AE-681 Composite Materials

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Course Credits: 4
LTPD: 3-0-0-0

Course Content:
• Introduction, Definition, classification, behaviors of unidirectional composites
• Analysis of lamina; constitutive classical laminate theory, thermal stresses,
• Design consideration, analysis of laminates after initial failure, interlaminar stresses, fracture mechanics, joints and experimental characterization,
• Micromechanics
• Factors influencing strength and stiffness failure modes,
• Performance under adverse environment
• Prediction of strength, stiffness
AE-681 Composite Materials

Reference Books/Material:
- Mechanics of Fibrous Composites, CT Herakovich.
- Analysis and Performance of Fibre Composites, BD Agarwal and LJ Broutman.
- Any other book on composite materials
- Research papers

Grading Policy:

Midsem I + II: 40%
Assignments: 20% (Individual + Group)
Endsem: 40%

- Absolute 40% for passing. Relative grading after that.
- Assignments should be submitted on due date by 5.00 pm. Late submission and copying will be heavily penalized!
- Attendance will be monitored regularly.
About Fibrous Composites
What is composite?

Definition:

• A material which is composed of two or more materials at a microscopic scale and have chemically distinct phases.

• Heterogeneous at a microscopic scale but statically homogeneous at macroscopic scale.

• Constituent materials have significantly different properties.

Classification of certain materials as a composite:

1. Combination of materials should result in significant property changes
2. Content of the constituents is generally more than 10% 
3. In general, property of one constituent is much greater ($\geq 5$) than the other
History: Oldest application/existence of composite material?

4000 B.C. – laminated writing material from the papyrus plant
1300 B.C. – Egyptians and Mesopotamian used straw bricks
1200 A.D. - Mongols invented the first composite bow
Composite: Formal Definition and History

Composite Bow – dates back to 3000 BC (Angara Dating)

Materials Used:

- Wood, Horn, Sinew (Tendon), Leather, Bamboo and Antler (Deer horn)

Horn and Antler: naturally flexible and resilient

Sinews: back tendons or hamstrings of cows and deer

Glue: From bladder of fish

Strings: Sinew, Horse hair, Silk

Overall processing time was almost a year!

Source: http://medieval2.heavengames.com
Composite: Formal Definition and History

Composite Bow – dates back to 3000 BC (Angara Dating)
Evolution of Materials

Composite: Examples from Day-to-Day Life

Examples:
1. Straw-bricks
2. Concrete
3. Wood (cellulose + lignin)
4. Human body (muscles + bones)
5. Tyres
6. Plywood
7. Sports good
Evolution of Materials

Use of Modern (Polymer) Composites:
During World War II –

Military application
Non-metallic shielding of Radomes
(to house electronic radar equipments)
Glass Fibre Reinforced Plastics (GFRP)

The first application of wood - composite laminates in -
Havilland Mosquito Fighter/Bomber of British Royal Air-Force
Evolution of Materials

Use of Modern (Polymer) Composites:
During World War II –

Attack on Pearl Harbour by Japanese Torpedo bomber

Source: http://en.wikipedia.org/wiki/Torpedo_bomber
Composite: Necessity

Why do you need composite materials?

**Enhanced desired properties!**

What are these desired properties?

- **Strength**
- **Stiffness**
- **Toughness**
- **Corrosion resistance**
- **Wear resistance**
- **Reduced weight**
- **Fatigue life**
- **Thermal/Electrical insulation and conductivity**
- **Acoustic insulation**
- **Energy dissipation**
- **Attractiveness, cost, .........................**
- **Tailorable properties**
Composite: Necessity

High Fatigue Life:

Composite: Necessity

High Specific Strength and Modulus:

Composite: Necessity

Stress strain curve for fibres:

Composite: Constituents

What are the constituents in a composite material?

1. Reinforcement:
   - discontinuous
   - stronger
   - harder

2. Matrix:
   - Continuous

What are the functions of a reinforcement?

1. Contribute desired properties
2. Load carrying
3. Transfer the strength to matrix
Composite: Constituents

What are the functions of a matrix?

1. Holds the fibres together
2. Protects the fibres from environment
3. Protects the fibres from abrasion (with each other)
4. Helps to maintain the distribution of fibres
5. Distributes the loads evenly between fibres
6. Enhances some of the properties of the resulting material and structural component (that fibre alone is not able to impart). These properties are such as:
   - Transverse strength of a lamina
   - Impact resistance
7. Provides better finish to final product
Classification of Composites

Based on the type of matrix material

- Polymer
  - Thermoset
  - Thermoplastic
- Metal
- Ceramic
- Carbon and Graphite
Classification of Composites

Based on the form of reinforcement

- **Fibre** - a filament with L/D very high (of the order 1000)
  - A composite with fibre-reinforcement is called **Fibrous Composite**

- **Whiskers** - nearly perfect single crystal fibre
  - Short, discontinuous, polygonal cross-section

- **Flake** - non fibrous with no long dimension
  - A composite with particles as reinforcement is called **Particulate Composite**

- **Particulate** - non fibrous with no long dimension
Classification of Composites

Based on the form of reinforcement

- Continuous fibre
  - Unidirectional
  - Bidirectional
    - Single layer
      - Laminates
      - Hybrids
    - Multilayer

- Discontinuous fibre
  - Woven
    - 3 Dimensional
  - Random
    - Preferred

Interest of this course!
Classification of Composites

Based on the form of reinforcement

- Random orientation
- Preferred orientation
Fibres as a Reinforcement

Fibre reinforced composites is the interest of this course!

Why do you make fibre reinforcements of a thin diameter?

1. As the diameter decreases the inherent flaws in the material also decreases and the strength increases.

Fibres as a Reinforcement

2. For better load transfer from matrix to fibre composites require larger surface area of the fibre matrix interface.

Fibre matrix interface area: \[ A = N \pi D L \]
(N – No. of fibres, D – fibre diameter, L – length of fibres)

Replace D by d (smaller diameter fibres)

For same Fibre Volume Fraction*: \[ n = N(D/d)^2 \]

New fibre matrix interface area: \[ A = N \pi D^2 L/d = 4 \times \text{Volume of fibres} / d \]

Thus, for a given fibre volume fraction, the area of the fibre-matrix interface is inversely proportional to the diameter of the fibre.

* Fibre Volume Fraction \((V_f) = \text{Volume of fibres/Volume of composite}\)
Matrix Volume Fraction \((V_m) = \text{Volume of matrix/Volume of composite}\)
\[ V_f + V_m = 1 \]
Fibres as a Reinforcement

3. The fibres should be flexible/pliant so that they can be bend easily without breaking. For example, woven fibre composites needs flexible fibres.

**Flexibility is defined as inverse of bending stiffness.**

Consider a fibre as beam under pure bending, then

EI – Bending stiffness or Flexural rigidity

Flexibility $\alpha \frac{1}{EI}$

where, $I = \pi \frac{d^4}{64}$

Flexibility $\alpha \frac{1}{Ed^4}$

Thus, flexibility of a fibre is inversely proportional to 4th power of the fibre diameter.
Types of Fibres

1. Advanced Fibres:

Fibres possessing high specific stiffness \([E/\rho]\) and specific strength \([\sigma/\rho]\))

a) Glass

b) Carbon

c) Organic

d) Ceramic
Types of Fibres

2. Natural Fibres:
   a) Animal fibres
      i) Silk  ii) Wool  iii) Spider silk
      iv) Sinew  v) Camel hair  vi)
   b) Vegetable fibres
      i) Cotton  ii) Jute  iii) Bamboo
      iv) Sisal  v) Maze  vi) Hemp
      vii) Sugarcane  viii) Banana  ix) Ramie
      x) Kapok  xi) Coir  xii) Abaca
      xii) Kenaf  xiv) Flax  xv) Raffia palm
   c) Mineral fibres
      i) Asbestos  ii) Basalt
      iii) Mineral wool  iv) Glass wool
### Types of Fibres

<table>
<thead>
<tr>
<th>Conventional Metals</th>
<th>Used for Advanced fibres</th>
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<tbody>
<tr>
<td>Hydrogen</td>
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<td>Lithium</td>
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<td>Sodium</td>
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<td>Magnesium</td>
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<td>Silicon</td>
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<td>Phosphorus</td>
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<td>Sulfur</td>
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<td>Chlorine</td>
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<td>Argon</td>
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<td>Boron</td>
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<td>Carbon</td>
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<td>Nitrogen</td>
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<td>Oxygen</td>
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<tr>
<td>Fluorine</td>
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<tr>
<td>Neon</td>
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<tr>
<td>Aluminium</td>
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<tr>
<td>Silicon</td>
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<td>Phosphorus</td>
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<td>Carbon</td>
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<td>Nitrogen</td>
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<td>Oxygen</td>
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<td>Chlorine</td>
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<tr>
<td>Argon</td>
<td></td>
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<tr>
<td>Lanthanide series</td>
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<tr>
<td>Actinide series</td>
<td></td>
</tr>
</tbody>
</table>

**Lanthanide series**

**Actinide series**
Advanced Fibres

Glass fibres:
- ancient Egyptians made containers from coarse fibres drawn from heat-softened glass
- produced by extruding molten glass at 1200°C
- passed through spinnerets of 1-2 mm diameter
- then drawing the filaments to produce fibres of diameter between 1-5 μm
- individual filament is small in diameter, isotropic in behaviour and very flexible
- variety of forms:
  - $E$ glass: high strength and high resistivity
  - $S_2$ glass: high strength, modulus and stability under extreme temperature, corrosive environment
  - $R$ glass: enhanced mechanical properties
  - $C$ glass: resists corrosion in an acid environment
  - $D$ glass: dielectric properties
- In general, glass fibres are isotropic in nature
**Advanced Fibres**

**Carbon fibres:**
- carbon-carbon covalent bond is the strongest in nature

**Guess who made the first carbon fibre?**

Thomas Edison made carbon fibre from bamboo when experimenting for light bulb!

**What is the difference between carbon and graphite fibres?**
- Carbon fibre contains 80-95% of carbon and graphite fibre contains more than 99% carbon
- Carbon fibre is produced at 1300°C while graphite fibre is produced in excess of 1900°C

**Caution!** - In general term carbon fibre is used for both fibres

**Made from two types of precursor materials:**
1) Polyacrylonitrile (PAN) (PAN Based)
2) Rayon Pitch - residue of petroleum refining (Pitch Based)
Advanced Fibres

**Carbon fibres:**

- Precursor fiber is carbonized rather than melting
- Filaments are made by controlled **pyrolysis** (chemical deposition by heat) of a precursor material in fiber form by heat treatment at temperature 1000-3000º C
- Different fibers have different morphology, origin, size and shape. The morphology is very dependent on the manufacturing process.
- The size of individual filament ranges from 3 to 14 µm. Hence, very flexible.
- Maximum temperature of use of the fibers ranges from 250 ºC to 2000 ºC. Properties change with temperature at higher temperature.
- The maximum temperature of use of a composite is controlled by the use temperature of the matrix
- Modulus and strength is controlled by the process-thermal decomposition of the organic precursor under well-controlled conditions of temperature and stress
- Heterogeneous microstructure consisting of numerous lamellar ribbons
- Thus, carbon fibers are anisotropic in nature
Advanced Fibres

Organic fibres: Aramid fibres

- **Aromatic polyamide** – family ofnylons.
- Polyamide 6 = nylon 6, Polyamide 6.6 = nylon 6.6
- Melt-spun from a liquid solution
- Morphology – radially arranged crystalline sheets resulting into anisotropic properties
- Filament diameter about 12 $\mu$m and partially flexible
- High tensile strength
- Intermediate modulus
- Very low elongation up to breaking point
- Significantly lower strength in compression
- Du Pont developed these fibers under the trade name Kevlar. From poly (p-Phenylene terephthalamide (PPTA) polymer
- 5 grades of Kevlar with varying engineering properties are available kevlar-29, Kevlar-49, Kevlar-100, Kevlar-119, Kevlar-129
Advanced Fibres

Ceramic Fibres: Boron

It was the first advanced fibre developed for structural application (Talley 1959)

• Ceramic monofilament fiber
• Manufactured by CVD on to a tungsten core of 12 µm diameter
• Fiber itself is a composite
• Circular cross section
• Fiber diameter ranges between 33 -400µm and typical diameter is 140µm
• Boron is brittle hence large diameter results in lower flexibility

Ceramic Fibres: Boron

• Thermal coefficient mismatch between boron and tungsten results in thermal residual stresses during fabrication cool down to room temperature
• When coated with Sic or B₄C can be used to reinforce light alloys
• Strong in both tension and compression
• Exhibit linear axial stress-strain relationship up to 650°C
• High cost of production
Advanced Fibres

Ceramic fibres: Alumina (Al$_2$O$_3$)

• These are ceramics fabricated by spinning a slurry mix of alumina particles and additives to form a yarn which is then subjected to controlled heating.

• Fibers retain strength at high temperature
Advanced Fibres

Ceramic fibres: Silicon Carbide (SiC)

First method: CVD on tungsten or carbon
- Carbon – pyrolytic graphite coated carbon core SCS-6
- This fiber is similar in size and microstructure to boron
- Relativity stiff, size of 140 µm

Second method: (Nicalon by Japan)
- Controlled pyrolysis (chemical deposition by heat) of a polymeric precursor
- Filament is similar to carbon fiber in size.
- Size ≈ 14 µm
- More flexible

• SiC shows high structural stability and strength retention even at temperature above 1000ºC
Cross Sectional Shapes of Fibres

<table>
<thead>
<tr>
<th>Shape</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular:</td>
<td>Glass, Carbon, Organic fibres, Alumina, Silicon Carbide</td>
</tr>
<tr>
<td>Elliptical:</td>
<td>Alumina, Mullite</td>
</tr>
<tr>
<td>Triangular:</td>
<td>Silk, Silicon Carbide whiskers</td>
</tr>
</tbody>
</table>
Cross Sectional Shapes of Fibres

<table>
<thead>
<tr>
<th>Shape</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexagonal:</td>
<td>Sapphire (Al₂O₃) whiskers</td>
</tr>
<tr>
<td>Rounded Triangular:</td>
<td>Sapphire (Al₂O₃) single crystal fibre</td>
</tr>
<tr>
<td>Kidney bean:</td>
<td>Carbon</td>
</tr>
<tr>
<td>Trilobal:</td>
<td>Carbon, Rayon</td>
</tr>
</tbody>
</table>
Types of Matrix Materials

Polymers:

**Thermoplastic:** Soften upon heating and can be reshaped with heat & pressure

**Thermosetting:** become cross linked during fabrication & do not soften upon reheating

Metals:

Ceramics:

Carbon and Graphite:
Types of Matrix Materials

Thermoplastics:

polypropylene,
polyvinyl chloride (PVC),
nylon,
polyurethane,
poly-ether-ether ketone (PEEK),
polyphenylene sulfide (PPS),
polysulfone

• higher toughness
• high volume
• low- cost processing
• Temperature range $\geq 225^\circ$C
Types of Matrix Materials

Thermoplastics:
Thermoplastics are increasingly used over thermosets because of the following reasons:

• Processing is faster than thermoset composites since no curing reaction is required. Thermoplastic composites require only heating, shaping and cooling.

• Better properties:
  - high toughness (delamination resistance) and damage tolerance,
  - low moisture absorption
  - chemical resistance

• They have low toxicity.

• Cost is high!
Types of Matrix Materials

Thermosets:
- polyesters,
- epoxies,
- polyimides
- Other resins

Polyesters:
- Low cost
- Good mechanical strength
- Low viscosity and versatility
- Good electrical properties
- Good heat resistance
- Cold and hot molding
- Curing temperature is 120°C
Types of Matrix Materials

**Thermosets:**

**Epoxy:**

- Epoxy resins are widely used for most advanced composites.

**Advantages:**

- Low shrinkage during curing
- High strength and flexibility
- Adjustable curing range
- Better adhesion between fibre and matrix
- Better electrical properties
- Resistance to chemicals and solvents
Types of Matrix Materials

Thermosets:

Epoxy:

Disadvantages:

• somewhat toxic in nature
• limited temperature application range upto 175°C
• moisture absorption affecting dimensional properties
• high thermal coefficient of expansion
• slow curing
Types of Matrix Materials

Thermosets:

Polyimides:

• Excellent mechanical strength
• Excellent strength retention for long term in 260-315°C (500-600°F) range and short term in 370°C (700°F) range
• Excellent electrical properties
• Good fire resistance and low smoke emission
• Hot molding under pressure and
• Curing temperature is 175°C (350°F) and 315°C
Types of Matrix Materials

Problems with using polymer matrix materials:

- Limited temperature range
- Susceptibility to environmental degradation due to moisture, radiation, atomic oxygen (in space)
- Low transverse strength
- High residual stress due to large mismatch in coefficients of thermal expansion both fiber and matrix
- Polymer matrix can not be used near or above the glass transition temperature
Types of Matrix Materials

**Metals:**

- Aluminum
- Titanium
- Copper

- Higher use temperature range
  - Aluminum matrix composite – use temperature range above 300ºC and titanium at 800 ºC
- Higher transfer strength, toughness (in contrast with brittle behavior of polymers and ceramics)
- The absence of moisture & high thermal conductivity (copper)

**Disadvantages:**

- Heavier
- More susceptible to interface degradation at the fiber/matrix interface and to corrosion
Types of Matrix Materials

**Ceramics:**

- Carbon,
- Silicon carbide and
- Silicon nitride

- Ceramic have use very high temperature range > 2000 °C
- High elastic modulus
- Low density

**Disadvantages:**

- Brittleness
- Susceptible to flows
Types of Matrix Materials

**Carbon:**

- carbon fibres in carbon matrix – carbon/carbon composites
- used under extreme mechanical and thermal loads (space applications)

**Advantages:**
- Low specific weight
- High heat absorption capacity
- Resistance to thermal shock
- High resistance to damage
- Exceptional frictional properties at high energy levels
- Resistance to high temperatures
- Chemical inertness
- Low coefficient of thermal expansion (excellent dimensional stability)

**Disadvantages:**
- Low resistance to oxidation above 500°C
- High cost of materials and manufacturing
Properties of Fibre and Matrix Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density $\rho$, $g/cm^3$ (lb/in$^3$)</th>
<th>Modulus $E_L$, GPa (Msi)</th>
<th>Poisson’s Ratio $v_L$</th>
<th>Strength $\sigma_L$, MPa (ksi)</th>
<th>Specific Stiffness $(E/\rho)/\rho$</th>
<th>Specific Strength $(\sigma/\rho)/\rho$</th>
<th>Thermal Expansion Coefficient</th>
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</thead>
<tbody>
<tr>
<td>Metals</td>
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<tr>
<td>Steel</td>
<td>7.8(0.284)</td>
<td>200(29)</td>
<td>0.32</td>
<td>1724(250)</td>
<td>1.0</td>
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<td>12.8(7.1)</td>
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<td>Aluminum</td>
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<td>1.0</td>
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<tr>
<td>Titanium</td>
<td>4.5(0.163)</td>
<td>91(13.2)</td>
<td>0.36</td>
<td>758(110)</td>
<td>0.95</td>
<td>1.2</td>
<td>8.8(4.9)</td>
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<tr>
<td>Fibres (Axial Properties)</td>
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<tr>
<td>AS4</td>
<td>1.80(0.065)</td>
<td>235(34)</td>
<td>0.20</td>
<td>3599(522)</td>
<td>5.1</td>
<td>11.1</td>
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<td>T300</td>
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<td>-</td>
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<td>Boron</td>
<td>2.6(0.094)</td>
<td>385(55.8)</td>
<td>0.21</td>
<td>3799(551)</td>
<td>5.8</td>
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<td>2000(290)</td>
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<td>Alumina</td>
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<td>379(55)</td>
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<td>1585(230)</td>
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<td>S-2 Glass</td>
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<td>5.4(3.0)</td>
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<td>Sapphire</td>
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<td>435(63)</td>
<td>0.28</td>
<td>3600(522)</td>
<td>4.3</td>
<td>5.1</td>
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<td>Epoxy</td>
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<td>4.6(0.67)</td>
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<td>58.6(8.5)</td>
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<td>63(35)</td>
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<tr>
<td>Polymide</td>
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<td>3.5(0.5)</td>
<td>0.35</td>
<td>103(15)</td>
<td>0.03</td>
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<td>Copper</td>
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<td>400(58)</td>
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</tr>
<tr>
<td>Silicon carbide</td>
<td></td>
<td>400(58)</td>
<td>0.25</td>
<td>310(45)</td>
<td>4.9</td>
<td>0.5</td>
<td>4.8(2.67)</td>
</tr>
</tbody>
</table>
Forms of Fibrous Composites

Layered composites:

Layer
Lamina
Ply

any of the term is used

Axial – along fibre length (1)

Transverse – perpendicular to fibre length
2 – in-plane transverse
3 – out of plane transverse
Forms of Fibrous Composites

Layered composites:

Laminate
Forms of Fibrous Composites

Woven Bi-directional composite:

Three types of weave

Our interest is lamina and laminate!

http://www.britannica.com/EBchecked/topic/638448/weaving
Types of Fibrous Composites

Fibre and Matrix Systems:

Notation:

- fibre/matrix
- carbon/epoxy, glass/epoxy, Kevlar/epoxy
- proportion of contents must be mentioned (volume fraction)

Examples:

- AS4/PEEK
- T300/5208
- T700/M21
- IM8/Epoxy
- Kevlar/Epoxy
- Boron/Al
- SCS-6/Ti-15-3
- S2 Glass/Epoxy
Properties of Fibrous Composites

- Reduction in properties Compared to reinforcement properties
- Axial along fibre length
- Transverse perpendicular to fibre
- Degree of orthotropy

<table>
<thead>
<tr>
<th>Material</th>
<th>AS4/35 01-6</th>
<th>T300/5208</th>
<th>Kevlar/epoxy</th>
<th>Boron/Al</th>
<th>SCS-6/Ti-15-3</th>
<th>S-2glass/epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³ (lb/in³))</td>
<td>1.52 (0.055)</td>
<td>1.54 (0.056)</td>
<td>1.38 (0.05)</td>
<td>2.65 (0.096)</td>
<td>3.86 (0.14)</td>
<td>4.35 (0.131)</td>
</tr>
<tr>
<td>Axial modulus $E_1$, GPa(Msi)</td>
<td>148 (21.5)</td>
<td>132 (19.2)</td>
<td>76.8 (11.0)</td>
<td>227 (32.9)</td>
<td>221 (32)</td>
<td>43.5 (6.31)</td>
</tr>
<tr>
<td>Transverse modulus $E_2$, GPa(Msi)</td>
<td>10.50 (1.46)</td>
<td>10.8 (1.56)</td>
<td>5.5 (0.8)</td>
<td>139 (20.2)</td>
<td>145 (21)</td>
<td>11.5 (1.87)</td>
</tr>
<tr>
<td>Poisson’s ratio $v_{12}$</td>
<td>0.30</td>
<td>0.24</td>
<td>0.34</td>
<td>0.24</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Poisson’s ratio $v_{13}$</td>
<td>0.59</td>
<td>0.59</td>
<td>0.37</td>
<td>0.36</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Shear modulus $G_{12}$, GPa(Msi)</td>
<td>5.61 (0.81)</td>
<td>5.65 (0.82)</td>
<td>2.07 (0.3)</td>
<td>57.6 (8.35)</td>
<td>53.2 (7.78)</td>
<td>3.45 (0.50)</td>
</tr>
<tr>
<td>Shear modulus $G_{23}$, GPa(Msi)</td>
<td>3.17 (0.46)</td>
<td>3.36 (0.49)</td>
<td>1.4 (0.20)</td>
<td>49.1 (7.12)</td>
<td>51.7 (7.50)</td>
<td>4.12 (0.60)</td>
</tr>
<tr>
<td>Modulus ratio $E_1/E_2$</td>
<td>12.6</td>
<td>12.3</td>
<td>14.8</td>
<td>1.6</td>
<td>1.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Axial tensile strength $x_T$, MPa(ksi)</td>
<td>2137 (310)</td>
<td>1513 (219.5)</td>
<td>1380 (200)</td>
<td>1290 (187)</td>
<td>1517 (220)</td>
<td>1724 (250)</td>
</tr>
<tr>
<td>Transverse tensile strength $Y_T$, MPa(ksi)</td>
<td>53.4 (7.75)</td>
<td>43.4 (6.3)</td>
<td>27.6 (4.0)</td>
<td>117 (17)</td>
<td>317 (46)</td>
<td>41.4 (6.0)</td>
</tr>
<tr>
<td>Strength ratio $X_T/Y_T$</td>
<td>27</td>
<td>33</td>
<td>30</td>
<td>11</td>
<td>4.8</td>
<td>42</td>
</tr>
<tr>
<td>Axial CTE $\alpha_1$, $\mu^\circ C(\mu^\circ F)$</td>
<td>-0.8 (-0.44)</td>
<td>-0.77 (-0.43)</td>
<td>-4 (-2.2)</td>
<td>5.94 (3.3)</td>
<td>6.15 (3.4)</td>
<td>6.84 (3.8)</td>
</tr>
<tr>
<td>Transverse CTE $\alpha_2$, $\mu^\circ C(\mu^\circ F)$</td>
<td>29 (16)</td>
<td>25 (13.6)</td>
<td>57 (32)</td>
<td>16.6 (9.2)</td>
<td>7.90 (4.4)</td>
<td>29 (16)</td>
</tr>
<tr>
<td>Fiber volume fraction $V_f$</td>
<td>0.62</td>
<td>0.62</td>
<td>0.55</td>
<td>0.46</td>
<td>0.39</td>
<td>0.60</td>
</tr>
<tr>
<td>Ply thickness, mm/in</td>
<td>0.127 (0.005)</td>
<td>0.127 (0.005)</td>
<td>0.127 (0.005)</td>
<td>0.178 (0.007)</td>
<td>0.229 (0.009)</td>
<td></td>
</tr>
</tbody>
</table>
Properties of Fibrous Composites

Parameters affecting the properties of fibrous composites:

1. Length of the fibre

2. Orientation of the fibre (with respect to the loading direction)

3. Shape of the fibre

4. Distribution of the fibres in matrix material

5. Properties of the fibres

6. Properties of the matrix material

7. Proportion of fibre and matrix material
Factors Affecting Fabrication Processes

1. User requirements
2. Performance requirements
3. Total production volume
4. Production rate
5. Cost of production
6. Size of the production
7. Surface finish of the final product
8. Geometry of the product
9. Material
Fabrication Processes of Fibrous Composites

- More than 50 processes depending upon the fibre and matrix type and nature

- Wet/Hand Lay-Up
- Spray Lay-Up
- Vacuum Bagging
- Filament Winding
- Pultrusion
- Resin Transfer Molding (RTM)
- Braiding
- Vacuum Assisted RTM
- Centrifugal Casting
Fabrication Processes of Fibrous Composites

- Wet/Hand Lay-Up

Source: http://www.gurit.com
Fabrication Processes of Fibrous Composites

• **Spray Lay-Up**

Source: http://www.gurit.com
Fabrication Processes of Fibrous Composites

- Vacuum Bagging

Source: http://www.gurit.com
Fabrication Processes of Fibrous Composites

• Filament Winding

Source: http://www.gurit.com
Fabrication Processes of Fibrous Composites

- Pultrusion

Source: http://www.gurit.com
Fabrication Processes of Fibrous Composites

- Resin Transfer Moulding (RTM)

Source: http://www.gurit.com
Fabrication Processes of Fibrous Composites

• Braiding
Fabrication Processes of Fibrous Composites

- **Centrifugal Casting**
Applications of Fibrous Composites

• Aerospace/Military:

• Civil:

• Electronic:

• Energy:

• Automobile/Transportation:

• Sports:

• Medical:

• Marine:
Applications of Fibrous Composites

Aerospace: Use of composites in LCA Tejas

- Glass Composite
- Aluminium
- Kevlar Composite
- Carbon Composite
Applications of Fibrous Composites

Aerospace: Use of composites in LCH
Applications of Fibrous Composites

Aerospace: Use of composites in LCH
Applications of Fibrous Composites

Aerospace: Helicopter Blade

Cross-Sectional View of a Composite Blade
Applications of Fibrous Composites

Automobile/Transportation:
Applications of Fibrous Composites

Sports:
Applications of Fibrous Composites

Wind Energy:
Applications of Fibrous Composites

Medical:
Applications of Fibrous Composites

Civil/Infrastructure:
Applications of Fibrous Composites

**Marine:**

*water lubricated propeller shaft bearings*
Disadvantages of Composite Materials

1. High cost of raw materials and fabrication.
2. Composites are brittle and thus are more easily damagable.
3. Transverse properties may be weak.
4. Matrix is weak, therefore, low toughness.
5. Reuse and disposal may be difficult.
6. Health hazards during manufacturing, during and after use.
7. Joining to parts is difficult.
8. Repair introduces new problems, for the following reasons:
   - Materials require refrigerated transport and storage and have limited shelf life.
   - Hot curing is necessary in many cases requiring special tooling.
   - Curing takes time.
9. Analysis is difficult.
10. Matrix is subject to environmental degradation.
References and Additional Reading


Natural Fibres

Animal fibres:
Silk:

Soft, long fibres,

Lustrous

Yarns, threads in textile uses
Natural Fibres

Animal fibres:
Spider Silk:

Protein fibre
Natural Fibres

Vegetable fibres:
Cotton:

Soft, fluffy, short fibres

12-20 µm diameter, 10-60 mm length

Yarns, threads in textile uses
Natural Fibres

Vegetable fibres:

Hemp:

Long fibres about 2 m in length

Lustrous like linen with special processing

Strong and durable. Used for twine, yarn, rope, string

Used as artificial sponge
# Natural Fibres

## Comparison of Properties:

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Density (g/cm³)</th>
<th>Elongation (%)</th>
<th>Tensile Strength (MPa)</th>
<th>Young's Modulus (Gpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>1.5 – 1.6</td>
<td>7.0 – 8.0</td>
<td>287 – 597</td>
<td>5.5 – 12.6</td>
</tr>
<tr>
<td>Jute</td>
<td>1.3</td>
<td>1.5 – 1.8</td>
<td>393 – 773</td>
<td>26.5</td>
</tr>
<tr>
<td>Flax</td>
<td>1.5</td>
<td>2.7 – 3.2</td>
<td>345 – 1035</td>
<td>27.6</td>
</tr>
<tr>
<td>Hemp</td>
<td>---</td>
<td>1.6</td>
<td>690</td>
<td>---</td>
</tr>
<tr>
<td>Ramie</td>
<td>---</td>
<td>3.6 – 3.8</td>
<td>400 – 938</td>
<td>61.4 – 128</td>
</tr>
<tr>
<td>Sisal</td>
<td>1.5</td>
<td>2.0 – 2.5</td>
<td>511 – 635</td>
<td>9.4 – 22.0</td>
</tr>
<tr>
<td>Coir</td>
<td>1.2</td>
<td>30.0</td>
<td>175</td>
<td>4.0 – 6.0</td>
</tr>
<tr>
<td>Viscose (cord)</td>
<td>---</td>
<td>11.4</td>
<td>593</td>
<td>11.0</td>
</tr>
<tr>
<td>Soft Wood Kraft</td>
<td>1.5</td>
<td>---</td>
<td>1000</td>
<td>40.0</td>
</tr>
</tbody>
</table>