General information at
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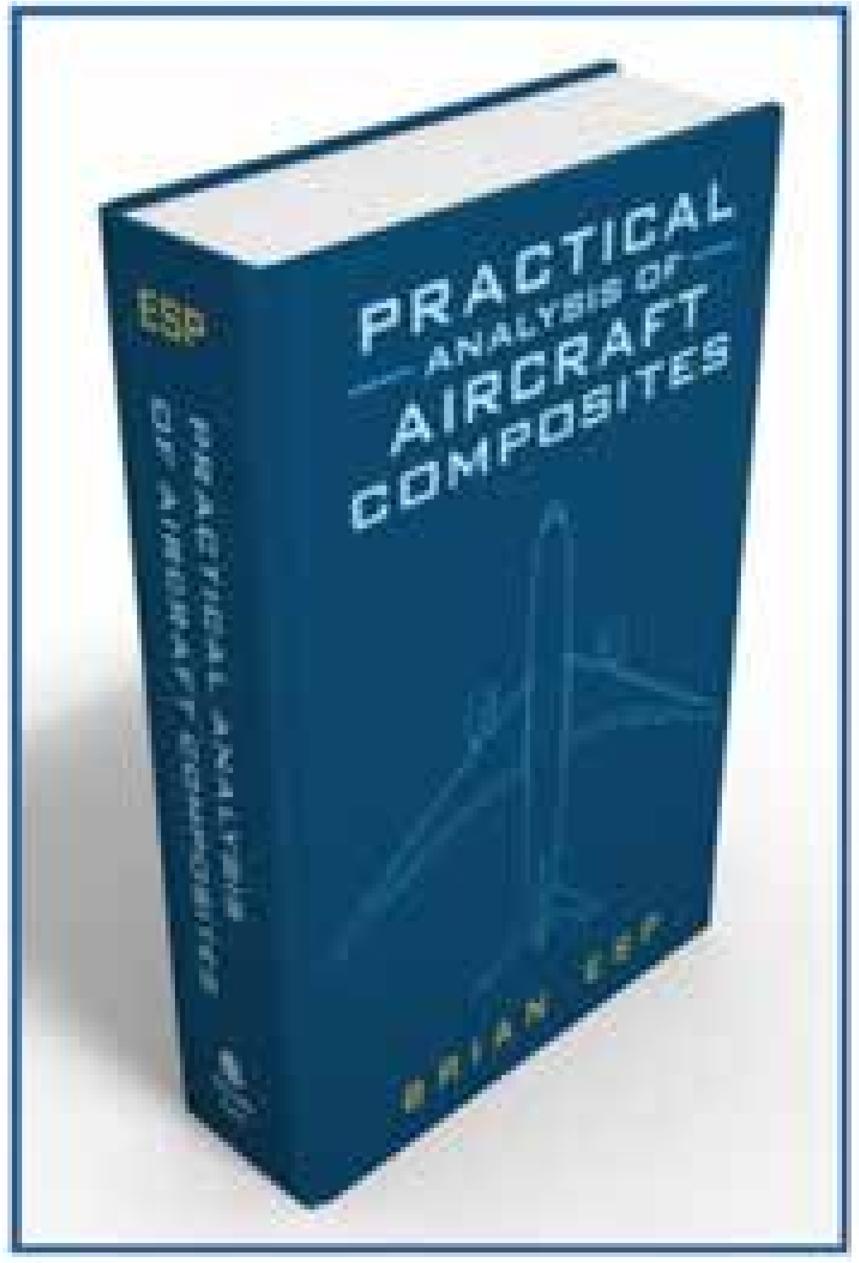
Slide Information

- Course (video/PDF) **chapter numbers** *correspond* to the book chapter numbers
- Course (video/PDF) **subsection numbers (X.X)** usually *do not correspond* to the book subsections



chapter or major section ↓

general information ↓

slide number ↓

Chapter 1: Introduction

1.1 — What are Composites?

1.2 — Applications for Aircraft Structures

1.3 — Composite Material Constituents

1.4 — Plies (Unidirectional and Fabric)

1.5 — Laminates

1.6 — Material Characterization

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Chapter 1: Introduction

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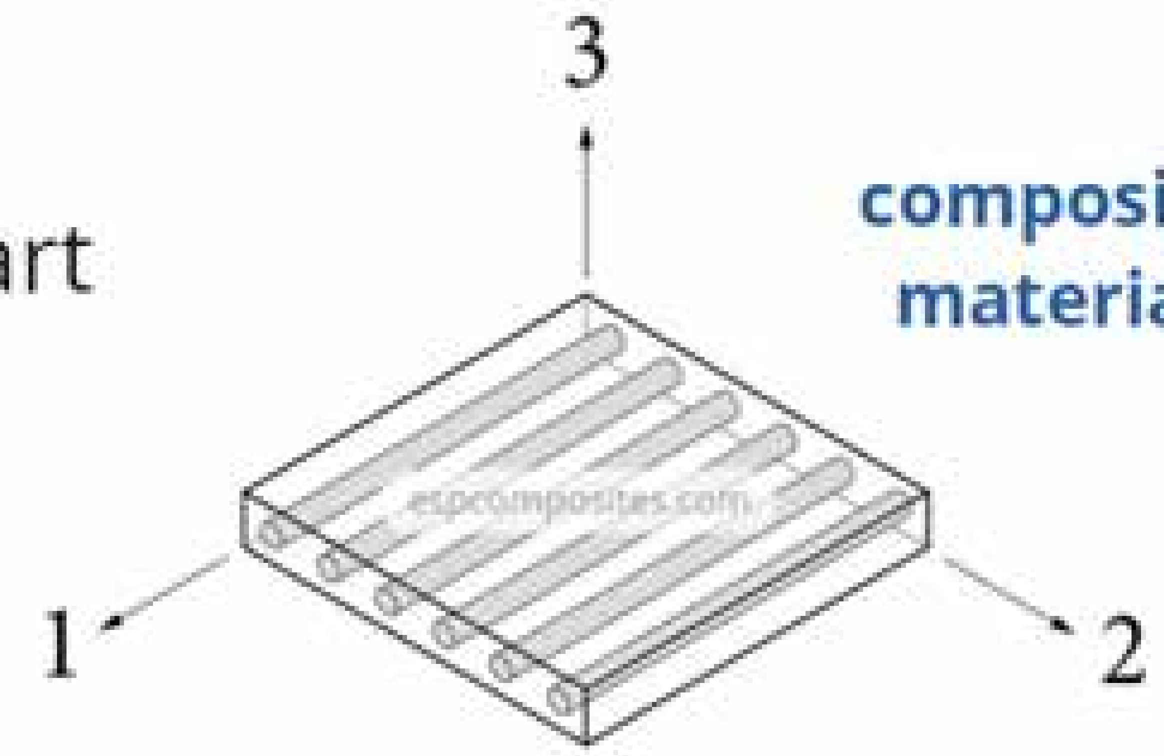
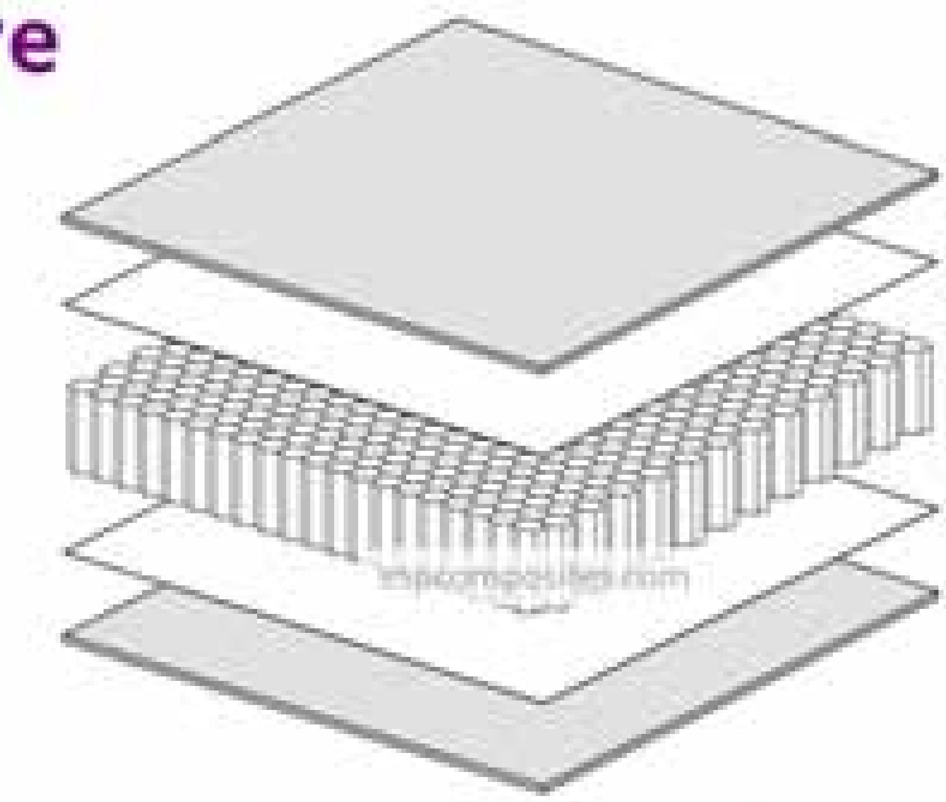
1.1 — What are Composites?

- Composite: **multiple** materials or parts combined to act as a **single** material or part
- Composite **material** (or material system)
  - fiber + matrix



- Sandwich structure is a **composite structure**
  - metal facesheet + metal core = composite structure with metal parts
  - composite facesheet + core = composite structure with composite material(s)



- When saying "composite", usually mean a **composite material**
  - fiber + matrix

1.2 — Applications for Aircraft Structures

- Large aircraft
  - early uses for composites were for secondary structures (radomes, fairings, etc.)
  - composites later used for primary structures (wings, fuselage, etc.)

Primary structure usage with carbon fibers (large aircraft):

- Military
  - extensive use on F-117, B-2, F-22, F-35
  - usually carbon fiber for external structures

- Large Civil Aircraft (Civilian Transport)
  - Boeing 777 - empennage and floor beams
  - Boeing 787 - empennage, fuselage skins/frames/shear tie, wing, floor beams
  - Airbus A350 – extensive use

1.2 — Applications for Aircraft Structures (cont.)

- Large aircraft composite usage
  - carbon fiber for primary structures (wing, fuselage, other)
  - glass or aramid fibers for secondary structures (radomes, fairings, wingtips, floor panels, interiors)
- Small aircraft composite usage
  - glass fiber may be used for primary and secondary structures
- Analysis focus of this course
  - large aircraft
  - carbon fiber composites

1.3 — Composite Material Constituents

- Composite material (a.k.a. composite material system)
  - Fiber (reinforcement) + matrix (surrounds and supports the fibers)
  - Combines two (or more) materials to make a more useful "material"
    - book explains why this is possible

NOTE: The book goes into further detail on many of the topics discussed in this course

1.3 — Composite Material Constituents (cont.)

- Fiber (reinforcement)
  - **major load carrying constituent**
  - **greatly affects the stiffness and many strength properties of a composite laminate** (multiple plies make up a laminate)
    - matrix can also significantly affect some strength properties of a laminate
  - carbon (and graphite)
    - high stiffness and strength
    - excellent fatigue properties
    - high cost
  - glass
    - low stiffness (one major distinction compared to carbon fibers)
    - low cost
  - boron
    - less usage, but may be appropriate for some specialized applications
  - aramid (Kevlar®, Nomex®, other)
    - high toughness (energy absorbing)
    - tendency to absorb moisture (negatively affects some structural properties)

1.3 — Composite Material Constituents (cont.)

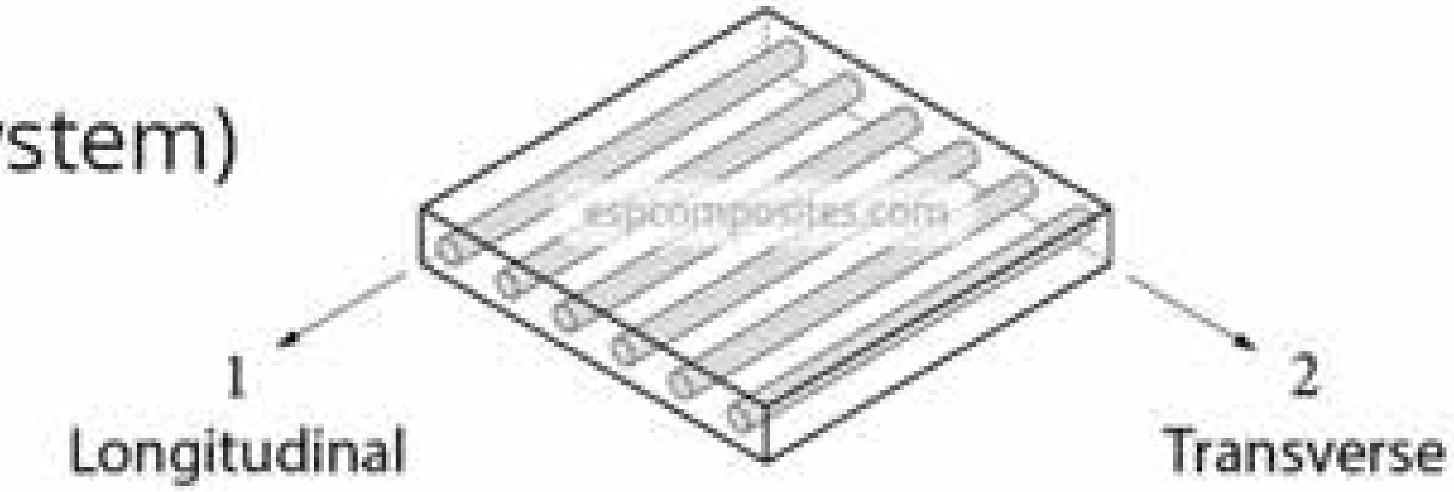
- This course/book: consider long, continuous fibers
  - high performance
  - typical for aircraft structures
- Discontinuous fibers (chopped fibers) not considered
  - lower performance
  - analyzed differently
  - sometimes used for aircraft applications, but not as common
  - used more frequently in some other industries

1.3 — Composite Material Constituents (cont.)

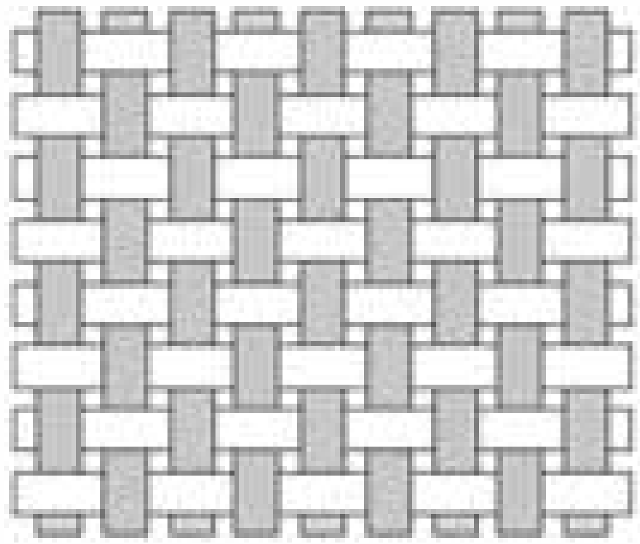
- Matrix
  - surrounds and "connects" the fibers
    - protects fibers from physical and environmental threats
    - stabilized the fibers (provides compression capability)
    - energy absorbing mechanism (helps with impacts, adds "ductility")
    - can affect some strength properties of a laminate (compression strength, compression after impact strength, interlaminar strength, bearing strength)
    - a polymer matrix is primarily responsible for the change of the composite's properties under extreme temperature and moisture environments
  - PMC, CMC, MMC, CCC
    - PMC (Polymer Matrix Composite) is most typical for aircraft applications
  - epoxy is a commonly used PMC for aircraft structures
    - variety of desirable properties (relatively high cost)
    - modern toughened epoxies are less brittle than first generation epoxies (improved impact damage resistance)

1.4 — Plies (Unidirectional and Fabric)

- Unidirectional Ply (uni-ply, UD ply, uni-tape)
  - Fibers oriented in a **single** direction
  - 1-2-3 (or 1-2) coordinate system (local system)
  - a.k.a. lamina
  - Carbon/Epoxy, CF/EP, CF-EP, CFRP



- Woven Fabric
  - Fibers oriented in **multiple** directions
  - 1-2-3 (or 1-2) coordinate system (local system)



- Prepreg
  - fibers preimpregnated with a matrix in a semi-cured state

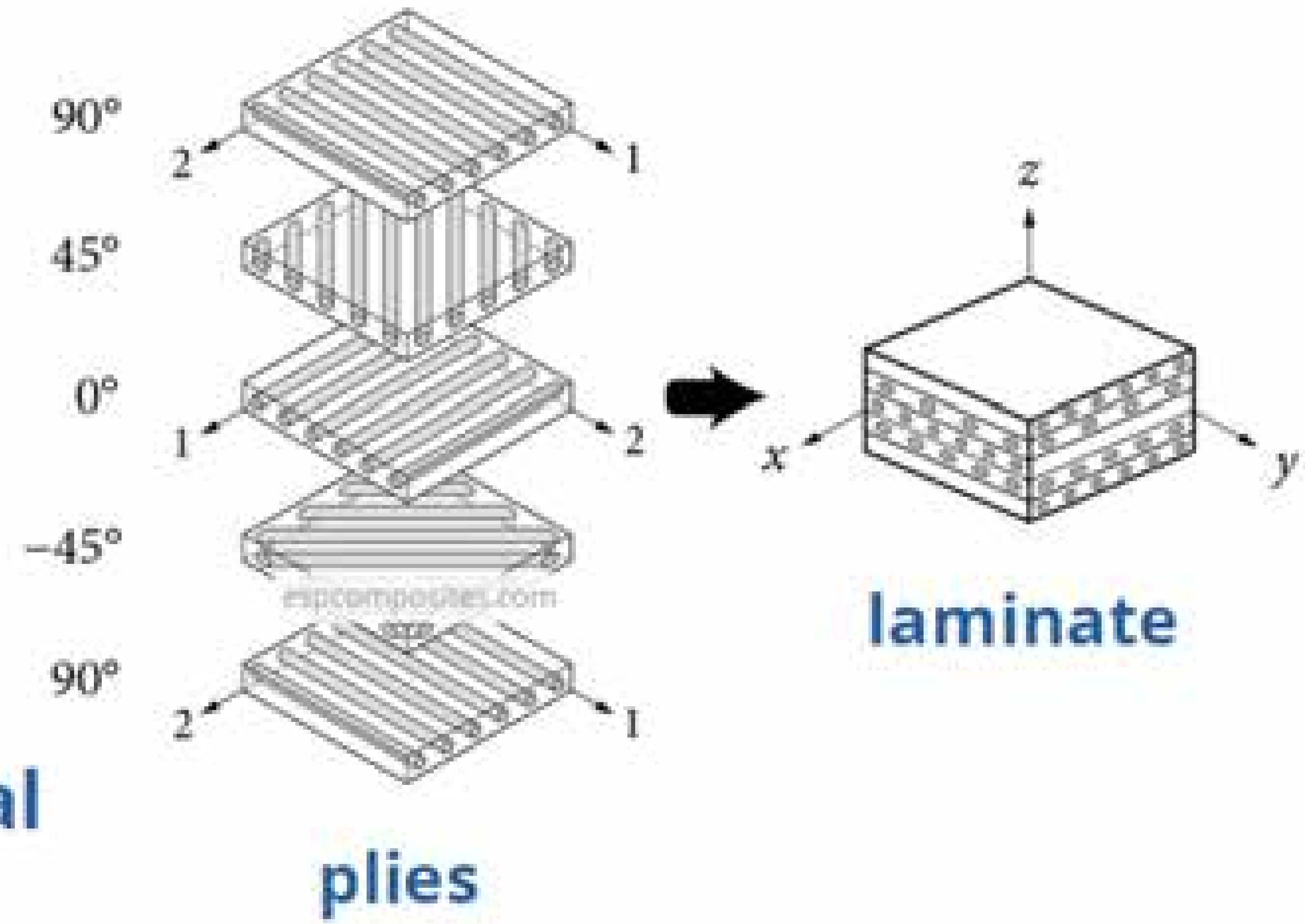
NOTE: The book has additional information.
Free excerpt at www.espcomposites.com

1.5 — Laminates

- **Laminates** are composed of plies (lamina)
- Laminate is in the x-y-z **system**
  - 1-direction of a 0° ply is aligned with the laminate's x-direction
- **Layup** describes:
  - ply form (UD or fabric)
  - material system(s)
  - orientation
  - ply position
  - example: [90/−45/0/+45/0]

stacking sequence ↓

- Practical laminates are **multi-directional**
  - consider bearing strength
  - multi-directional loading
  - compression after impact strength



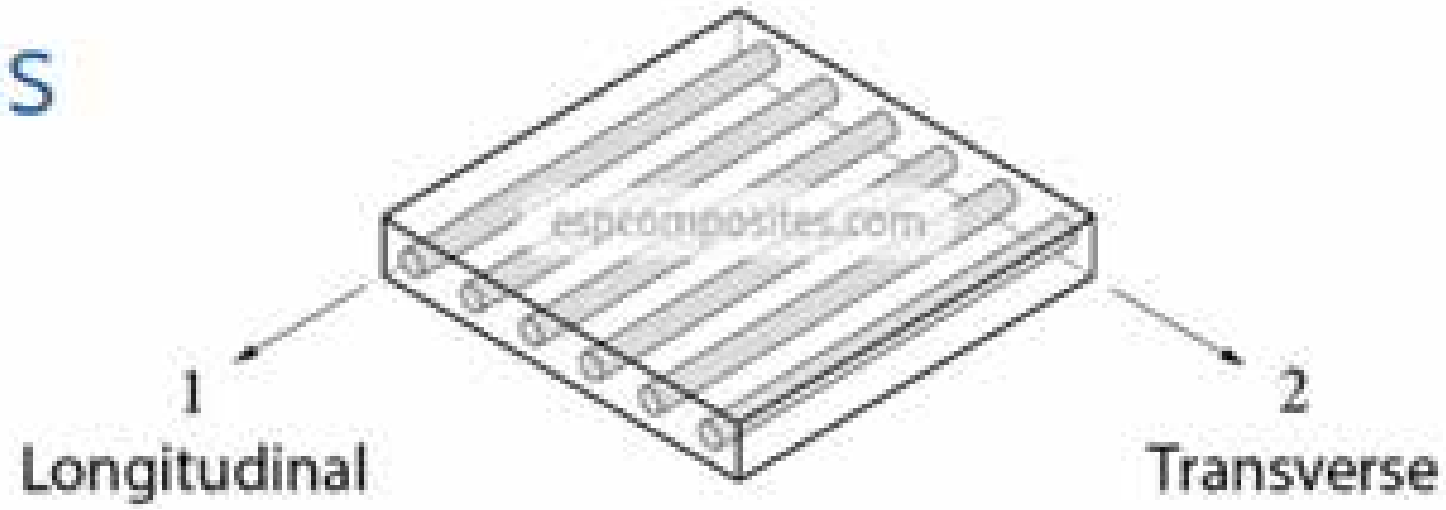
See Chapter 22 of the book for general design guidelines

1.5 — Laminates (cont.)

- Laminate coding
  - **brackets** used to describe the layup
  - [0/−45/45/90/90/45/−45/0]
  - $[0/-45/45/90]_S$ = [0/−45/45/90/90/45/−45/0]
  - omit the degree symbol
- Percentages
  - % of plies or % of fibers in the standard orientations
  - **parenthesis** used to describe percentages in the (0°/±45°/90°) directions
  - % of plies (unidirectional plies only)
  - fiber percentages is more general (appropriate for UD and fabrics)
  - Example: (25/50/25)% or (25/50/25) = quasi-isotropic
  - (40/40/20) = bias laminate

1.6 — Material Characterization

- Isotropic Material
  - properties the same in all directions (may be w.r.t elasticity, strength, etc.)
- General Orthotropic Material
  - properties different in each of the 3 perpendicular planes
- 2D Orthoropic Material in Plane Stress
  - ply (w.r.t elasticity and use with Classical Laminate Theory)
    - further in Chapters 3 and 4
  - 3D stresses affect the strength of laminates (interlaminar stresses – Chapter 8)
    - further in Chapters 9 and 10



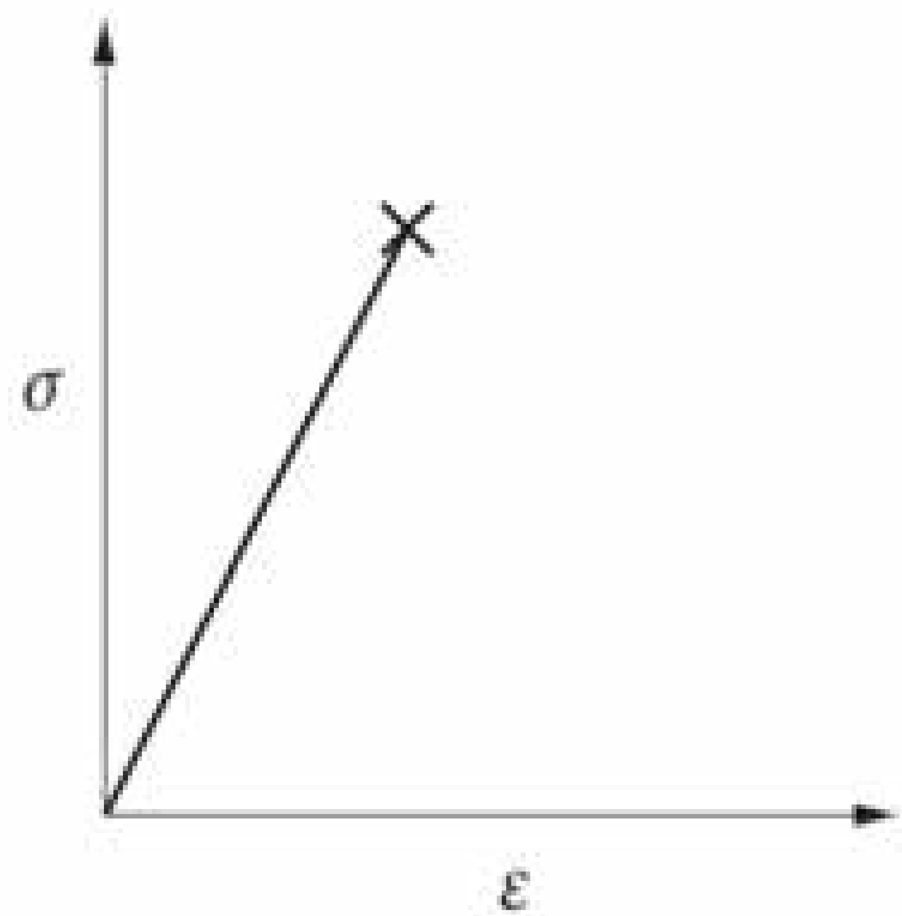
plane stress
$\sigma_3 = \tau_{13} = \tau_{23} = 0$

- Anisotropic Material (most general)

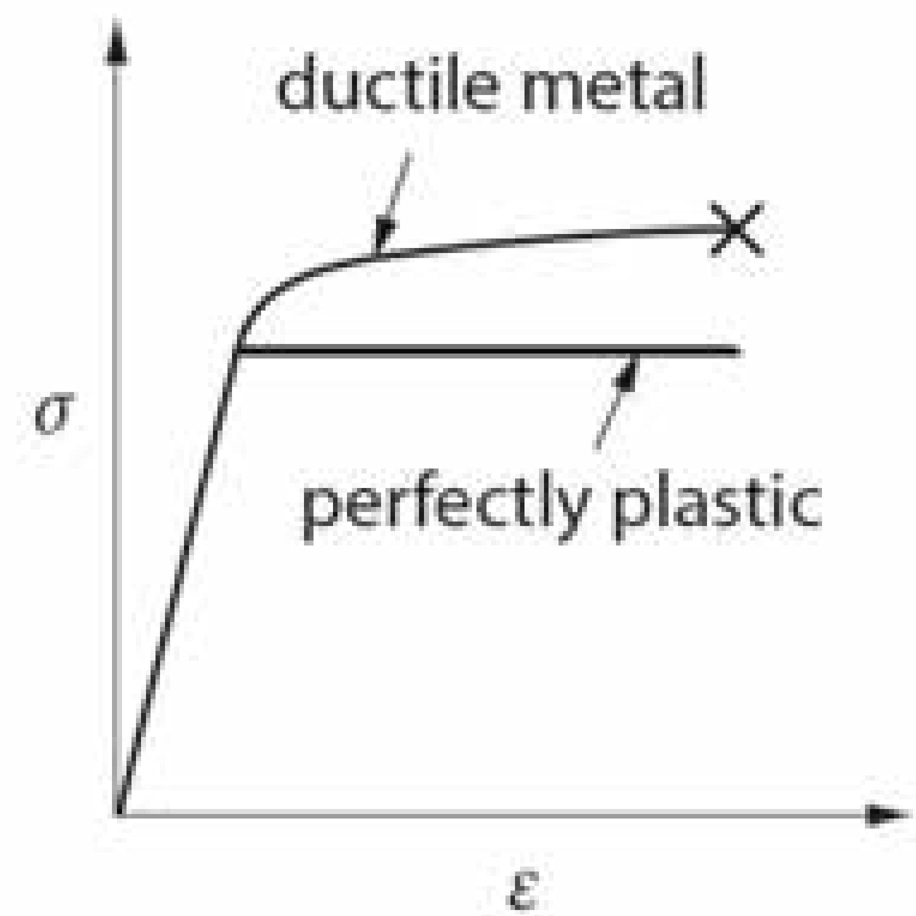
1.6 — Material Characterization (cont.)

- Micromechanics
  - considers **individual** fiber and matrix properties
  - limited practical value
  - discussed further in the Appendix A video and the book
- Macromechanics
  - **ply is treated as a homogenous material ("smeared" from the fiber and matrix properties)**
  - ply is the lowest level "material"
  - more practical approach (used in this course)

1.7 — Brittle and Ductile Materials



(a) brittle

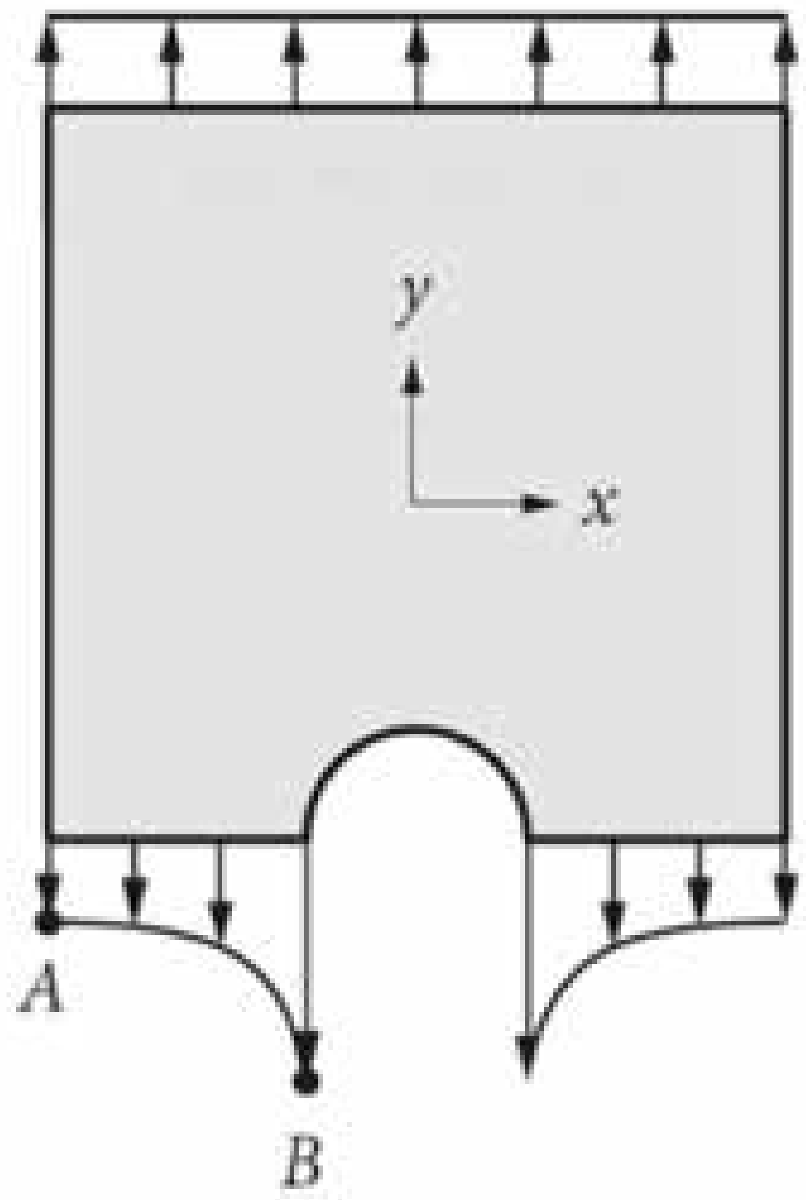


(b) ductile

glass, ceramic, some steels

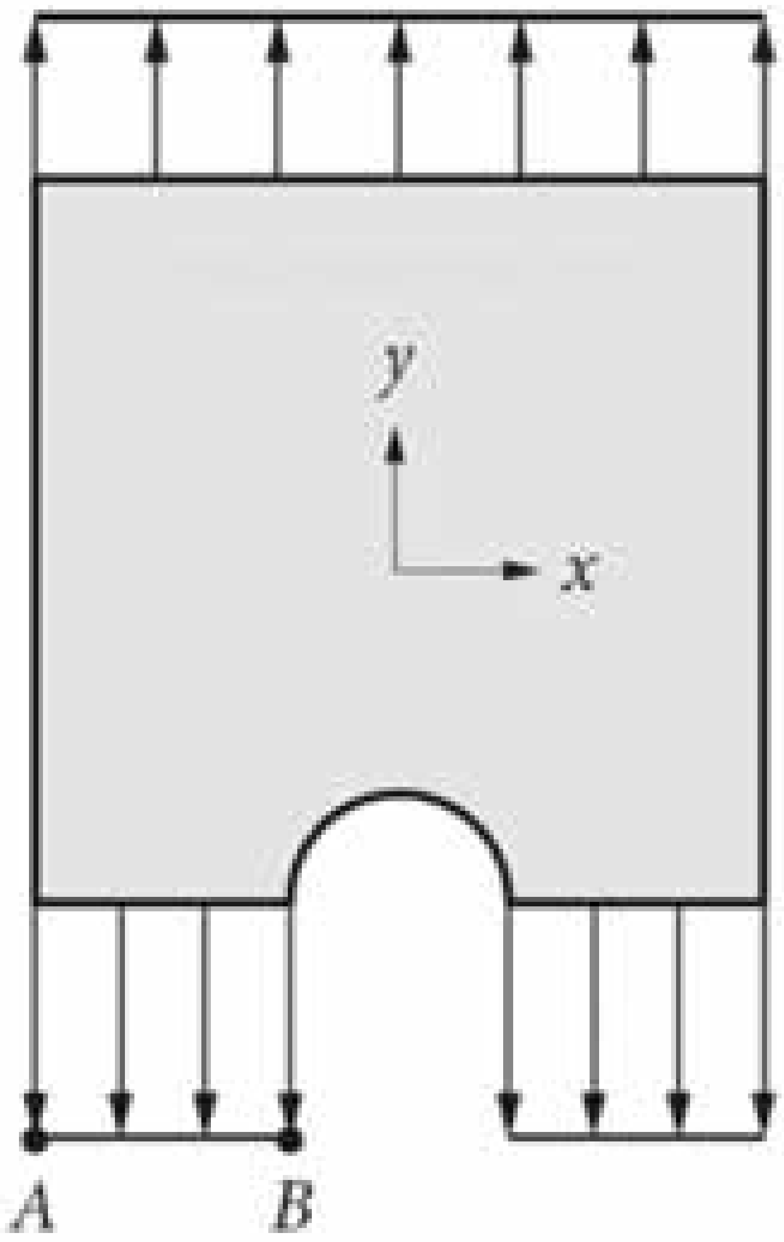
most aircraft metals

1.7 — Brittle and Ductile Materials (cont.)



brittle part with hole

stress state when two-piece fracture occurs



ductile part with hole

stress state (approximate) when two-piece fracture occurs

For the ultimate load, brittle materials are sensitive to stress concentrations, but ductile materials are not.

1.7 — Brittle and Ductile Materials (cont.)

- Are composites brittle or ductile?
  - Individual fibers usually brittle
  - unnotched laminates (pristine, without significant defects) can be brittle
  - **multi-directional laminates with a hole**
    - somewhere in between brittle and ductile
    - increased load capability compared to a brittle material
    - more difficult analysis than brittle or ductile materials
    - Chapter 2, 10, ST2
    - major distinction between composites and metals (requires a different approach to strength prediction)

1.8 — General Advantages of Composites

- Comparisons made between composites and typical aircraft metals
- CF/EP (carbon fiber/epoxy) – high stiffness-to-weight
- Potential for higher strength-to-weight
- Weight – about 10-25% savings for **some** structures
- Stealth – military aircraft
- Cost – reduced cost for **some** applications
- Fatigue/Durability – CF/EP very good fatigue performance
- Corrosion – composites do not corrode
  - some metals may corrode in the presence of composites
  - aluminum and carbon fiber should be well isolated
- Other: Producibility, complex shapes and aerodynamic smoothness, tailored design, thermal expansion, electrical permeability, aeroelastic tailoring

1.9 — General Disadvantages of Composites

- low impact resistance, reduction of strength after impact, damage detection challenges, notch sensitivity
- sensitive to temperature and humidity
- low interlaminar strength (through-the thickness stresses and stresses with a z-component)
- repairability may be reduced
- relatively complex analysis
  - **this course and the book aim to reduce this drawback**
- cost may be high
- other:
  - carbon fibers have low galvanic compatibility with aluminum
  - requires additional electrical path
  - limited ability to redistribute loads
  - mechanical property database not well established
  - not suitable for some parts and applications

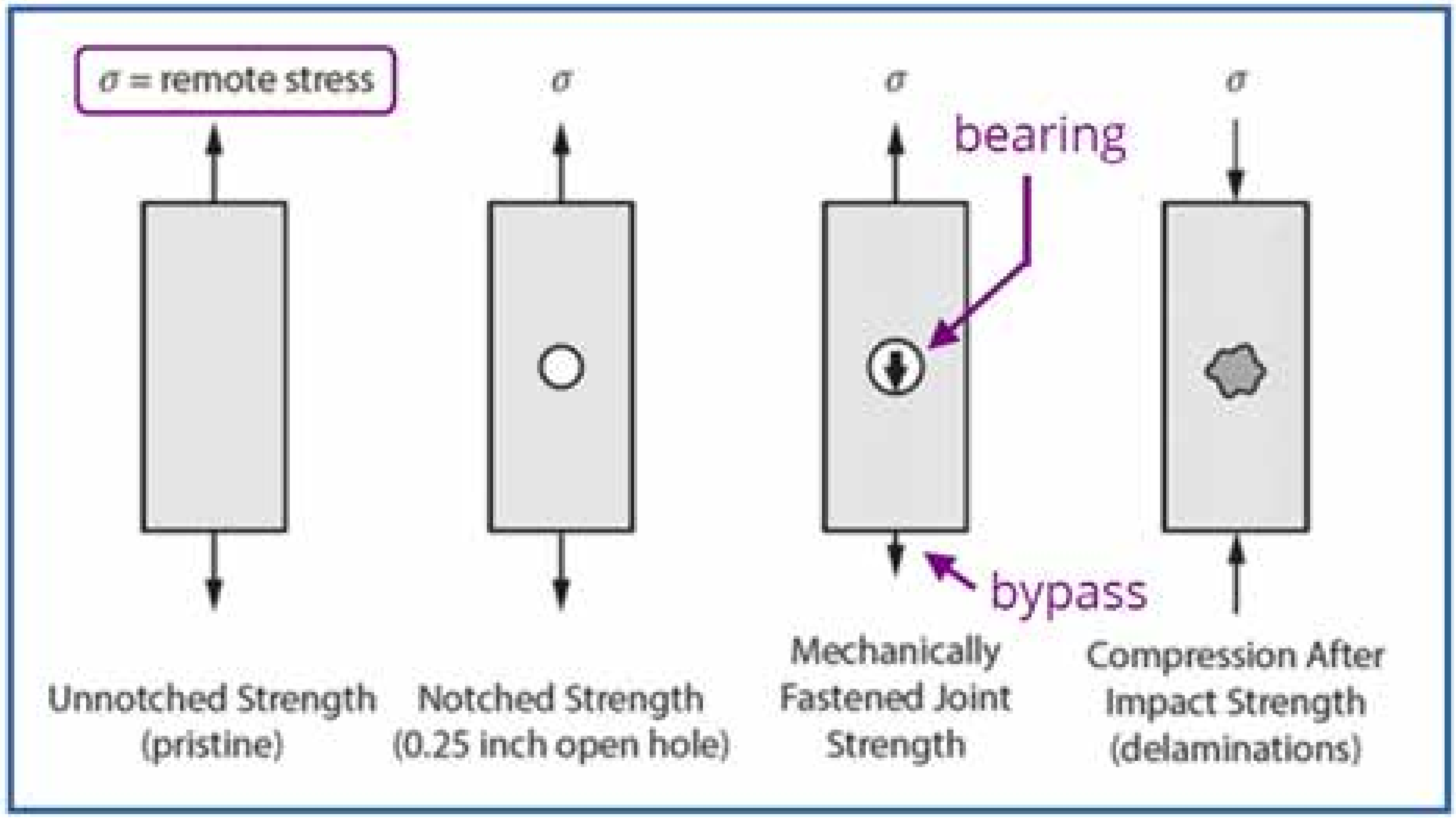
metals may be preferred

understand the disadvantages

1.10 — Stiffness/Strength Compared to Metals

- Typical carbon/epoxy laminates **compared** to metals (approximate)
  - in-plane stiffness
  - in-plane strength
  - consider Hexcel IM-7 intermediate modulus fiber + Hexcel 8552 toughened epoxy matrix as the composite material system

consider these scenarios for the following comparisons (next 2 slides):

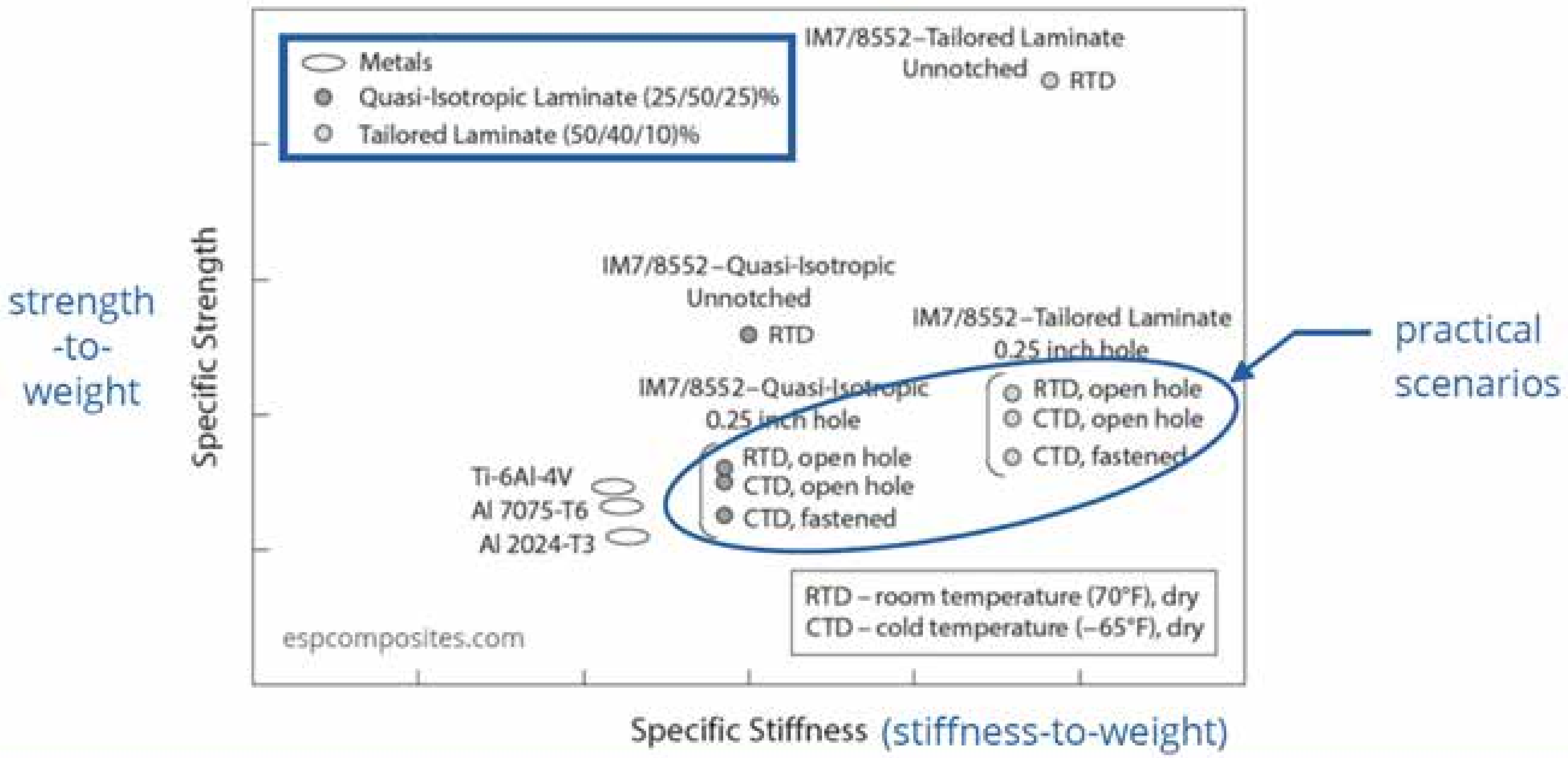


Note: See also Section 1.11 of the book

1.10 — Stiffness/Strength Compared to Metals (cont.)

- Typical carbon/epoxy laminates compared to metals (approximate)
  - in-plane stiffness (tension)
  - in-plane strength (tension)

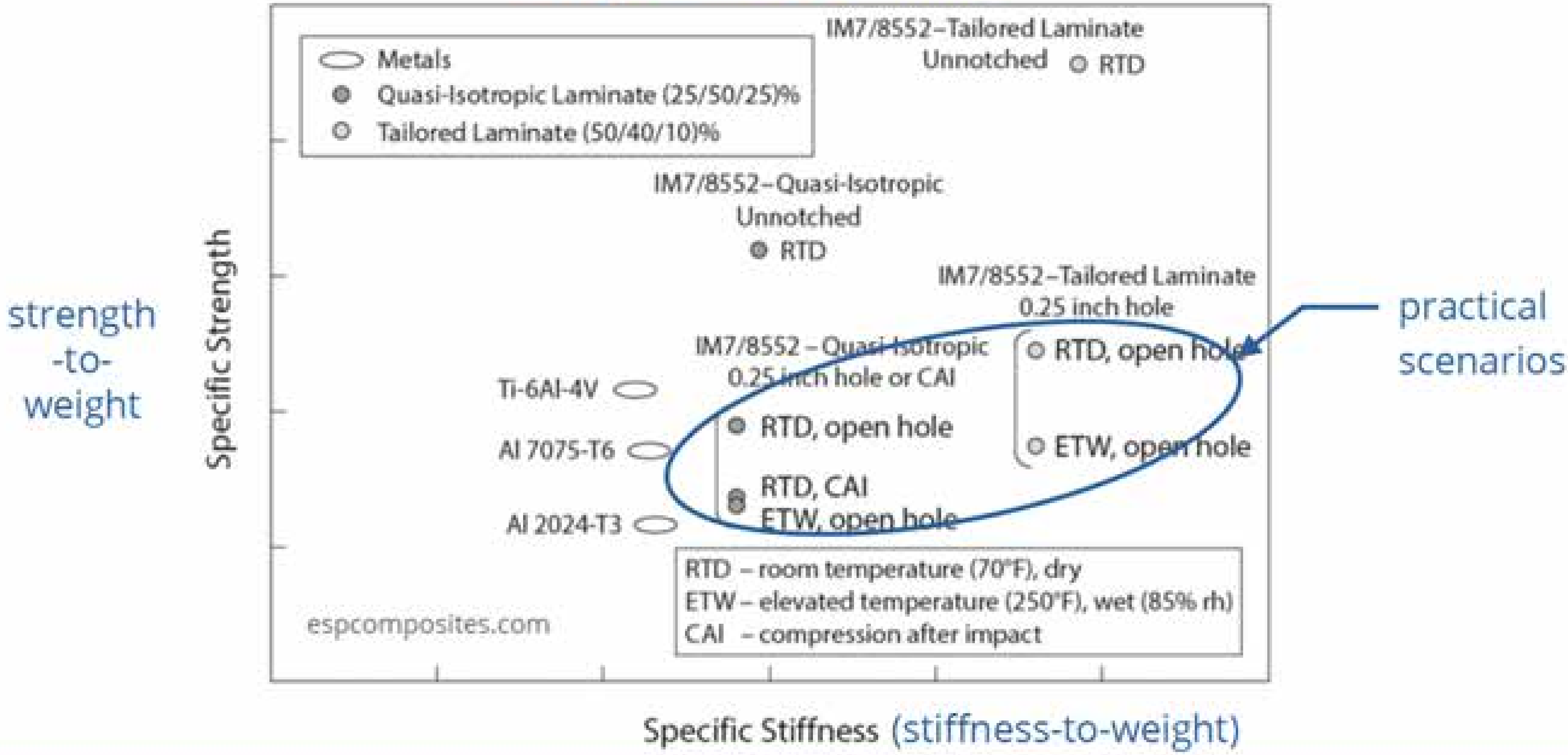
Tension Loading



1.10 — Stiffness/Strength Compared to Metals (cont.)

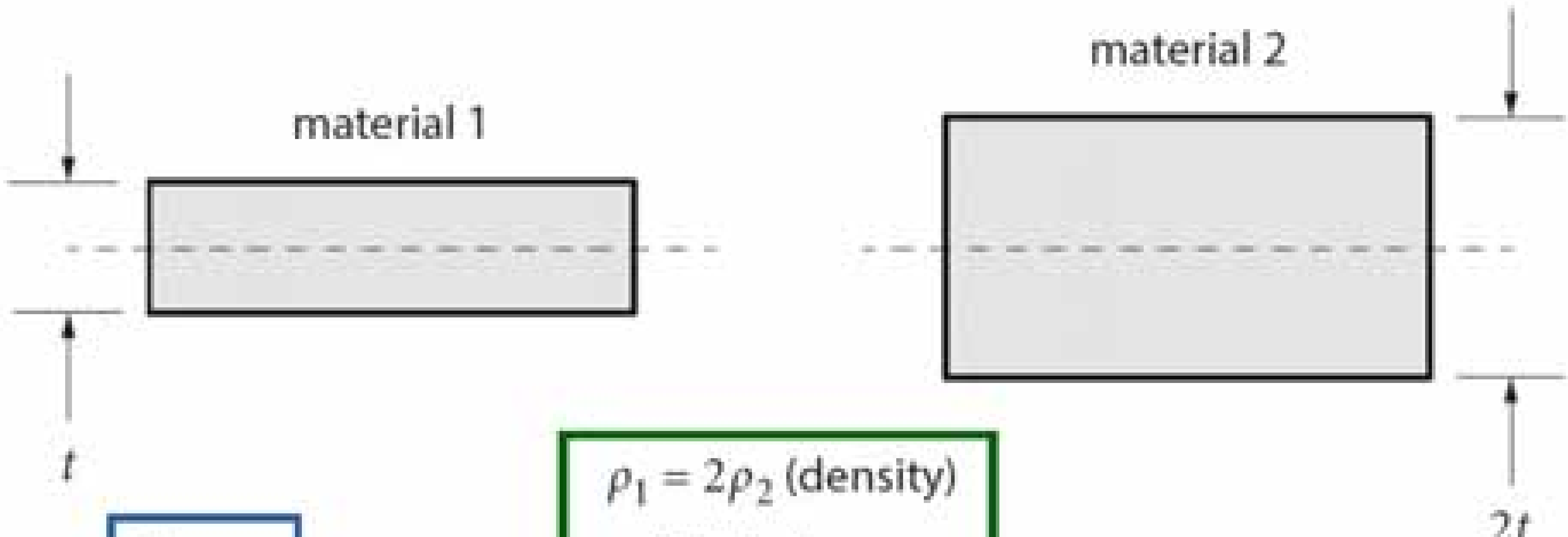
- Typical carbon/epoxy laminates compared to metals (approximate)
  - in-plane stiffness (compression)
  - in-plane strength (compression)

Compression Loading



1.11 — Bending Stiffness and Density Effect

- Previous comparisons were for **in-plane** stiffness/strength
- Now compare **out-of-plane** stiffness (bending stiffness) for a simple **rectangular** cross section
  - PMC composites are **less dense than metals** (~60% as much as aluminum)



$$I_1 = \boxed{\frac{1}{12} b t^3}$$

$\rho_1 = 2\rho_2$ (density)
weight is the same
$I_2 = 8 I_1$ (inertia)

$$I_2 = \frac{1}{12} b (2t)^3 = \boxed{8 \cdot \frac{1}{12} b t^3}$$

NOTE: The area moment of inertia of built-up sections (I-beam, etc) is not significantly affected by the effect of density (overall section inertia vs simple plate)

1.12 — Fatigue of Metals and Composites

- Metals
  - aircraft structures are often fatigue critical, especially pressurized fuselages
  - may require increased thickness/weight to accommodate fatigue requirements
- Carbon fiber composites
  - excellent resistance to fatigue damage
  - not usually fatigue critical after the structure is capable of the ultimate load requirement (with the presence of hole and allowing for impact damage)

End of Chapter 1

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Up Next

Chapter 2: Analysis Overview and Composites versus Metals