CHAPTER 1 OBJECTIVES

This handbook documents engineering methodologies for the development of standardized, statistically-based material property data for polymer matrix composite materials. Also provided are data summaries for a number of relevant composite material systems for which available data meets specific MIL-HDBK-17 requirements for publication. Additionally, supporting engineering and manufacturing technologies and common practices related to composite materials are summarized.

1.1 INTRODUCTION

It is generally understood that standardized, statistically-based, material property data are essential to an efficient engineering development process; such data are needed by material suppliers, engineering users, and system end-users alike. Since the inherent properties of materials are independent of specific applications, data development methodologies and material property data are applicable to a wide variety of industries; they also form much of the technical basis for establishment of statistically-based design values acceptable to procuring or certifying agencies.[1] This evaluation of the inherent properties of composite materials, as shown in Figure 1.1, is the focus of MIL-HDBK-17.

While the source and context for much of the handbook has historically come from experience with aerospace flight-critical structures, all transportation industries (aerospace, ground, rail, and marine), whether commercial or military, as well as other applications including general industrial products, will find the handbook useful. Incorporation of additional information related to broader applications is ongoing.

This handbook has been developed and is maintained as a joint effort of the US Department of Defense (DOD) and the US Federal Aviation Administration (FAA). The data contained herein, or appearing as approved items[2] in the minutes of MIL-HDBK-17 coordination group meetings, while not mandatory,, are acceptable for use in the development of structural design values to the FAA and to all branches of the DOD. Note however, that methods for incorporating handbook data into structural design values for specific applications generally require additional procurement or certification agency approval.

1.2 PURPOSE

The primary purpose of MIL-HDBK-17 is the standardization of engineering data development methodologies related to characterization testing, data reduction, and data reporting of properties for polymer matrix composite materials. In support of this objective MIL-HDBK-17 publishes properties on composite material systems for which data meeting specific requirements is available. In addition, MIL-HDBK-17 provides selected guidance on other technical topics related to composites, including material selection, material specification, material processing, design, analysis, quality control and repair of typical polymer matrix composite materials. Thus, MIL-HDBK-17 is published in three volumes, and serves as a source for the following:

- *Volume 1:* Documents material characterization, data development, and methodology guidelines adaptable to a wide variety of needs, as well as specific requirements to be met by data published in the handbook. Most procuring and certifying agencies prefer, and some may require, that composite material systems used in critical applications either be characterized in accordance with Volume 1 guidelines or selected from material systems published in Volume 2.

[1]An example of a procuring agency is a branch of the US Department of Defense (DOD). An example of a certifying agency is an office of the US Federal Aviation Administration (FAA).
[2]Accepted as of the MIL-HDBK-17 Coordination Committee approval date.

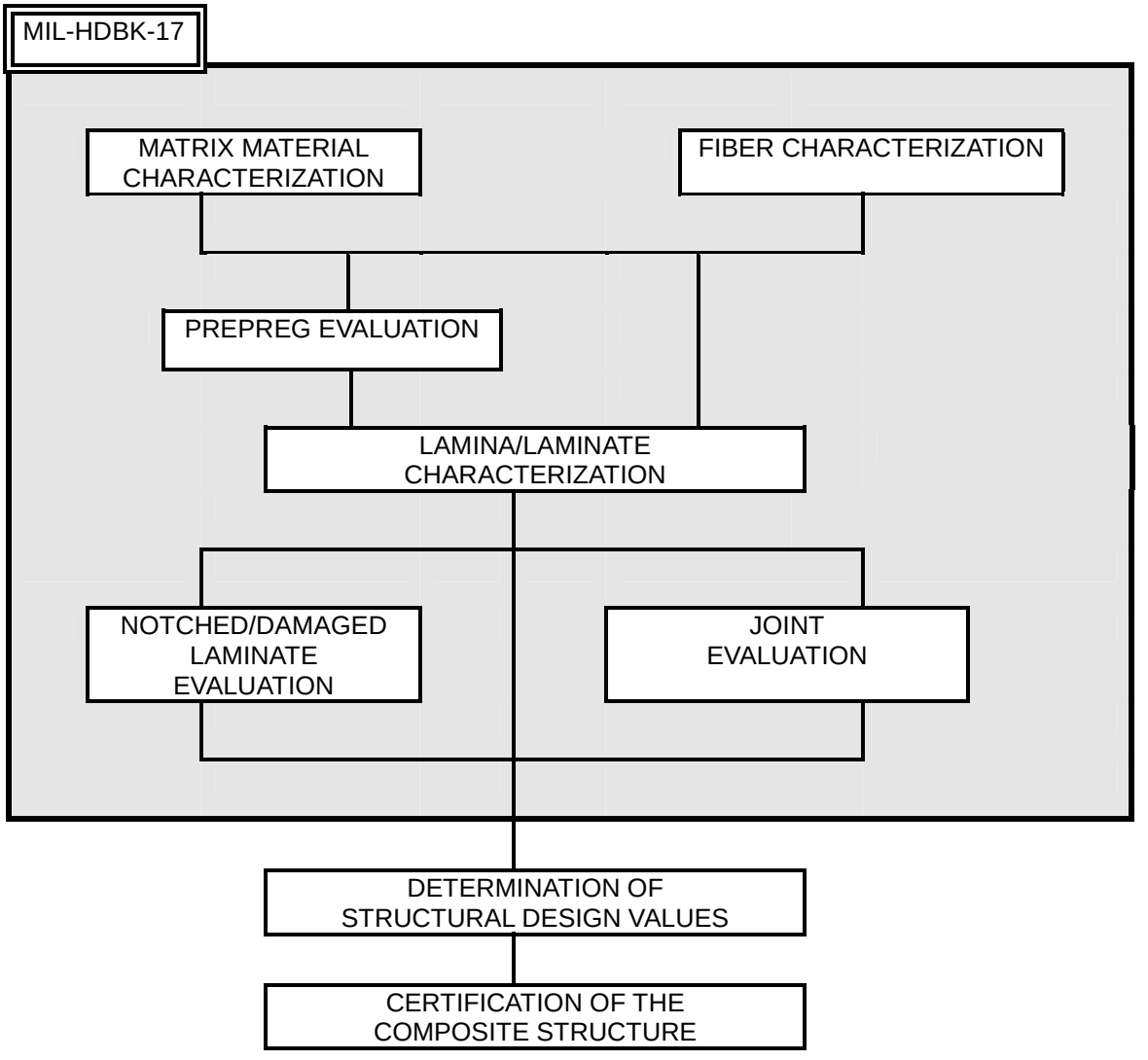


FIGURE 1.1 *Focus of MIL-HDBK-17 indicated by shaded block.*

- *Volume 2:* Provides a repository of potential design data. The documented property summaries for material systems provide data meeting the criteria for any of the MIL-HDBK-17 data classes.
- *Volume 3:* Source for additional technical guidance on a wide variety of disciplines related to polymer matrix composites.

1.3 SCOPE

For Department of Defense purposes, this handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply. This mandate is a DoD requirement only; it is not applicable to the Federal Aviation Administration (FAA) or other government agencies.

The three volumes of MIL-HDBK-17 serve as a general reference source for technical information on polymer matrix composites, including:

1.3.1 Strength properties and allowables data

Statistically-based strength property data are defined for each composite material system over a range of potential usage conditions. The intent is to provide data at the upper and lower limits of the potential environmental conditions for a particular material, so that application issues do not govern the mechanical property characterizations. If data are also available at intermediate environmental conditions, they are used to more exactly define the relationship between the mechanical properties and the effect of the environment on those properties.

The statistically-based strength data that are available are tabulated in Volume 2. These data are useful as a starting point for establishing structural design allowables when stress and strength analysis capabilities permit lamina level margin of safety checks. Where such cases exist, the MIL-HDBK-17 statistically reduced strength data may be used in determining material design allowables. Depending on the application, some structural design allowables will have to be determined empirically by laminate, element, or higher level of testing, since MIL-HDBK-17 does not provide these data.

Additional information and properties are added as they become available and are demonstrated to meet the guideline criteria. Typical property values, as well as S-values (see definitions) are included if they meet the approval of the MIL-HDBK-17 Coordination Group.

When the guidelines or data requirements of MIL-HDBK-17 cannot be followed, the certifying or procuring government agency should be contacted to determine data requirements and other documentation which may be necessary to justify data values proposed or used by the manufacturer.

1.3.2 Volume 1: Guidelines for Characterization of Structural Materials

This volume contains guidelines for determining the properties of composite material systems, their constituents, and generic structural elements, including test planning, test matrices, sampling, conditioning, test procedure selection, data reporting, data reduction, statistical analysis, and other related topics. Special attention is given to the statistical treatment and analysis of data. Volume 1 contains *guidelines* for general development of material characterization data as well as *specific requirements* for publication of material data in MIL-HDBK-17.

It must be emphasized that this handbook differentiates between material basis values (material allowables) and design allowable values. Material basis values, being an intrinsic property of a composite material system, are the focus of this handbook. Design allowable values, while often rooted in material basis values, are application dependent, and consider and include specific additional considerations that may further affect the strength or stiffness of the structure. Also, when establishing application design values there may be additional certification or procurement agency requirements that go beyond MIL-HDBK-17.

1.3.3 Volume 2: Material Properties

Volume 2 contains statistically-based data meeting specific MIL-HDBK-17 population sampling and data documentation requirements, covering constituents and material systems of general interest. Data published in Volume 2 are under the jurisdiction of the Data Review Working Group and are approved by the overall Coordination Group (The MIL-HDBK-17 Coordination Group and Working Groups are discussed in Section 1.5). New material systems will be included and additional material data for existing systems will be added as data becomes available and are approved. Selected historical data from the MIL-HDBK-17A version of the handbook that do not meet current data sampling, test methodology, or documentation requirements, but that still are of potential interest to the industry, are also documented in an appendix to this volume.

The material properties in Volume 2 are defined over a range of potential use conditions, focusing, when possible, on the upper and lower material environmental limits so that application-specific environ-

ments do not limit use of the data. Data at intermediate environmental conditions, when available, provide additional definition of the relation between material response and environment.

While the process of establishing structural design values for specific applications can begin with the data contained in Volume 2, most applications require collection of additional data, especially if there are requirements for data from the laminate or higher structural complexity levels (structural complexity level is discussed in 2.1.2.1). Also, the ability to manufacture material equivalent to that from which the data in Volume 2 were obtained typically must be proven to the procuring or certifying agency, which usually involves limited testing and data comparison. General guidelines for such material/process equivalence evaluation are presented in Volume 1; however, many of the details of such an evaluation remain at the discretion of the procuring or certifying agency.

1.3.4 Volume 3: Materials Usage, Design, and Analysis Guidelines

Volume 3 provides methodologies and lessons learned for the design, manufacture, analysis, and supportability of composite structures, and for utilization of the material data provided in Volume 2 consistent with the guidance provided in Volume 1. Topics discussed in Volume 3 include materials and processing, quality control, design and analysis, joints, reliability, thick composites, and supportability.

1.4 USE OF THE DOCUMENT AND LIMITATIONS

1.4.1 Roadmaps for use of Volumes 1 - 3

The following pages provide summary roadmaps that are intended to be brief guides to relevant sections of this document pertaining to the following topics. The roadmaps are brief guides to the handbook, and while they indicate a general process flow for the topics, they do not show the detailed process flows, interactions and loops that are required in the actual process implementation. In some cases there are overlaps between the various roadmaps. Some minor sections have not been included; for these the reader is referred to the complete handbook table of contents.

Roadmap #1: Use of New Material in Design and Structural Substantiation

This roadmap covers the qualification of a new material, development of material allowables and structural design values, and designing, analyzing and certifying a structure with the new material. This roadmap would be typically used by a design organization.

Roadmap #2: Qualification of New Material

This roadmap covers the process for qualifying a new material and establishing the corresponding material procurement specification. This roadmap would be typically used by an design organization.

Roadmap #3: Development of Lamina Allowables

This roadmap covers the process for developing lamina level material allowables for a material. This roadmap could be used by a material supplier who wishes to provide allowables to customers or by a design organization.

Roadmap #4: Development of Data for New Material for Submittal to Volume 2

This roadmap covers the process for developing material data for submittal to the Handbook for the calculation of material properties and allowables, and subsequent publication in Volume 2. This roadmap could be used by a material supplier or by a design organization.

Roadmap #5: Use of Volume 2 Data for Design and Structural Substantiation

This roadmap covers the process for obtaining Volume 2 data, and for performing "equivalency" testing to validate use of the material in the manufacturer's fabrication process.

Roadmap #6: Demonstration of Equivalency for Revised Material and/or Process

This roadmap covers the process for demonstrating the "equivalency" of a minor change to a material or to a part fabrication process. This roadmap could be used by a material supplier or by a design organization.

Roadmap #7: Demonstration of Application Acceptance for "2nd Source" Material

This roadmap covers the process for demonstrating the acceptability of substituting a new material for the original material used to design and certify a part. "New" material refers to a different fiber or resin material, or to a major change to the original material. This roadmap would be typically used by an design organization.

Roadmap #8: Bolted Joint Tests and Analysis Methods

This roadmap covers development of allowables and design values for, and the design and analysis of bolted joints.

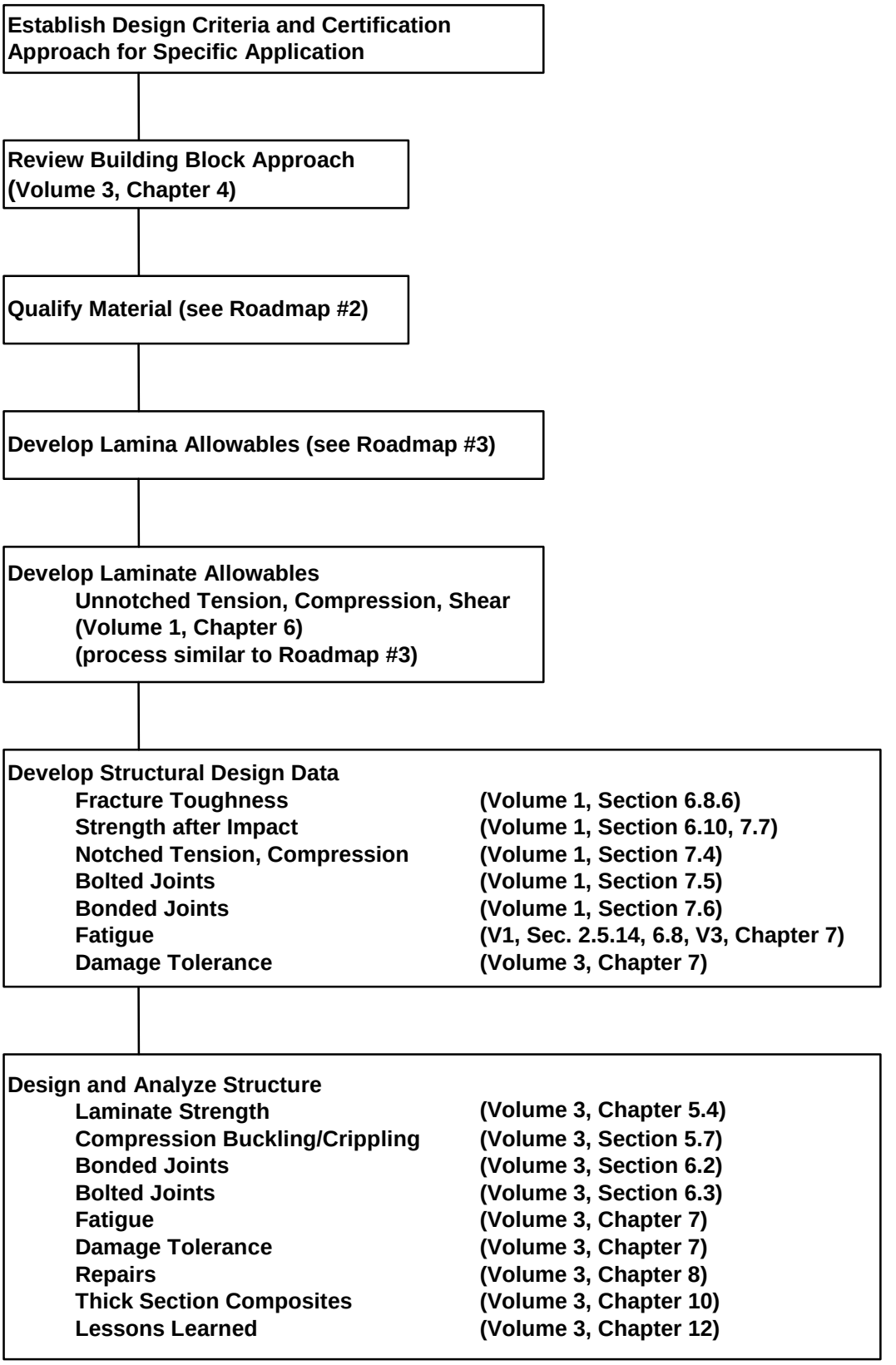
Roadmap #9: Bonded Joint Tests and Analysis Methods

This roadmap covers development of allowables and design values for, and the design and analysis of bonded joints.

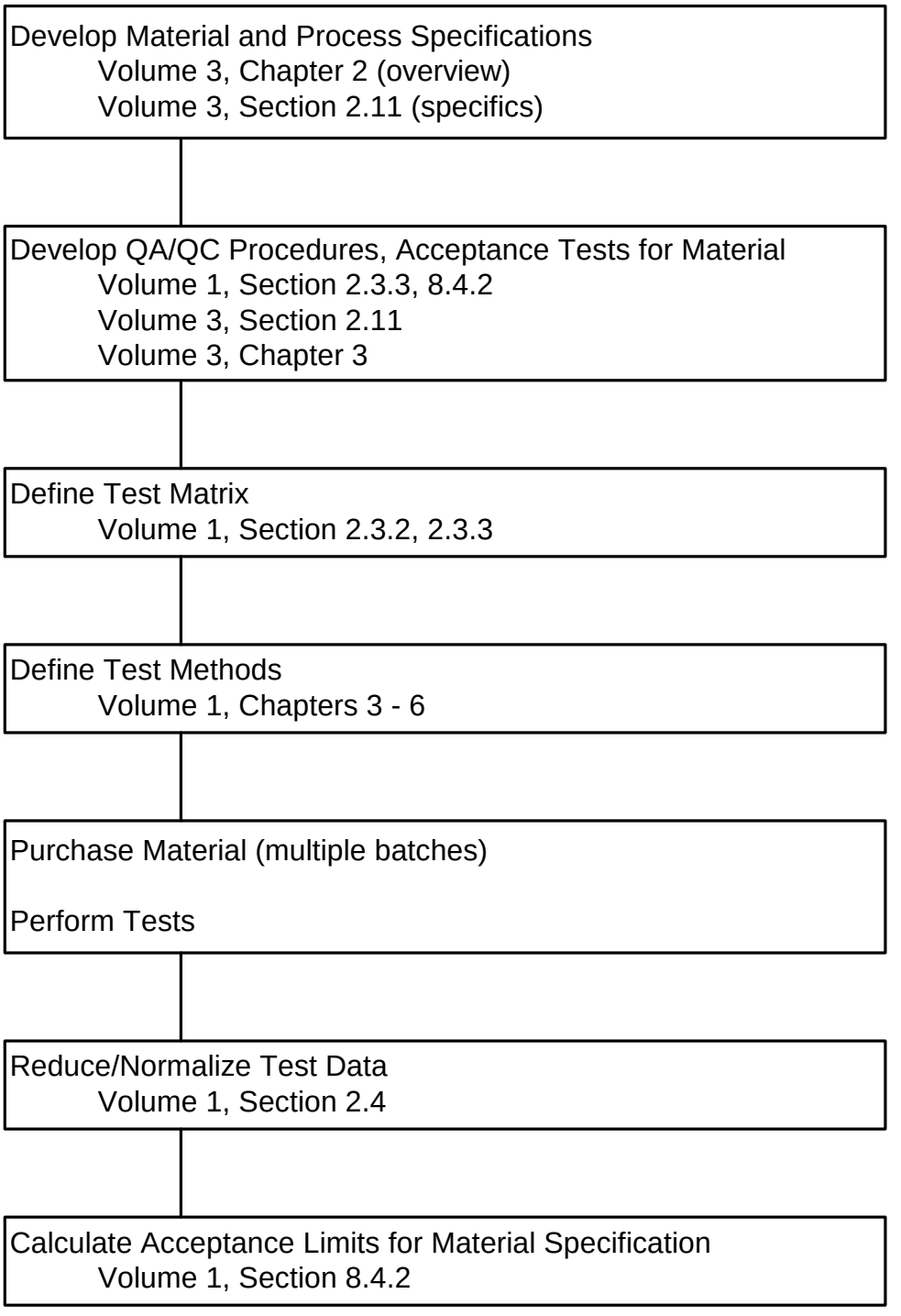
Roadmap #10: Design, Analysis and Fabrication of Repairs

This roadmap covers development of allowables and design values for, the design and analysis, and the fabrication of repairs to composite laminates.

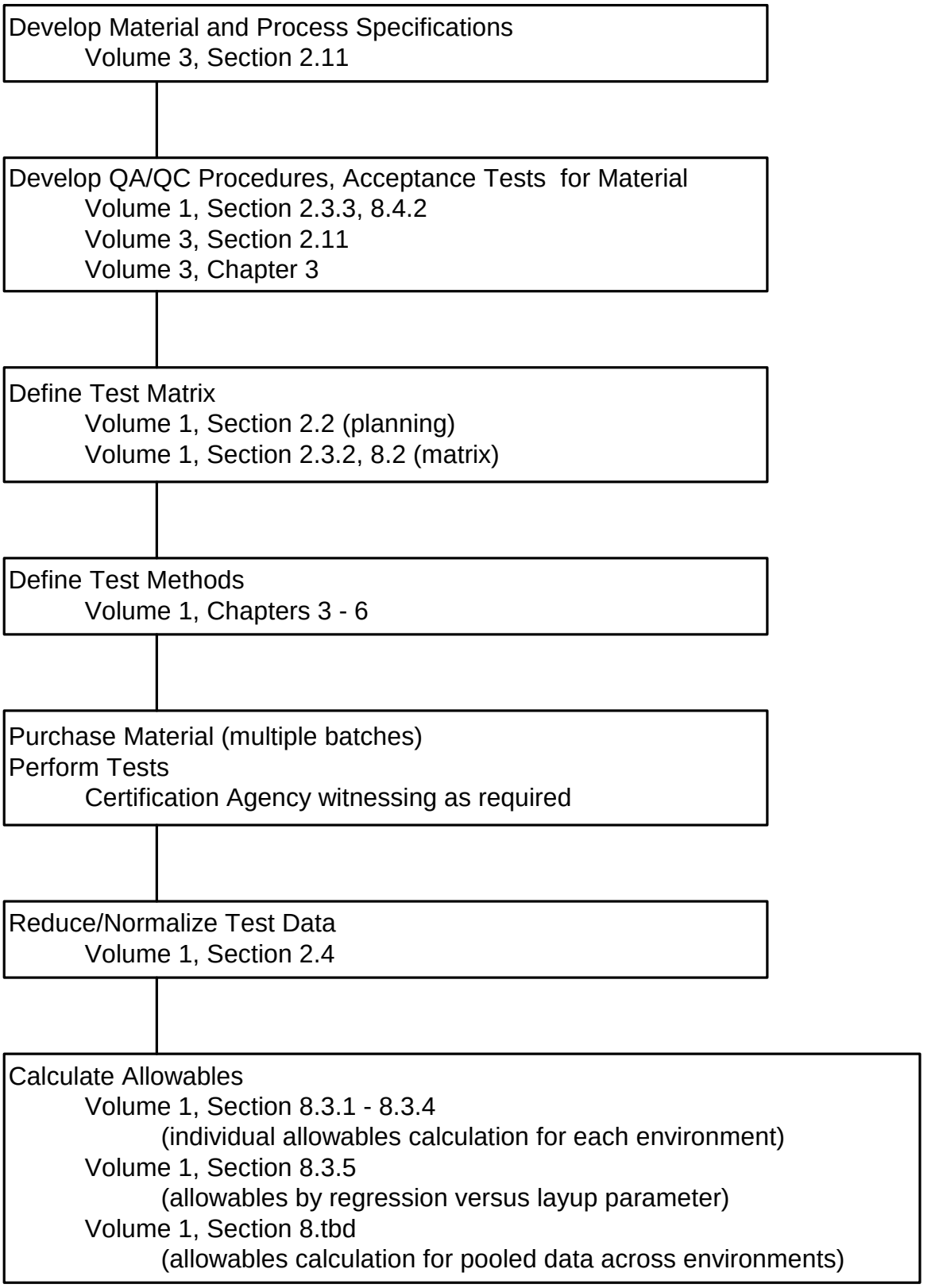
Roadmap #1: Use of New Material in Design and Structural Substantiation



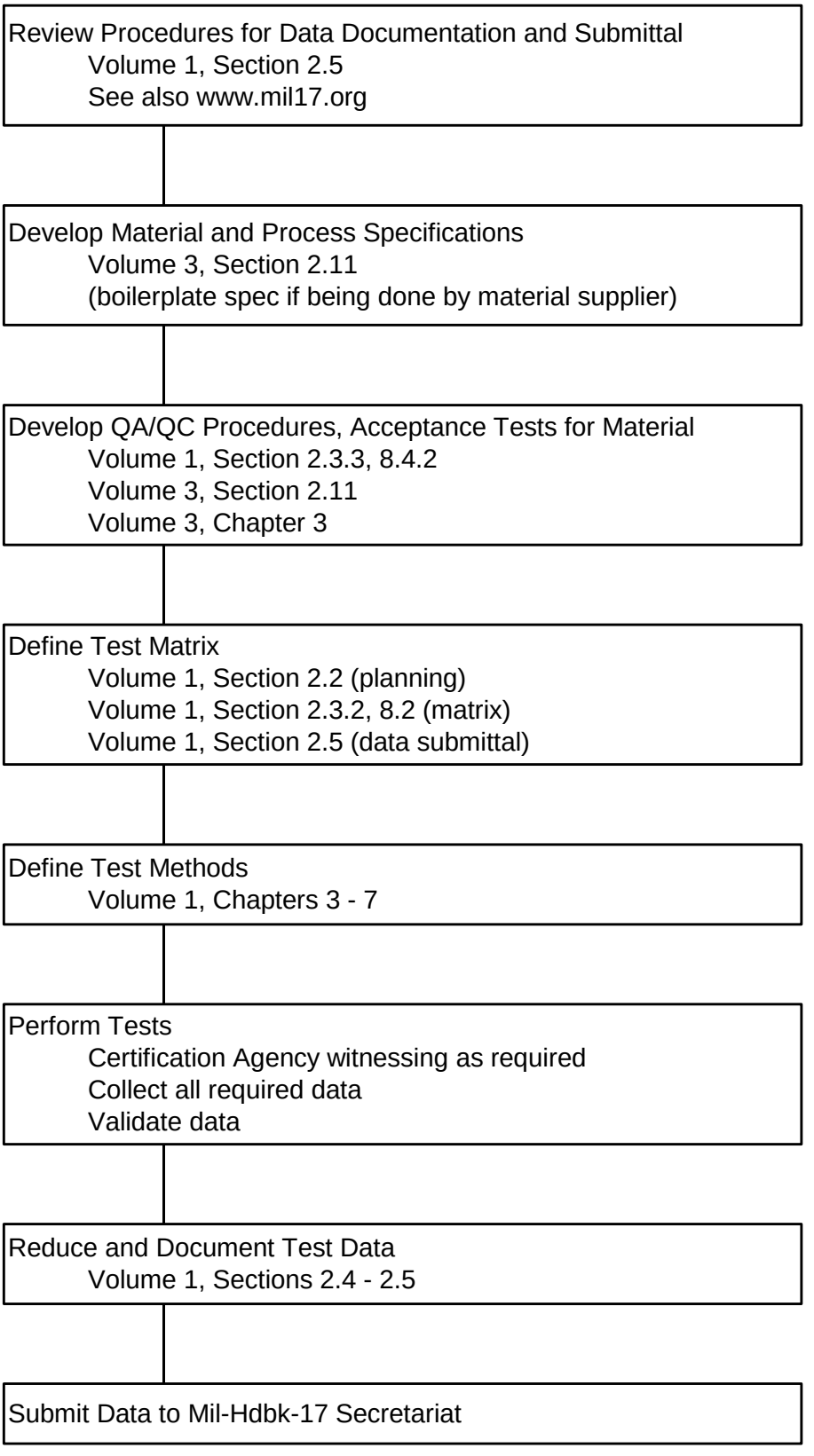
Roadmap #2: Qualification of New Material



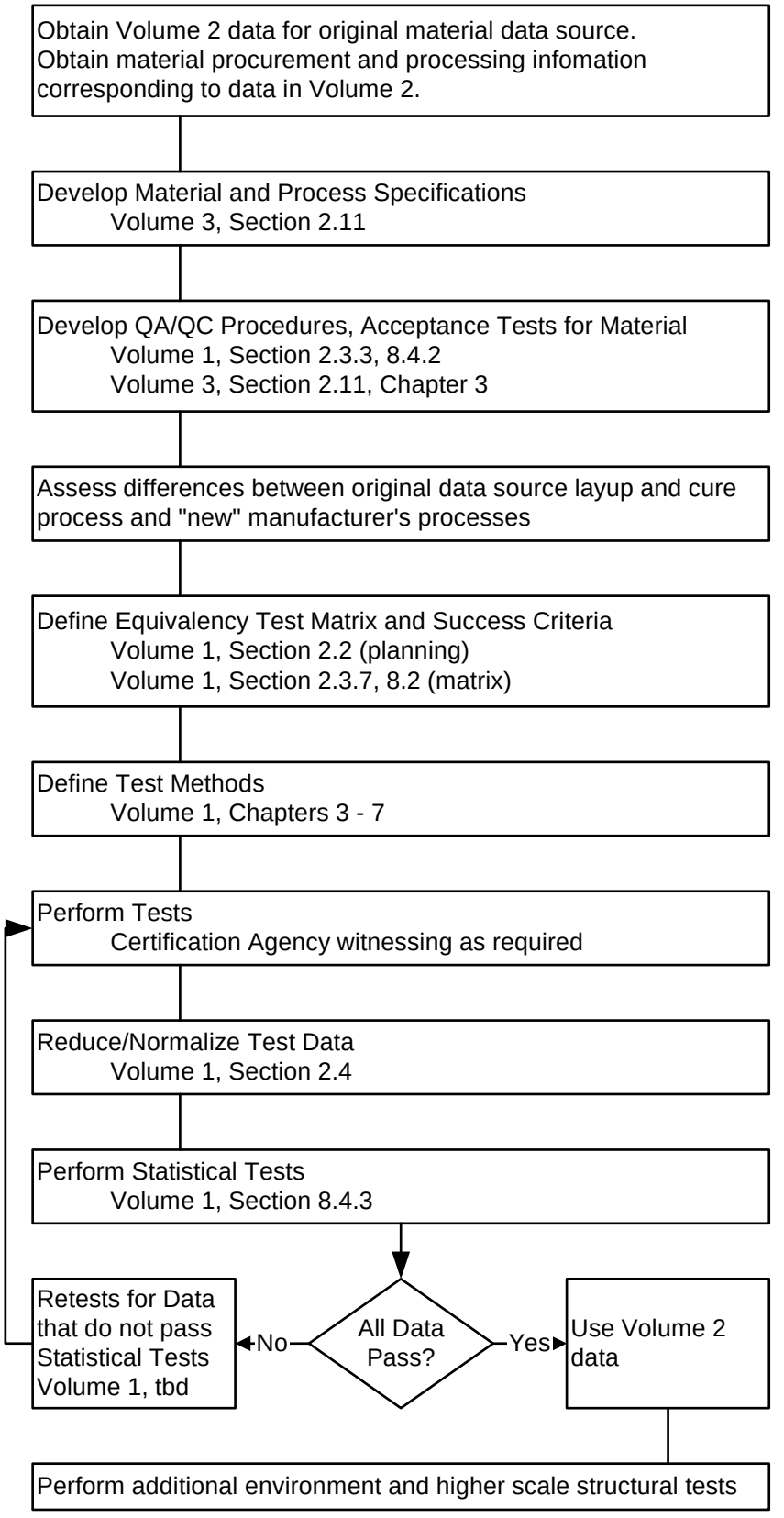
Roadmap #3: Development of Lamina Allowables



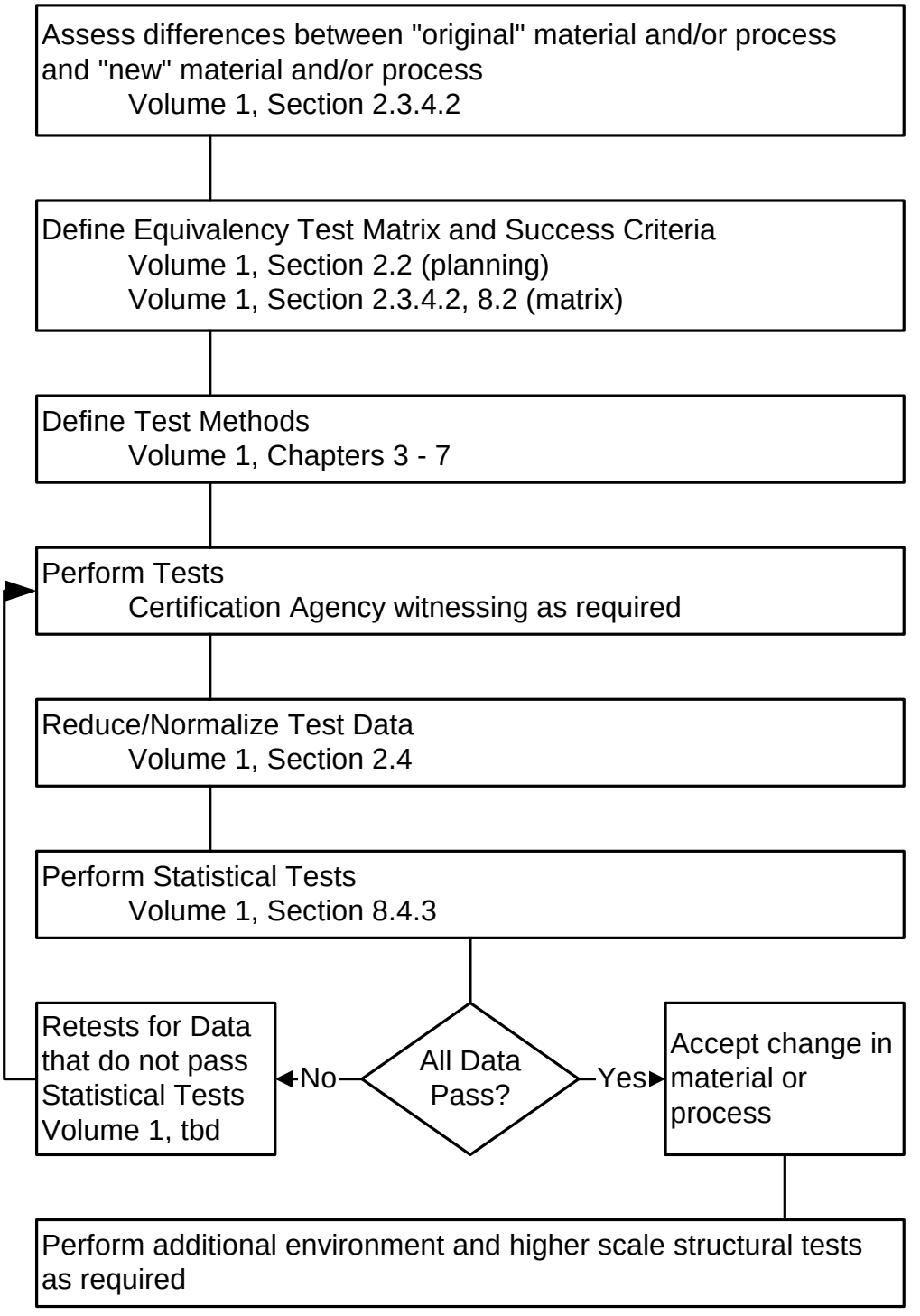
Roadmap #4: Development of Data for New Material for Submittal to Volume 2



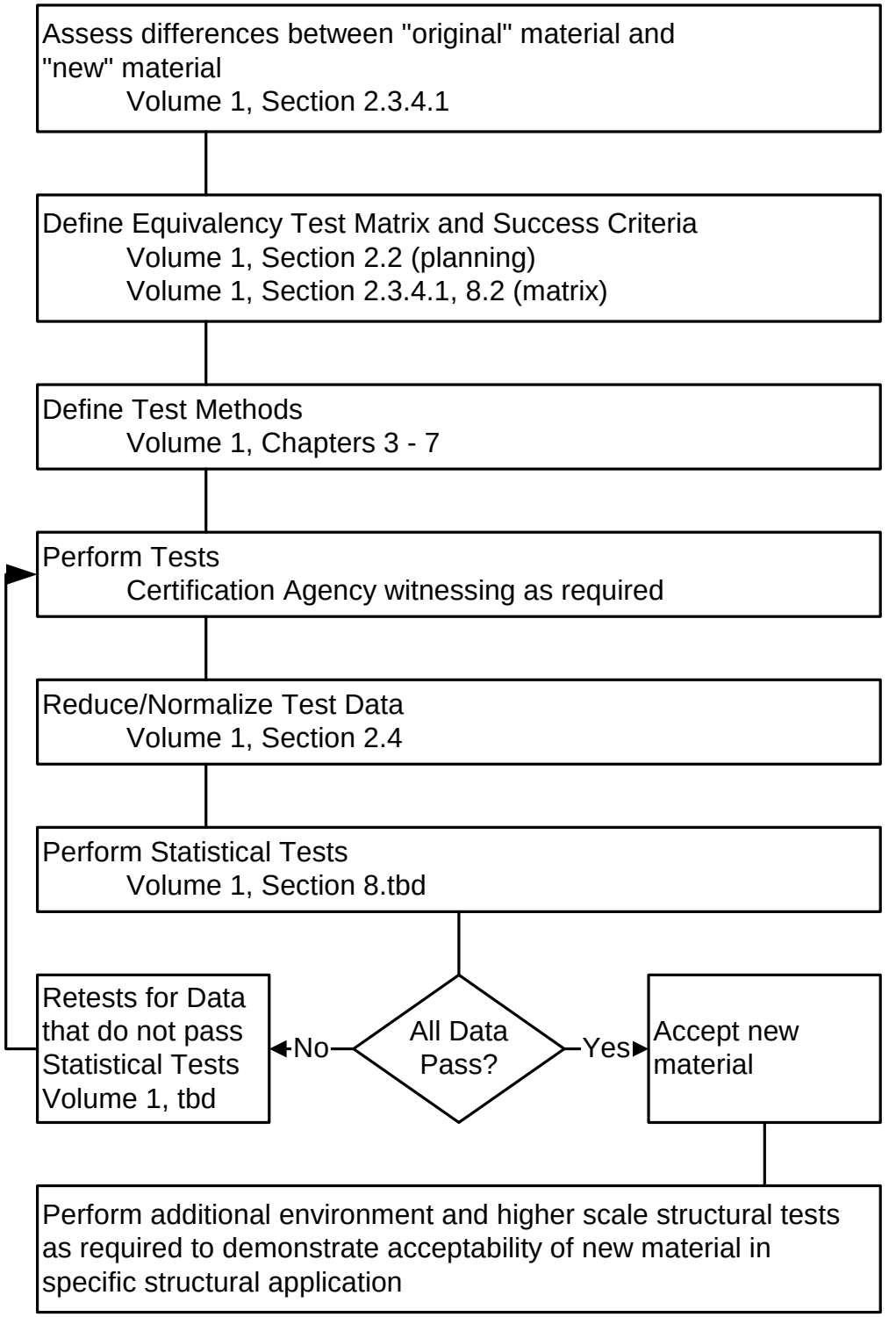
Roadmap #5: Use of Volume 2 Data for Design and Structural Substantiation



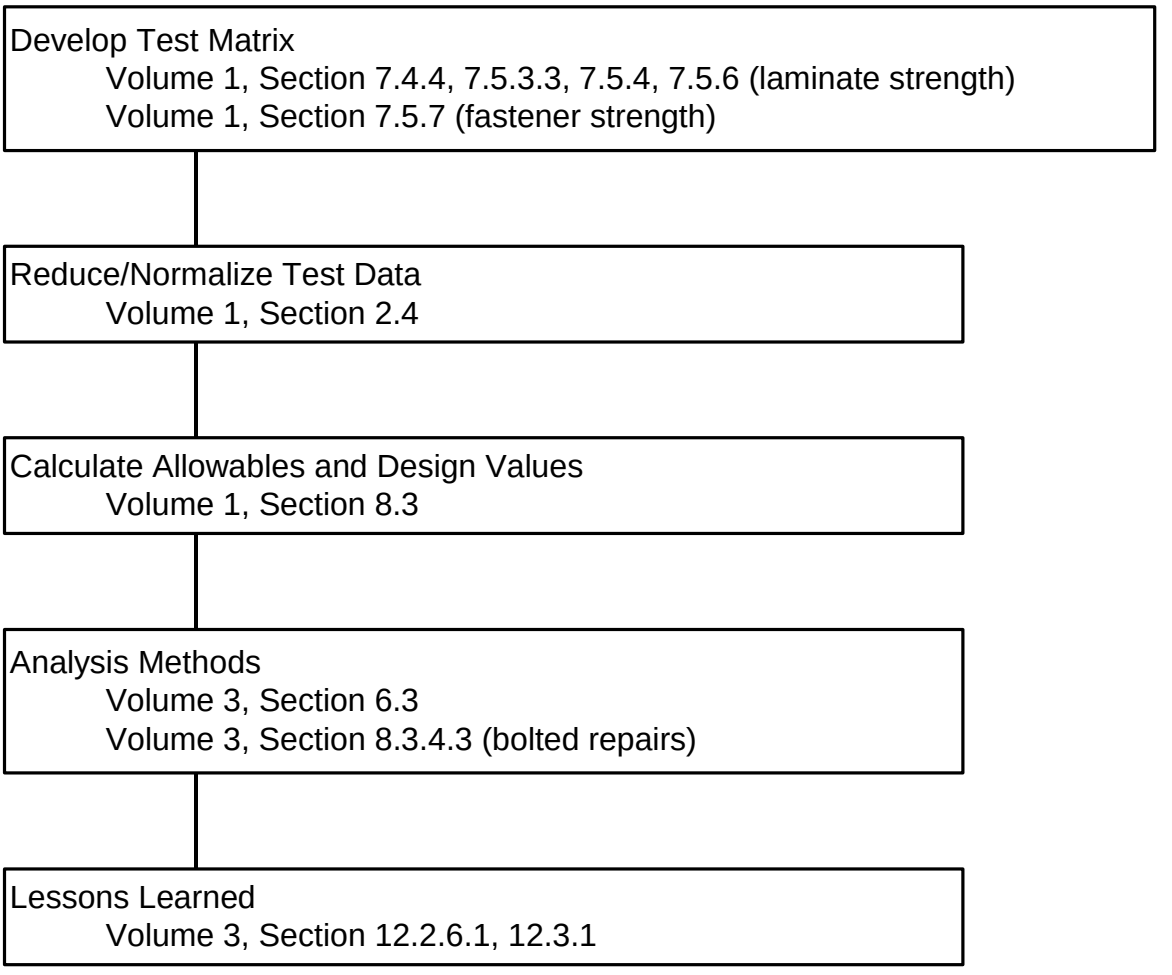
Roadmap #6: Demonstration of Equivalency for Revised Material and/or Process



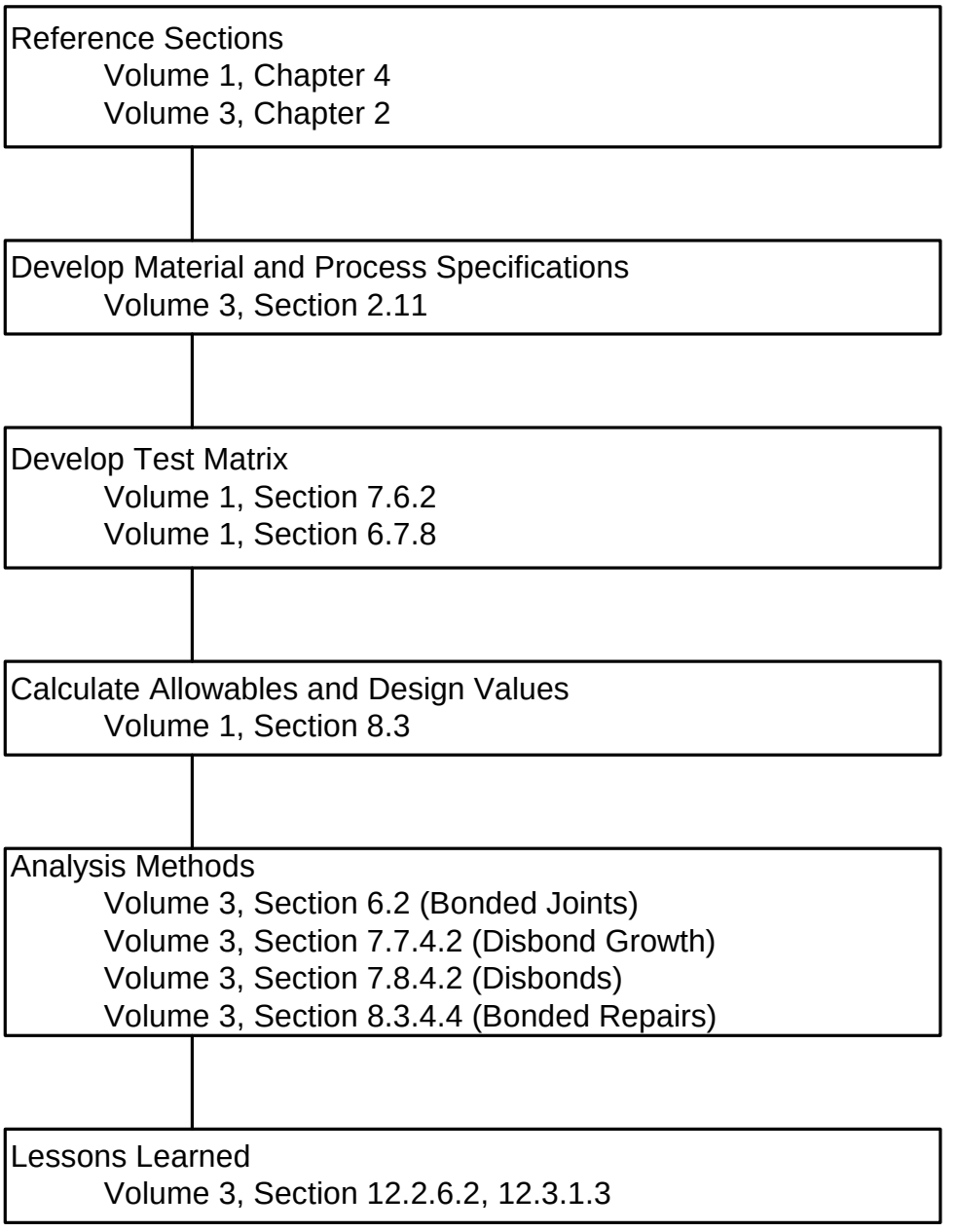
Roadmap #7: Demonstration of Application Acceptance for "2nd Source" Material



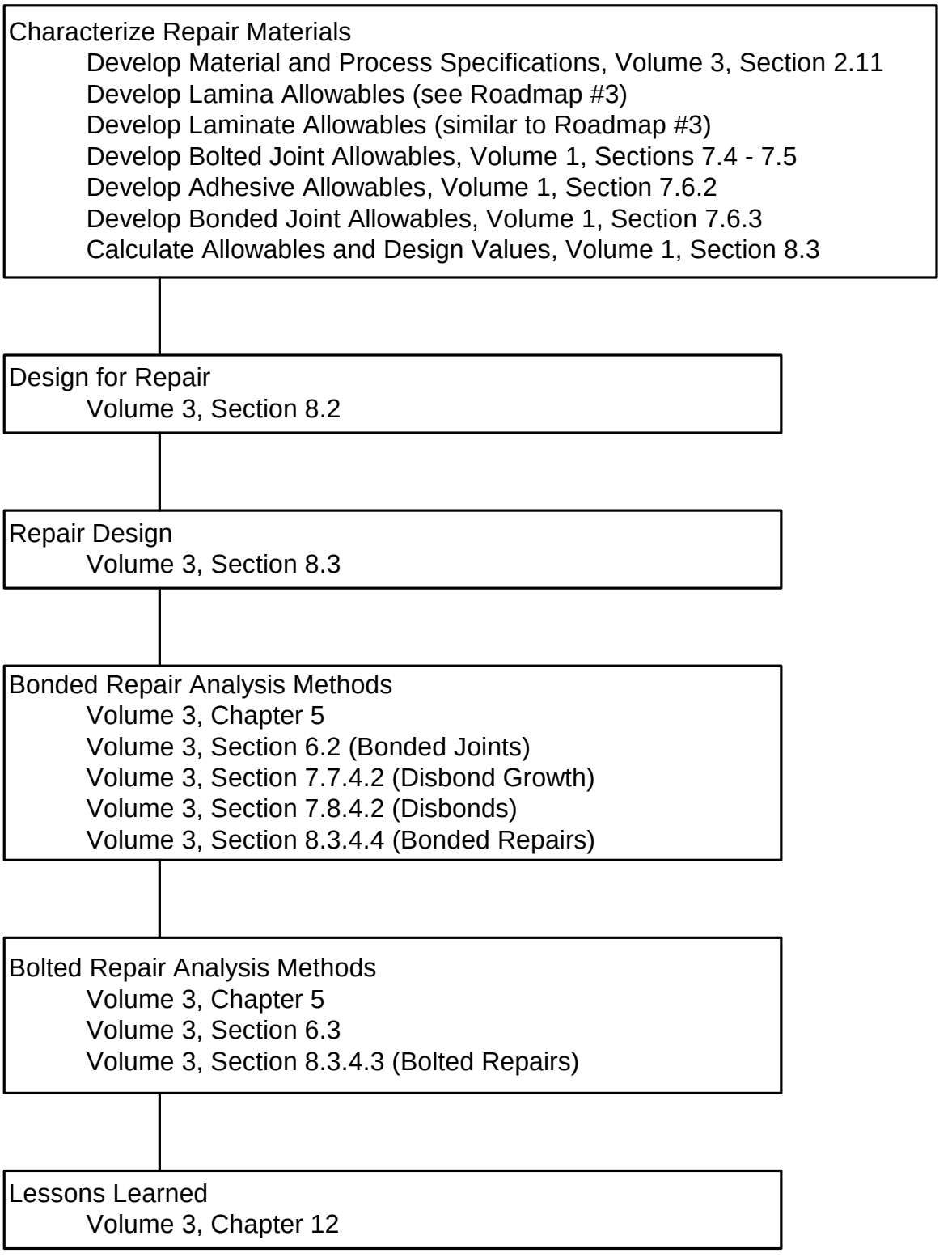
Roadmap #8: Bolted Joint Tests and Analysis Methods



Roadmap #9: Bonded Joint Tests and Analysis Methods



Roadmap #10: Design, Analysis and Fabrication of Repairs



1.4.2 Source of information

The information contained in MIL-HDBK-17 is obtained from materials producers and fabricators, the aerospace industry, reports on government-sponsored research, the open literature, direct contacts with researchers, and from participants in MIL-HDBK-17 coordination activities. All information published in this document has been coordinated and reviewed by representatives from industry, the US Army, the US Navy, the US Air Force, NASA, and the US Federal Aviation Administration. Every effort has been made to reflect the most up-to-date information on the use of composite materials, with particular emphasis on use of composites in structures. The handbook is continually reviewed and revised to keep current with the state-of-the-art and insure completeness and accuracy.

1.4.3 Use of data and guidelines in applications

All data contained herein are based on small-scale test specimens for specific environmental conditions, largely limited to uniaxial quasi-static loading.[1] It is the user's responsibility to determine if handbook data is appropriate for a given application, and if selected, to translate or scale the data as necessary for use:

- in a multi-directional laminate,
- on a structure of different characteristic size and geometry,
- under a multi-directional stress state,
- when exposed to a different environment, and/or
- when subjected to non-static loading.

Further discussions of these and other issues are provided in Volume 3. Specific uses of handbook data are beyond the scope and responsibility of MIL-HDBK-17, and applicability and interpretation of specific provisions of this handbook may require approval by an appropriate procurement or certification agency.

1.4.4 Strength properties and allowables terminology

The handbook intent is to provide guidelines for generating material property data, including statistically-based strength data at environmental extremes that bracket most intermediate application-specific environments. The philosophy is to avoid having application-specific issues govern generic material property characterization programs. If data are also available at intermediate environmental conditions, they can be used to more completely define the relationship between the property and the effect of the environment on that property. However, in some cases an environmental limit for a composite material system may be application dependent, and in others, data at environmental limits may not be available.

Available statistically-based strength data are tabulated in Volume 2. These data are useful as a starting point for establishing structural design allowable values when stress and strength analysis capabilities permit lamina-level margin-of-safety calculations. For such cases the MIL-HDBK-17 strength basis value may also be termed a material design allowable. Depending on the application, some structural design allowables may have to be empirically determined from additional laminate, element, or higher-level test data not provided by MIL-HDBK-17.

1.4.5 Use of references

While many references are provided at the end of each chapter, note that the information in these citations may not necessarily comply in every respect either with the general guidelines for data development or with the specific requirements for publication of data in the handbook. The references are simply

[1]Unless otherwise noted, tests were conducted in conformance with the particular test method noted. The emphasis is on data obtained from ASTM standard test methods for advanced composites, but where an ASTM test method has been deemed inappropriate or is not yet available, or when data from a nonstandard but commonly practiced test procedure is available, then data from a non-standard test method may have been accepted for publication. The specific test method used is noted in the data documentation. See also the statement on test method acceptance criteria in Section 2.5.5.

intended to be helpful, but not necessarily complete or authoritative sources of additional related information on specific subject areas.

1.4.6 Use of tradenames and product names

Use of tradenames or proprietary product names does *not* constitute an endorsement of those products by the US Government or by the MIL-HDBK-17 Coordination Group.

1.4.7 Toxicity, health hazards, and safety

Certain processing and test methods discussed in MIL-HDBK-17 may involve hazardous materials, operations, or equipment. These methods may not address safety problems, if any, associated with their use. It is the responsibility of the user of these methods to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use. The user is referred to the Advanced Composite Materials US Army Interim Health and Safety Guidance for a discussion of the health and safety issues involved in the processing and use of composite materials. This document is generated by the US Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD. Material manufacturers, as well as various composites user groups, may also provide guidance on health and safety issues pertinent to composite materials.

1.4.8 Ozone depleting chemicals

Restrictions on the use of ozone depleting chemicals are detailed in the US Clean Air Act of 1991.

1.5 APPROVAL PROCEDURES

The content of the handbook is developed and approved by the MIL-HDBK-17 Coordination Group, which meets twice yearly to consider changes and additions to the handbook. This Group consists of the handbook Co-Chairs, Coordinator, Secretariat, Working Group Chairs, and the active Working Group participants, which include representatives from various US and international procuring and certifying agencies, in addition to the producing industries and academic and research institutions. MIL-HDBK-17 Coordination Group meetings are announced to participants by mail about eight weeks prior to the scheduled meeting date, and minutes of the meetings are mailed eight weeks following the close of the meeting.

While each of the Working Groups functions similarly, they are of three types: *Executive*, a single Working Group with oversight responsibility composed of the Working Group Chairs, the handbook Co-Chairs, Coordinator, and Secretariat; *Standing*, including Data Review, Guidelines, Materials and Processing, Statistics, and Testing Working Groups; and *Specialty*, which varies with time but currently includes the Braiding and Filament Winding, Supportability, Structural Joints, and Thick-Sections Working Groups. The makeup and organization of the Coordination Group and Working Groups, as well as the procedures followed for document change approval, are summarized in the MIL-HDBK-17 Coordination Group Member's Guide, separately published and available from either the Coordinator or Secretariat.

Proposals for addition to, deletion from, or modification to the handbook should be submitted to both the appropriate Working Group and the Secretariat well in advance of the announcement mailing date, and should include specific notation of the proposed changes and adequate documentation of supporting data or analytical procedures. Reproducible copies of figures, drawings, or photographs proposed for publication in the document should be furnished to the Secretariat. Following approval by the appropriate Working Group, the proposed changes are published in the next minutes of the Coordination Group, in a special section of the minutes called the "yellow pages", and all participants are allowed comment on the proposed changes. If no substantive comments are received on any individual item by the posted response date, then that item is considered approved by the Coordination Group and is considered effective as of that date. (Prior to publication in the next revision of the handbook the collected changes are reviewed by various branches of the US DOD. Additional proposals for revision may result from this US DOD review.)

Requests for inclusion of material property data into MIL-HDBK-17 should be submitted to either the Coordinator or the Secretariat, accompanied by the documentation specified in Section 2.5.5. A Data Source Information Package has been created to aid those considering submitting data for inclusion in MIL-HDBK-17, and is available from either the Coordinator or the Secretariat. The Secretariat reviews and analyzes each data submission and at the next available meeting of the Coordination Group presents a summary for evaluation by the Data Review Working Group. The choice of new materials to be included herein is governed by the MIL-HDBK-17 Coordination Group. Practical considerations preclude inclusion of all advanced composite materials, but reasonable attempts will be made to add new material systems of interest in a timely manner.

1.6 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 1.6(a), 1.6(b), and 1.6(c) served as primary sources for this information.

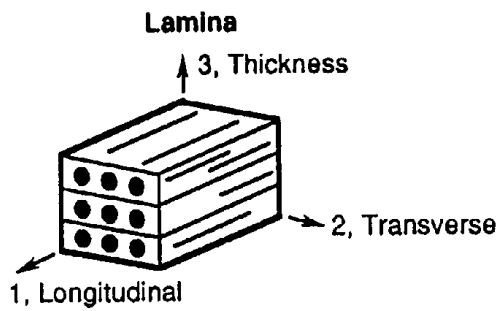
1.6.1 Symbols and abbreviations

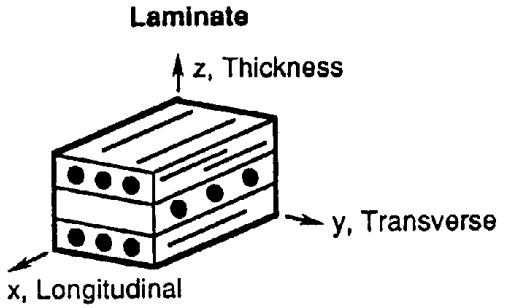
The symbols and abbreviations used in this document are defined in this section with the exception of statistical symbols. These latter symbols are defined in Chapter 8. The lamina/laminate coordinate axes used for all properties and a summary of the mechanical property notation are shown in Figure 1.6.1.

- 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 - compression 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 compression panel normal to load, or breadth of beam cross-section





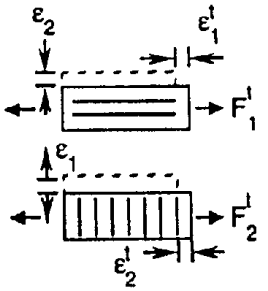
Notation = H_i^{jk}

Where,

$H = \begin{cases} \sigma, \tau; \text{ Applied Normal, Shear Stress} \\ F; \text{ Allowable Stress} \\ \varepsilon, \gamma; \text{ Extensional, Shear Strain} \\ E, G; \text{ Young's, Shear Modulus} \\ \nu; \text{ Poisson's Ratio} \end{cases}$

Note: ν_{12}^t = Major Poisson's Ratio = $-\frac{\varepsilon_2}{\varepsilon_1^t}$

ν_{21}^t = Minor Poisson's Ratio = $-\frac{\varepsilon_1}{\varepsilon_2^t}$



$i = \begin{cases} 1; \text{ Longitudinal} \\ 2; \text{ Transverse} \\ 3; \text{ Thickness} \\ 12, 13, 32; \text{ Shear, Poisson's} \end{cases}$ Lamina

$i = \begin{cases} x; \text{ Longitudinal} \\ y; \text{ Transverse} \\ z; \text{ Thickness} \\ xy, xz, zy; \text{ Shear, Poisson's} \end{cases}$ Laminate

$j = \begin{cases} c; \text{ Compression} \\ t; \text{ Tension} \\ s; \text{ Shear} \end{cases}$

$k = \begin{cases} y; \text{ Yield} \\ u; \text{ Ultimate, Not Used for Stiffness} \end{cases}$

Examples, F_2^{tu} = Lamina Ultimate Transverse Tensile Allowable Stress

E_z^c = Laminate Compressive Young's Modulus, Thickness Direction

FIGURE 1.6.1 *Mechanical property notation.*

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

$\mathcal{C}$
$\mathcal{L}$ - 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)

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 compression 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

R.H. - 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 - strain (m/m,in/in)
ε^e - elastic strain (m/m,in/in)
ε^p - 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/m3,lb/in3)
- (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

1.6.1.1 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)

1.6.1.2 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]
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)
$\bar{\rho}_c$ - 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 (°)

1.6.1.3 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

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

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.

1.6.1.4 Superscripts

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

b - bending
br - bearing
c - (1) compression
- (2) creep
cc - compression crippling
cr - compression buckling
e - elastic
f - filament
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

1.6.1.5 Acronyms

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

AA - atomic absorption
AES - Auger electron spectroscopy
AIA - Aerospace Industries Association
ANOVA - analysis of variance
ARL - US Army Research Laboratory
ASTM - American Society for Testing and Materials
BMI - bismaleimide
BVID - barely visible impact damage
CAI - compression after impact
CCA - composite cylinder assemblage
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
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
ENF - end notched flexure
EOL - end-of-life
ESCA - electron spectroscopy for chemical analysis
ESR - electron spin resonance
ETW - elevated temperature wet
FAA - Federal Aviation Administration
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
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
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
PEEK - polyether ether ketone
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 - International System of Units (Le Système International d'Unités)
SIMS - secondary ion mass spectroscopy
TBA - torsional braid analysis
TEM - transmission electron microscopy
TGA - thermogravimetric analysis
TLC - thin-layer chromatography
TMA - thermal mechanical analysis
TOS - thermal oxidative stability
TVM - transverse microcrack
UDC - unidirectional fiber composite
VNB - V-notched beam
XPS - X-ray photoelectron spectroscopy

1.6.2 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 1.6.2(a)). Further guidelines on the use of the SI system of units and conversion factors are contained in the following publications (References 1.6.2(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 1.6.2.

TABLE 1.6.2 *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.

1.7 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 -- Any balanced laminate consisting of plus and minus theta plies where theta is an acute angle with respect to a reference direction.

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

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.

Consolidation -- 1) *in metal matrix composites*, the diffusion bonding operation in which an oriented stack of preplies is transformed into a finished composite laminate; 2) *in thermoplastic composites*, a processing step in which fiber and matrix are compressed by one of several methods to reduce voids and achieve desired density.

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.

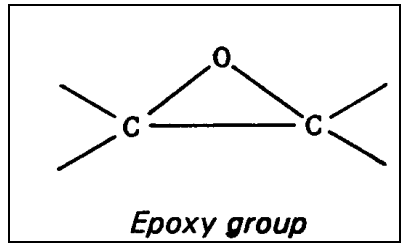
Eluate -- The liquid emerging from a column (in liquid chromatography).

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, *v* -- To stack plies of material in specified sequence and orientation.

Lay-up, *n* -- 1) the stack of plies in specified sequence and orientation prior to cure or consolidation; 2) the complete stack of plies, bagging material, breather material, and so on, prior to cure or consolidation; 3) a description of the component materials, geometry, and so on, of a laminate.

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:

$$F^b = \frac{Mc}{I} \qquad 1.7(a)$$

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:

$$F^s = \frac{Tr}{J} \qquad 1.7(b)$$

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

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \qquad 1.7(c)$$

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.

Ply Count -- *In laminated composite materials*, the number of plies or laminae used to construct the composite.

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 D 2344.

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.

Tab -- A piece of material used to hold the laminate specimen in a grip or fixture for testing so that the laminate is not damaged, and is adequately supported.

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.

Void Content -- The volume percentage of voids in a composite.

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

Warp Surface -- The ply surface that shows the larger area of warp tows with respect to filling tows.

Discussion: Fabrics where both surfaces show an equal area of warp tows with respect to filling tows do not have a warp surface.

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.

Weibull Distribution (Two - Parameter) -- A probability distribution for which the probability that a randomly selected observation from this population lies between a and b ($0 < a < b < \infty$) is given by Equa-

tion 1.7(d) where α is called the scale parameter and β is called the shape parameter. (See Volume 1, Section 8.1.4.)

$$\exp\left[-\left(\frac{a}{\alpha}\right)^{\beta}\right]-\exp\left[-\left(\frac{b}{\alpha}\right)^{\beta}\right] \qquad 1.7(d)$$

Wet Lay-up -- A method of making a reinforced product by applying a liquid resin system while 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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