A Brief Overview of Structural Composite Materials

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Composites and their Constituents
Why fiber reinforcement?
Griffith’s measurements of tensile strength of glass fibers
(From Gordon, 1976)

Fibers for Reinforcement

- Glass (E-Glass, S-Glass)
- Graphite (carbon)
- Aramid (Kevlar™)
- Boron
- Basalt
- Other metals (steel, tungsten)
- Whiskers
- Oriented polyethylene (Spectra™)
- Carbon nanotubes
Specific modulus vs. specific strength for bulk materials and fibers

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**Lamina Types**

- **Continuous Fiber**
- **Woven**
- **Chopped Fiber**
- **Hybrids**
Composite Sandwich Structure

Thermosetting Polymer Matrix Materials

- Epoxies *
- Phenolics
- Polyesters
Advanced Thermoplastic Matrix Materials

• Polyether ether ketone (PEEK)
• Polyphenylene sulphide (PPS)
• Polysulphone (PS)
• Polyether sulfone (PES)
• Polyimide (PI)
• Polyetherimide (PEI)

Applications
900 KW wind turbine with composite blades
(Courtesy of GE Wind Energy, 2003)

2002 Ford Thunderbird with composite body panels
(Courtesy of Ford Motor Company, Research Staff)
Use of composites in Aston Martin Vanquish
(Courtesy of Ford Motor Company, Research Staff)

Automotive Composites Consortium
Focal Project 3 carbon fiber composite body-in-white
(Courtesy of Automotive Composites Consortium)
Composite Leaf Springs for Automotive Suspension
(Source: LiteFlex LLC)

Airport People Mover with Composite Cabins
(Source: TPI Composites Inc.)
Installation of Composite Bridge Deck
(Source: Hardcore Composites)

Cirrus S22 composite fuselage aircraft
(Courtesy Cirrus Design, 2003)
Use of composites in Boeing 777 airliner
(Courtesy of Boeing Company)

From M. Shuart, NASA Langley, 2001
F-22 Structural Materials are about 25% CFRP

- Wing skins are monolithic graphite / bismaleimide
- Horizontal and vertical stabilizers are graphite / bismaleimide

From M. Shuart, NASA Langley, 2001

Composite Applications in Military Fighter Aircraft

Performance and weight drivers have led to significant levels of composite application

From M. Shuart, NASA Langley, 2001
Overview of Composite Mechanics

Unidirectional Continuous Fiber Reinforcement

Material is Orthotropic, not Isotropic
Unidirectional Continuous Fiber Reinforcement

Elastic Properties:
E_1 = Longitudinal Young’s Modulus
E_2 = Transverse Young’s Modulus
G_{12} = In-plane shear Modulus
\nu_{12} = Major Poisson’s Ratio

Strength:
S_L = Longitudinal Strength
S_T = Transverse Strength
S_{LT} = Shear Strength

∴ Properties depend on orientation.

Classical Lamination Theory (CLT)

• More general than laminated beam theory
• Includes extensional, flexural and torsional deformations
• Includes coupling effects –
  bending / twisting
  bending / extension
  twisting / extension
• Does not include interlaminar stresses – each ply assumed to be in plane stress
Classical Lamination Theory – each lamina in plane stress \((\sigma_x, \sigma_y, \tau_{xy})\)

Exploded View of \([+45/-45/-45/+45]\) Symmetric Laminate
Exploded View of [-45/+45/-45/+45] Antisymmetric Laminate

Exploded View of [+60/0/-60] Quasi–Isotropic Laminate
Design Criteria (and Associated Failure Modes)

- Strength (excessive stresses)
- Stiffness (excessive deformations)
- Compressive and shear stability (buckling)
- Hygrothermal response (property degradation, expansion and contraction, residual stresses)
- Life (fatigue, creep)
- Weight (heavier than conventional design)
- Cost (not affordable)
- Manufacturability (impractical to build, warping due to residual coupling effects)

References on Mechanics of Composites

Mechanics of Composite Materials, R. M. Jones, Taylor & Francis, 1999
An Introduction to Composite Materials, D. Hull, Cambridge Univ. Press, 1996