Lecture 1: Introduction to composite materials

At the end of this lecture you will have:

☑ An understanding of what are composite materials

☑ What the various types of composite materials

☑ Why they are used

☑ How they are designed
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✓ What are composites materials?
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☑ What are composites materials?

Many materials are composites made up of at least two constituents.
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✓ What are the various types of composites materials?
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✓ What are the various types of composites materials?

Typically made of a matrix and 1 or more reinforcements

They have different compositions, shapes and physical/chemical properties

![Diagram of composite materials](image-url)
What are the various types of composites materials?

- **Matrices**
  - **Polymer**
    - Thermosets (Epoxy, Polyester)
    - Thermoplastics (Polystyrene, Nylons)
  - **Metal**
    - Alloys (Steels, Aluminiums)
  - **Ceramic**
    - Glass
    - Ceramics (Semiconductors, Cermets)
    - Cements
  - **Carbon and Graphite**
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What are the various types of composites materials?

- Fibres
  - Short
  - Long
  - Plies
- Whiskers
  - Single crystals
- Laminar
- Flakes
- Filled
- Particulates
- Microspheres

The arrangement of the reinforcement (distribution, size, shape, and orientation matters)
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✓ What are the various types of composites materials?

The type, distribution, size, shape, orientation, and arrangement of the reinforcement will determine the properties of the composites material and its anisotropy.
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✓ What are the various types of composites materials?

Classification of composites:
  • Matrices:
    Organic Matrix Composites (OMCs)
    Polymer Matrix Composites (PMCs)
    carbon-carbon composites
    Metal Matrix Composites (MMCs)
    Ceramic Matrix Composites (CMCs)
  • Reinforcements:
    Fibres reinforced composites
    Laminar composites
    Particulate composites
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✓ Why are composites materials used?
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✓ Why are composites materials used?

Advantages
• Lower density (20 to 40%)
• Higher directional mechanical properties (specific tensile strength (ratio of material strength to density) 4 times greater than that of steel and aluminium.
• Higher Fatigue endurance.
• Higher toughness than ceramics and glasses.
• Versatility and tailoring by design.
• Easy to machine.
• Can combine other properties (damping, corrosion).
• Cost.
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✓ Why are composites materials used?

Disadvantages
• Not often environmentally friendly.
• Low recyclability.
• Cost can fluctuate.
• Can be damaged.
• Anisotropic properties.
• Matrix degrades.
• Low reusability.
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✓ Why are composites materials used?

Interesting mix of properties in which density is always a plus

![Diagram showing a scatter plot of Young's Modulus (E) versus Density (ρ) for various materials, including wood, carbon fibre composites, and others.]

Fig.1.1 Data for some engineering materials, in the form of a map of Young’s modulus against density
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✓ Why are composites materials used?

High versatility of shape and properties by design
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✓ How are composites materials designed?
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✓ How are composites materials designed?

By comparing, and trying to combine the properties of the various engineered materials to meet the specifications of the usage planned for the composite.
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✓ How are composites materials designed?

Properties of some matrices

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Density $\rho$ (Mg m$^{-3}$)</th>
<th>Young’s modulus $E$ (GPa)</th>
<th>Poisson’s ratio $\nu$</th>
<th>Tensile strength $\sigma_t$ (GPa)</th>
<th>Failure strain $\epsilon_f$ (%)</th>
<th>Thermal expansivity $\alpha$ ($10^{-5}$ K$^{-1}$)</th>
<th>Thermal conductivity $K$ (W m$^{-1}$ K$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Thermosets</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Epoxies</em></td>
<td>1.1–1.5</td>
<td>3–6</td>
<td>0.38–0.40</td>
<td>0.035–0.1</td>
<td>1–6</td>
<td>60</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Polyesters</em></td>
<td>1.2–1.5</td>
<td>2.0–4.5</td>
<td>0.37–0.39</td>
<td>0.04–0.09</td>
<td>2</td>
<td>100–200</td>
<td>0.2</td>
</tr>
<tr>
<td><em>Thermoplastics</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nylon 6.6</td>
<td>1.14</td>
<td>1.4–2.8</td>
<td>0.3</td>
<td>0.06–0.07</td>
<td>40–80</td>
<td>90</td>
<td>0.2</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0.90</td>
<td>1.0–1.4</td>
<td>0.3</td>
<td>0.02–0.04</td>
<td>300</td>
<td>110</td>
<td>0.2</td>
</tr>
<tr>
<td>PEEK</td>
<td>1.26–1.32</td>
<td>3.6</td>
<td>0.3</td>
<td>0.17</td>
<td>50</td>
<td>47</td>
<td>0.2</td>
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<tr>
<td><em>Metals</em></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Al</td>
<td>2.70</td>
<td>70</td>
<td>0.33</td>
<td>0.2–0.6</td>
<td>6–20</td>
<td>24</td>
<td>130–230</td>
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<tr>
<td>Mg</td>
<td>1.80</td>
<td>45</td>
<td>0.35</td>
<td>0.1–0.3</td>
<td>3–10</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>Ti</td>
<td>4.5</td>
<td>110</td>
<td>0.36</td>
<td>0.3–1.0</td>
<td>4–12</td>
<td>9</td>
<td>6–22</td>
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<tr>
<td><em>Ceramics</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Borosilicate glass</td>
<td>2.3</td>
<td>64</td>
<td>0.21</td>
<td>0.10</td>
<td>0.2</td>
<td>3</td>
<td>12</td>
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<tr>
<td>SiC</td>
<td>3.4</td>
<td>400</td>
<td>0.20</td>
<td>0.4</td>
<td>0.1</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>$\text{Al}_2\text{O}_3$</td>
<td>3.8</td>
<td>380</td>
<td>0.25</td>
<td>0.5</td>
<td>0.1</td>
<td>8</td>
<td>30</td>
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</tbody>
</table>
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✓ How are composites materials designed?

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Density $\rho$ (Mg m$^{-3}$)</th>
<th>Young’s modulus $E$ (GPa)</th>
<th>Poisson’s ratio $\nu$</th>
<th>Tensile strength $\sigma_t$ (GPa)</th>
<th>Failure strain $e_t$ (%)</th>
<th>Thermal expansivity $\alpha (10^{-6} \text{ K}^{-1})$</th>
<th>Thermal conductivity $K$ (W m$^{-1}$ K$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC monofilament</td>
<td>3.0</td>
<td>400</td>
<td>0.20</td>
<td>2.4</td>
<td>0.6</td>
<td>4.0</td>
<td>10</td>
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<tr>
<td>Boron monofilament</td>
<td>2.6</td>
<td>400</td>
<td>0.20</td>
<td>4.0</td>
<td>1.0</td>
<td>5.0</td>
<td>38</td>
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<tr>
<td>HM$^a$ carbon</td>
<td>1.95</td>
<td>axial 380 radial 12</td>
<td>0.20</td>
<td>2.4</td>
<td>0.6</td>
<td>axial -0.7</td>
<td>axial 105</td>
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<tr>
<td>HS$^b$ carbon</td>
<td>1.75</td>
<td>axial 230 radial 20</td>
<td>0.20</td>
<td>3.4</td>
<td>1.1</td>
<td>axial -0.4</td>
<td>axial 24</td>
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<tr>
<td>E-glass</td>
<td>2.56</td>
<td>76</td>
<td>0.22</td>
<td>2.0</td>
<td>2.6</td>
<td>4.9</td>
<td>13</td>
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<tr>
<td>Nicalon$^{TM}$</td>
<td>2.6</td>
<td>190</td>
<td>0.20</td>
<td>2.0</td>
<td>1.0</td>
<td>6.5</td>
<td>10</td>
</tr>
<tr>
<td>Kevlar$^{TM}$ 49</td>
<td>1.45</td>
<td>axial 130 radial 10</td>
<td>0.35</td>
<td>3.0</td>
<td>2.3</td>
<td>axial -6</td>
<td>axial 0.04</td>
</tr>
<tr>
<td>FP$^{TM}$ fibre</td>
<td>3.9</td>
<td>380</td>
<td>0.26</td>
<td>2.0</td>
<td>0.5</td>
<td>8.5</td>
<td>8</td>
</tr>
<tr>
<td>Saffil$^{TM}$</td>
<td>3.4</td>
<td>300</td>
<td>0.26</td>
<td>2.0</td>
<td>0.7</td>
<td>7.0</td>
<td>5</td>
</tr>
<tr>
<td>SiC whisker</td>
<td>3.2</td>
<td>450</td>
<td>0.17</td>
<td>5.5</td>
<td>1.2</td>
<td>4.0</td>
<td>100</td>
</tr>
<tr>
<td>Cellulose (flax)</td>
<td>1.0</td>
<td>80</td>
<td>0.3</td>
<td>2.0</td>
<td>3.0</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

$^a$ High modulus

$^b$ High strength