabrics and other forms may be combined).

Hygroscopic -- Capable of absorbing and retaining atmospheric moisture.

Hysteresis -- The energy absorbed in a complete cycle of loading and unloading.

Inclusion -- A physical and mechanical discontinuity occurring within a material or part, usually consisting of solid, encapsulated foreign material. Inclusions are often capable of transmitting some structural stresses and energy fields, but in a noticeably different manner from the parent material.

Integral Composite Structure -- Composite structure in which several structural elements, which would conventionally be assembled by bonding or with mechanical fasteners after separate fabrication, are instead laid up and cured as a single, complex, continuous structure; e.g., spars, ribs, and one stiffened cover of a wing box fabricated as a single integral part. The term is sometimes applied more loosely to any composite structure not assembled by mechanical fasteners.

Interface -- The boundary between the individual, physically distinguishable constituents of a composite.

Interlaminar -- Between the laminae of a laminate.

Discussion: describing objects (e.g., voids), events (e.g., fracture), or fields (e.g., stress).

Interlaminar Shear -- Shearing force tending to produce a relative displacement between two laminae in a laminate along the plane of their interface.

Intermediate Bearing Stress -- The bearing stress at the point on the bearing load-deformation curve where the tangent is equal to the bearing stress divided by a designated percentage (usually 4%) of the original hole diameter.

Intralaminar -- Within the laminae of a laminate.

Discussion: describing objects (for example, voids), event (for example, fracture), or fields (for example, stress).

Isotropic -- Having uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing.

Jammed State -- The state of a braided fabric under tension or compression where the deformation of the fabric is dominated by the deformation properties of the yarn.

Knitting -- A method of constructing fabric by interlocking series of loops of one or more yarns.

Knuckle Area -- The area of transition between sections of different geometry in a filament wound part.

k-Sample Data -- A collection of data consisting of values observed when sampling from k batches.

Laid-In Yarns -- A system of longitudinal yarns in a triaxial braid which are inserted between the bias yarns.

Lamina -- A single ply or layer in a laminate.

Discussion: For filament winding, a lamina is a layer.

Laminae -- Plural of lamina.

Laminate -- for fiber-reinforced composites, a consolidated collection of laminae (plies) with one or more orientations with respect to some reference direction.

Laminate Orientation -- The configuration of a crossplied composite laminate with regard to the angles of crossplying, the number of laminae at each angle, and the exact sequence of the lamina lay-up.

Lattice Pattern -- A pattern of filament winding with a fixed arrangement of open voids.

Lay-up -- A process of fabrication involving the assembly of successive layers of resin-impregnated material.

Lognormal Distribution -- A probability distribution for which the probability that an observation selected at random from this population falls between a and b ($0 < a < b < B$) is given by the area under the normal distribution between $\log a$ and $\log b$. The common (base 10) or the natural (base e) logarithm may be used. (See Volume 1, Section 8.1.4.)

Lower Confidence Bound -- See **Confidence Interval**.

Macro -- In relation to composites, denotes the gross properties of a composite as a structural element but does not consider the individual properties or identity of the constituents.

Macrostrain -- The mean strain over any finite gage length of measurement which is large in comparison to the material's interatomic distance.

Mandrel -- A form fixture or male mold used for the base in the production of a part by lay-up, filament winding or braiding.

Mat -- A fibrous material consisting of randomly oriented chopped or swirled filaments loosely held together with a binder.

Material Acceptance -- The testing of incoming material to ensure that it meets requirements.

Material Qualification -- The procedures used to accept a material by a company or organization for production use.

Material System -- A specific composite material made from specifically identified constituents in specific geometric proportions and arrangements and possessed of numerically defined properties.

Material System Class -- As used in this handbook, a group consisting of material systems categorized by the same generic constituent materials, but without defining the constituents uniquely; e.g., the carbon/epoxy class.

Material Variability -- A source of variability due to the spatial and consistency variations of the material itself and due to variation in its processing. (See Volume 1, Section 8.1.4.)

Matrix -- The essentially homogeneous material in which the fiber system of a composite is embedded.

Matrix Content -- The amount of matrix present in a composite expressed either as percent by weight or percent by volume. Discussion: For polymer matrix composites this is called resin content, which is usually expressed as percent by weight

Mean -- See **Sample Mean** and **Population Mean**.

Mechanical Properties -- The properties of a material that are associated with elastic and inelastic reaction when force is applied, or the properties involving the relationship between stress and strain.

Median -- See **Sample Median** and **Population Median**.

Micro -- In relation to composites, denotes the properties of the constituents, i.e., matrix and reinforcement and interface only, as well as their effects on the composite properties.

Microstrain -- The strain over a gage length comparable to the material's interatomic distance.

Modulus, Chord -- The slope of the chord drawn between any two specified points on the stress-strain curve.

Modulus, initial -- The slope of the initial straight portion of a stress-strain curve.

Modulus, Secant -- The slope of the secant drawn from the origin to any specified point on the stress-strain curve.

Modulus, Tangent -- The ratio of change in stress to change in strain derived from the tangent to any point on a stress-strain curve.

Modulus, Young's -- The ratio of change in stress to change in strain below the elastic limit of a material. (Applicable to tension and compression).

Modulus of Rigidity (also Shear Modulus or Torsional Modulus) -- The ratio of stress to strain below the proportional limit for shear or torsional stress.

Modulus of Rupture, in Bending -- The maximum tensile or compressive stress (whichever causes failure) value in the extreme fiber of a beam loaded to failure in bending. The value is computed from the flexure equation:

$$F^b = \frac{Mc}{I} \qquad 1.8(a)$$

where M = maximum bending moment computed from the maximum load and the original moment arm,
c = initial distance from the neutral axis to the extreme fiber where failure occurs,
I = the initial moment of inertia of the cross section about its neutral axis.

Modulus of Rupture, in Torsion -- The maximum shear stress in the extreme fiber of a member of circular cross section loaded to failure in torsion calculated from the equation:

$$F^s = \frac{Tr}{J} \qquad 1.8(b)$$

where T = maximum twisting moment,
r = original outer radius,
J = polar moment of inertia of the original cross section.

Moisture Content -- The amount of moisture in a material determined under prescribed condition and expressed as a percentage of the mass of the moist specimen, i.e., the mass of the dry substance plus the moisture present.

Moisture Equilibrium -- The condition reached by a sample when it no longer takes up moisture from, or gives up moisture to, the surrounding environment.

Mold Release Agent -- A lubricant applied to mold surfaces to facilitate release of the molded article.

Molded Edge -- An edge which is not physically altered after molding for use in final form and particularly one which does not have fiber ends along its length.

Molding -- The forming of a polymer or composite into a solid mass of prescribed shape and size by the application of pressure and heat.

Monolayer -- The basic laminate unit from which crossplied or other laminates are constructed.

Monomer -- A compound consisting of molecules each of which can provide one or more constitutional units.

NDE -- Nondestructive evaluation. Broadly considered synonymous with NDI.

NDI -- Nondestructive inspection. A process or procedure for determining the quality or characteristics of a material, part, or assembly without permanently altering the subject or its properties.

NDT -- Nondestructive testing. Broadly considered synonymous with NDI.

Necking -- A localized reduction in cross-sectional area which may occur in a material under tensile stress.

Negatively Skewed -- A distribution is said to be negatively skewed if the distribution is not symmetric and the longest tail is on the left.

Nominal Specimen Thickness -- The nominal ply thickness multiplied by the number of plies.

Nominal Value -- A value assigned for the purpose of a convenient designation. A nominal value exists in name only.

Normal Distribution -- A two parameter (μ,σ) family of probability distributions for which the probability that an observation will fall between a and b is given by the area under the curve

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2} \right] \qquad 1.8(c)$$

between a and b. (See Volume 1, Section 8.1.4.)

Normalization -- A mathematical procedure for adjusting raw test values for fiber-dominated properties to a single (specified) fiber volume content.

Normalized Stress -- Stress value adjusted to a specified fiber volume content by multiplying the measured stress value by the ratio of specimen fiber volume to the specified fiber volume. This ratio may be obtained directly by experimentally measuring fiber volume, or indirectly by calculation using specimen thickness and fiber areal weight.

Observed Significance Level (OSL) -- The probability of observing a more extreme value of the test statistic when the null hypotheses is true.

Offset Shear Strength --- (from valid execution of a material property shear response test) the value of shear stress at the intersection between a line parallel to the shear chord modulus of elasticity and the shear stress/strain curve, where the line has been offset along the shear strain axis from the origin by a specified strain offset value.

Oligomer -- A polymer consisting of only a few monomer units such as a dimer, trimer, etc., or their mixtures.

One-Sided Tolerance Limit Factor -- See **Tolerance Limit Factor**.

Orthotropic -- Having three mutually perpendicular planes of elastic symmetry.

Oven Dry -- The condition of a material that has been heated under prescribed conditions of temperature and humidity until there is no further significant change in its mass.

PAN Fibers -- Reinforcement fiber derived from the controlled pyrolysis of poly(acrylonitrile) fiber.

Parallel Laminate -- A laminate of woven fabric in which the plies are aligned in the same position as originally aligned in the fabric roll.

Parallel Wound -- A term used to describe yarn or other material wound into a flanged spool.

Peel Ply -- A layer of resin free material used to protect a laminate for later secondary bonding.

pH -- A measure of acidity or alkalinity of a solution, with neutrality represented by a value of 7, with increasing acidity corresponding to progressively smaller values, and increasing alkalinity corresponding to progressively higher values.

Pick Count -- The number of filling yarns per inch or per centimeter of woven fabric.

Pitch Fibers -- Reinforcement fiber derived from petroleum or coal tar pitch.

Plastic -- A material that contains one or more organic polymers of large molecular weight, is solid in its finished state, and, at some state in its manufacture or processing into finished articles, can be shaped by flow.

Plasticizer -- A material of lower molecular weight added to a polymer to separate the molecular chains. This results in a depression of the glass transition temperature, reduced stiffness and brittleness, and improved processability. (Note, many polymeric materials do not need a plasticizer.)

Plied Yarn -- A yarn formed by twisting together two or more single yarns in one operation.

Poisson's Ratio -- The absolute value of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

Polymer -- An organic material composed of molecules characterized by the repetition of one or more types of monomeric units.

Polymerization -- A chemical reaction in which the molecules of monomers are linked together to form polymers via two principal reaction mechanisms. Addition polymerizations proceed by chain growth and most condensation polymerizations through step growth.

Population -- The set of measurements about which inferences are to be made or the totality of possible measurements which might be obtained in a given testing situation. For example, "all possible ultimate tensile strength measurements for carbon/epoxy system A, conditioned at 95% relative humidity and room temperature". In order to make inferences about a population, it is often necessary to make assumptions about its distributional form. The assumed distributional form may also be referred to as the population. (See Volume 1, Section 8.1.4.)

Population Mean -- The average of all potential measurements in a given population weighted by their relative frequencies in the population. (See Volume 1, Section 8.1.4.)

Population Median -- That value in the population such that the probability of exceeding it is 0.5 and the probability of being less than it is 0.5. (See Volume 1, Section 8.1.4.)

Population Variance -- A measure of dispersion in the population.

Porosity -- A condition of trapped pockets of air, gas, or vacuum within a solid material, usually expressed as a percentage of the total nonsolid volume to the total volume (solid plus nonsolid) of a unit quantity of material.

Positively Skewed -- A distribution is said to be positively skewed if the distribution is not symmetric and the longest tail is on the right.

Postcure -- Additional elevated temperature cure, usually without pressure, to increase the glass transition temperature, to improve final properties, or to complete the cure.

Pot Life -- The period of time during which a reacting thermosetting composition remains suitable for its intended processing after mixing with a reaction initiating agent.

Precision -- The degree of agreement within a set of observations or test results obtained. Precision involves repeatability and reproducibility.

Precursor (for Carbon or Graphite Fiber) -- Either the PAN or pitch fibers from which carbon and graphite fibers are derived.

Preform -- An assembly of dry fabric and fibers which has been prepared for one of several different wet resin injection processes. A preform may be stitched or stabilized in some other way to hold its A shape. A commingled preform may contain thermoplastic fibers and may be consolidated by elevated temperature and pressure without resin injection.

Preply -- Layers of prepreg material, which have been assembled according to a user specified stacking sequence.

Prepreg -- Ready to mold or cure material in sheet form which may be tow, tape, cloth, or mat impregnated with resin. It may be stored before use.

Pressure -- The force or load per unit area.

Probability Density Function -- See Volume 1, Section 8.1.4.

Proportional Limit -- The maximum stress that a material is capable of sustaining without any deviation from the proportionality of stress to strain (also known as Hooke's law).

Quasi-Isotropic Laminate -- A balanced and symmetric laminate for which a constitutive property of interest, at a given point, displays isotropic behavior in the plane of the laminate.

Discussion: Common quasi-isotropic laminates are (0/±60)s and (0/±45/90)s.

Random Effect -- A shift in a measured quantity due to a particular level change of an external, usually uncontrollable, factor. (See Volume 1, Section 8.1.4.)

Random Error -- That part of the data variation that is due to unknown or uncontrolled factors and that affects each observation independently and unpredictably. (See Volume 1, Section 8.1.4.)

Reduction of Area -- The difference between the original cross sectional area of a tension test specimen and the area of its smallest cross section, usually expressed as a percentage of the original area.

Refractive Index - The ratio of the velocity of light (of specified wavelength) in air to its velocity in the substance under examination. Also defined as the sine of the angle of incidence divided by the sine of the angle of refraction as light passes from air into the substance.

Reinforced Plastic -- A plastic with relatively high stiffness or very high strength fibers embedded in the composition. This improves some mechanical properties over that of the base resin.

Release Agent -- See **Mold Release Agent**.

Resilience -- A property of a material which is able to do work against restraining forces during return from a deformed condition.

Resin -- An organic polymer or prepolymer used as a matrix to contain the fibrous reinforcement in a composite material or as an adhesive. This organic matrix may be a thermoset or a thermoplastic, and may contain a wide variety of components or additives to influence; handleability, processing behavior and ultimate properties.

Resin Content -- See **Matrix content.**

Resin Starved Area -- Area of composite part where the resin has a non-continuous smooth coverage of the fiber.

Resin System -- A mixture of resin, with ingredients such as catalyst, initiator, diluents, etc. required for the intended processing and final product.

Room Temperature Ambient (RTA) -- 1) an environmental condition of 73±5°F (23±3°C) at ambient laboratory relative humidity; 2) a material condition where, immediately following consolidation/cure, the material is stored at 73±5°F (23±3°C) and at a maximum relative humidity of 60%.

Roving -- A number of strands, tows, or ends collected into a parallel bundle with little or no twist. In spun yarn production, an intermediate state between sliver and yarn.

S-Basis (or S-Value) -- The mechanical property value which is usually the specified minimum value of the appropriate government specification or SAE Aerospace Material Specification for this material.

Sample -- A small portion of a material or product intended to be representative of the whole. Statistically, a sample is the collection of measurements taken from a specified population. (See Volume 1, Section 8.1.4.)

Sample Mean -- The arithmetic average of the measurements in a sample. The sample mean is an estimator of the population mean. (See Volume 1, Section 8.1.4.)

Sample Median -- Order the observation from smallest to largest. Then the sample median is the value of the middle observation if the sample size is odd; the average of the two central observations if n is even. If the population is symmetric about its mean, the sample median is also an estimator of the population mean. (See Volume 1, Section 8.1.4.)

Sample Standard Deviation -- The square root of the sample variance. (See Volume 1, Section 8.1.4.)

Sample Variance -- The sum of the squared deviations from the sample mean, divided by $n-1$. (See Volume 1, Section 8.1.4.)

Sandwich Construction -- A structural panel concept consisting in its simplest form of two relatively thin, parallel sheets of structural material bonded to, and separated by, a relatively thick, light-weight core.

Saturation -- An equilibrium condition in which the net rate of absorption under prescribed conditions falls essentially to zero.

Scrim (also called **Glass Cloth, Carrier**) -- A low cost fabric woven into an open mesh construction, used in the processing of tape or other B-stage material to facilitate handling.

Secondary Bonding -- The joining together, by the process of adhesive bonding, of two or more already-cured composite parts, during which the only chemical or thermal reaction occurring is the curing of the adhesive itself.

Selvage or Selvedge -- The woven edge portion of a fabric parallel to the warp.

Set -- The strain remaining after complete release of the force producing the deformation.

Shear Fracture (for crystalline type materials) -- A mode of fracture resulting from translation along slip planes which are preferentially oriented in the direction of the shearing stress.

Shelf Life -- The length of time a material, substance, product, or reagent can be stored under specified environmental conditions and continue to meet all applicable specification requirements and/or remain suitable for its intended function.

Short Beam Strength (SBS) -- a test result from valid execution of ASTM test method D2344.

Significant -- Statistically, the value of a test statistic is significant if the probability of a value at least as extreme is less than or equal to a predetermined number called the significance level of the test.

Significant Digit -- Any digit that is necessary to define a value or quantity.

Size System -- See **Finish**.

Sizing -- A generic term for compounds which are applied to yarns to bind the fiber together and stiffen the yarn to provide abrasion-resistance during weaving. Starch, gelatin, oil, wax, and man-made polymers such as polyvinyl alcohol, polystyrene, polyacrylic acid, and polyacetatates are employed.

Skewness -- See **Positively Skewed, Negatively Skewed**.

Sleeving -- A common name for tubular braided fabric.

Slenderness Ratio -- The unsupported effective length of a uniform column divided by the least radius of gyration of the cross-sectional area.

Sliver -- A continuous strand of loosely assembled fiber that is approximately uniform in cross-sectional area and has no twist.

Solute -- The dissolved material.

Specific Gravity -- The ratio of the weight of any volume of a substance to the weight of an equal volume of another substance taken as standard at a constant or stated temperature. Solids and liquids are usually compared with water at 39°F (4°C).

Specific Heat -- The quantity of heat required to raise the temperature of a unit mass of a substance one degree under specified conditions.

Specimen -- A piece or portion of a sample or other material taken to be tested. Specimens normally are prepared to conform with the applicable test method.

Spindle -- A slender upright rotation rod on a spinning frame, roving frame, twister or similar machine.

Standard Deviation -- See **Sample Standard Deviation**.

Staple -- Either naturally occurring fibers or lengths cut from filaments.

Step-Growth Polymerization -- One of the two principal polymerization mechanisms. In sep-growth polymerization, the reaction grows by combination of monomer, oligomer, or polymer molecules through the consumption of reactive groups. Since average molecular weight increases with monomer consumption, high molecular weight polymers are formed only at high degrees of conversion.

Strain -- the per unit change, due to force, in the size or shape of a body referred to its original size or shape. Strain is a nondimensional quantity, but it is frequently expressed in inches per inch, meters per meter, or percent.

Strand -- Normally an untwisted bundle or assembly of continuous filaments used as a unit, including slivers, tow, ends, yarn, etc. Sometimes a single fiber or filament is called a strand.

Strength -- the maximum stress which a material is capable of sustaining.

Stress -- The intensity at a point in a body of the forces or components of forces that act on a given plane through the point. Stress is expressed in force per unit area (pounds-force per square inch, megapascals, etc.).

Stress Relaxation -- The time dependent decrease in stress in a solid under given constraint conditions.

Stress-Strain Curve (Diagram) -- A graphical representation showing the relationship between the change in dimension of the specimen in the direction of the externally applied stress and the magnitude of the applied stress. Values of stress usually are plotted as ordinates (vertically) and strain values as abscissa (horizontally).

Structural Element -- a generic element of a more complex structural member (for example, skin, stringer, shear panels, sandwich panels, joints, or splices).

Structured Data -- See Volume 1, Section 8.1.4.

Surfacing Mat -- A thin mat of fine fibers used primarily to produce a smooth surface on an organic matrix composite.

Symmetrical Laminate -- A composite laminate in which the sequence of plies below the laminate midplane is a mirror image of the stacking sequence above the midplane.

Tack -- Stickiness of the prepreg.

Tape -- Prepreg fabricated in widths up to 12 inches wide for carbon and 3 inches for boron. Cross stitched carbon tapes up to 60 inches wide are available commercially in some cases.

Tenacity -- The tensile stress expressed as force per unit linear density of the unstrained specimen i.e., grams-force per denier or grams-force per tex.

Tex -- A unit for expressing linear density equal to the mass or weight in grams of 1000 meters of filament, fiber, yarn or other textile strand.

Thermal Conductivity -- Ability of a material to conduct heat. The physical constant for quantity of heat that passes through unit cube of a substance in unit time when the difference in temperature of two faces is one degree.

Thermoplastic -- A plastic that repeatedly can be softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and when in the softened stage, can be shaped by flow into articles by molding or extrusion.

Thermoset -- A class of polymers that, when cured using heat, chemical, or other means, changes into a substantially infusible and insoluble material.

Tolerance -- The total amount by which a quantity is allowed to vary.

Tolerance Limit -- A lower (upper) confidence limit on a specified percentile of a distribution. For example, the B-basis value is a 95% lower confidence limit on the tenth percentile of a distribution.

Tolerance Limit Factor -- The factor which is multiplied by the estimate of variability in computing the tolerance limit.

Toughness -- A measure of a material's ability to absorb work, or the actual work per unit volume or unit mass of material that is required to rupture it. Toughness is proportional to the area under the load-elongation curve from the origin to the breaking point.

Tow -- An untwisted bundle of continuous filaments. Commonly used in referring to man-made fibers, particularly carbon and graphite fibers, in the composites industry.

Transformation -- A transformation of data values is a change in the units of measurement accomplished by applying a mathematical function to all data values. For example, if the data is given by x, then $y = x + 1$, x , $1/x$, $\log x$, and $\cos x$ are transformations.

Transition, First Order -- A change of state associated with crystallization or melting in a polymer.

Transversely Isotropic -- Descriptive term for a material exhibiting a special case of orthotropy in which properties are identical in two orthotropic dimensions, but not the third; having identical properties in both transverse directions but not the longitudinal direction.

Traveller -- A small piece of the same product (panel, tube, etc.) as the test specimen, used for example to measure moisture content as a result of conditioning.

Twist -- The number of turns about its axis per unit of length in a yarn or other textile strand. It may be expressed as turns per inch (tpi) or turns per centimeter (tpcm).

Twist, Direction of -- The direction of twist in yarns and other textile strands is indicated by the capital letters S and Z. Yarn has S twist if, when held in a vertical position, the visible spirals or helices around its central axis are in the direction of slope of the central portion of the letter S, and Z twist is in the other direction.

Twist Multiplier -- The ratio of turns per inch to the square root of the cotton count.

Typical Basis -- A typical property value is a sample mean. Note that the typical value is defined as the simple arithmetic mean which has a statistical connotation of 50% reliability with a 50% confidence.

Unbond -- An area within a bonded interface between two adherends in which the intended bonding action failed to take place. Also used to denote specific areas deliberately prevented from bonding in order to simulate a defective bond, such as in the generation of quality standards specimens. (See **Disbond, Debond**).

Unidirectional Fiber-Reinforced Composite -- Any fiber-reinforced composite with all fibers aligned in a single direction.

Unit Cell -- The term applied to the path of a yarn in a braided fabric representing a unit cell of a repeating geometric pattern. The smallest element representative of the braided structure.

Unstructured Data -- See Volume 1, Section 8.1.4.

Upper Confidence Limit -- See **Confidence Interval**.

Vacuum Bag Molding -- A process in which the lay-up is cured under pressure generated by drawing a vacuum in the space between the lay-up and a flexible sheet placed over it and sealed at the edges.

Variance -- See **Sample Variance**.

Viscosity -- The property of resistance to flow exhibited within the body of a material.

Void - Any pocket of enclosed gas or near-vacuum within a composite.

Warp -- The longitudinally oriented yarn in a woven fabric (see **Fill**); a group of yarns in long lengths and approximately parallel.

Weibull Distribution (Two-Parameter) -- A probability distribution for which the probability that a randomly selected observation from this population lies between a and b ($0 < a < b < 4$) is given by Equation 1.8(d) where α is called the scale parameter and β is called the shape parameter. (See Volume 1, Section 8.1.4.)

$$\exp\left[-\left(\frac{a}{\alpha}\right)^{\beta}\right] - \exp\left[-\left(\frac{b}{\alpha}\right)^{\beta}\right] \qquad 1.8(d)$$

Wet Lay-up -- A method of making a reinforced product by applying a liquid resin system while or after the reinforcement is put in place.

Wet Strength -- The strength of an organic matrix composite when the matrix resin is saturated with absorbed moisture. (See **Saturation**).

Wet Winding -- A method of filament winding in which the fiber reinforcement is coated with the resin system as a liquid just prior to wrapping on a mandrel.

Whisker -- A short single crystal fiber or filament. Whisker diameters range from 1 to 25 microns, with aspect ratios between 100 and 15,000.

Winding -- A process in which continuous material is applied under controlled tension to a form in a predetermined geometric relationship to make a structure.

Discussion: A matrix material to bind the fibers together may be added before, during or after winding. Filament winding is the most common type.

Work Life -- The period during which a compound, after mixing with a catalyst, solvent, or other compounding ingredient, remains suitable for its intended use.

Woven Fabric Composite -- A major form of advanced composites in which the fiber constituent consists of woven fabric. A woven fabric composite normally is a laminate comprised of a number of laminae, each of which consists of one layer of fabric embedded in the selected matrix material. Individual fabric laminae are directionally oriented and combined into specific multiaxial laminates for application to specific envelopes of strength and stiffness requirements.

Yarn -- A generic term for strands or bundles of continuous filaments or fibers, usually twisted and suitable for making textile fabric.

Yarn, Plied -- Yarns made by collecting two or more single yarns together. Normally, the yarns are twisted together though sometimes they are collected without twist.

Yield Strength -- The stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. (The deviation is expressed in terms of strain such as 0.2 percent for the Offset Method or 0.5 percent for the Total Extension Under Load Method.)

X-Axis -- In composite laminates, an axis in the plane of the laminate which is used as the 0 degree reference for designating the angle of a lamina.

X-Y Plane -- In composite laminates, the reference plane parallel to the plane of the laminate.

Y-Axis -- In composite laminates, the axis in the plane of the laminate which is perpendicular to the x-axis.

Z-Axis -- In composite laminates, the reference axis normal to the plane of the laminate.

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