1 4th Year Materials Engineering

Mechanics of Composite Materials

2 Composite Materials

2.1 Composite Material

Material composed of two or more phases $\Rightarrow$ Heterogenous

2.2 Engineering Composites:

- Bulk matrix
- Embedded reinforcing materials

2.3 Why?

To produce better materials with desired properties:

- Cost
- Weight
- Stiffness
- Strength

3 Composite Materials

3.1 Reinforcements

The reinforcements can have different forms:

Particles: e.g. Gravel mixed into bituminous road surfaces

Fibres: e.g. Carbon fibre reinforced epoxy for canoes

Generally reinforcements are **stiffer** and **stronger** than the surrounding matrix.

3.2 Fibre Reinforced Polymers

Fibre reinforced polymers are the main focus of these lectures.

4 Fibre Reinforced Polymers – Matrix

4.1 Thermoset Matrix

- E.g. Epoxy ($$) or Thermoset Polyester ($)

- Precursor liquids have low viscosity ⇒ good wetting of fibres
- Moderate cost, but with good temperature range (e.g. up to $175°\mathrm{C}$ for epoxies).
- Large components

Composite materials incorporate **reinforcing materials** into a **bulk matrix** in order to optimise performance of engineering components and achieve a good balance of material properties. The reinforcements are generally stiffer and stronger than the matrix.

4.2 Thermoplastic Matrix

- Later innovation
- E.g. Polypropylene, Nylon
- Injection moulding & Extrusion (cheap high volume production)
  - Viscosity problematic (i.e. the presence of reinforcements increases the viscosity of the melt and can cause problems in mould filling).

5 Fibre Reinforced Polymers – Fibres

There is a wide variety of fibrous reinforcement:

5.1 Form

- Bundles of Fibres
- Woven Fabrics
- Chopped Fibres (inj. moulding)
- "Prepreg" sheets
- etc.,

Fibres have a coating (**"size"**) to protect them and to chemically bond with the matrix.

6 Fibre Reinforced Polymers – Fibres

6.1 Material

- Glass
  - ○ Mostly $\mathrm{SiO_2}$ plus other oxides
  - ○ No crystallinity allowed (rapid cooling sees to this).
  - \+ Cheap & v. common
  - \+ Temperature resistant
  - \+ Isotropic
  - \+ Transparent
  - – Vulnerable to surface damage & moisture

7 Fibre Reinforced Polymers – Fibres

7.1 Material

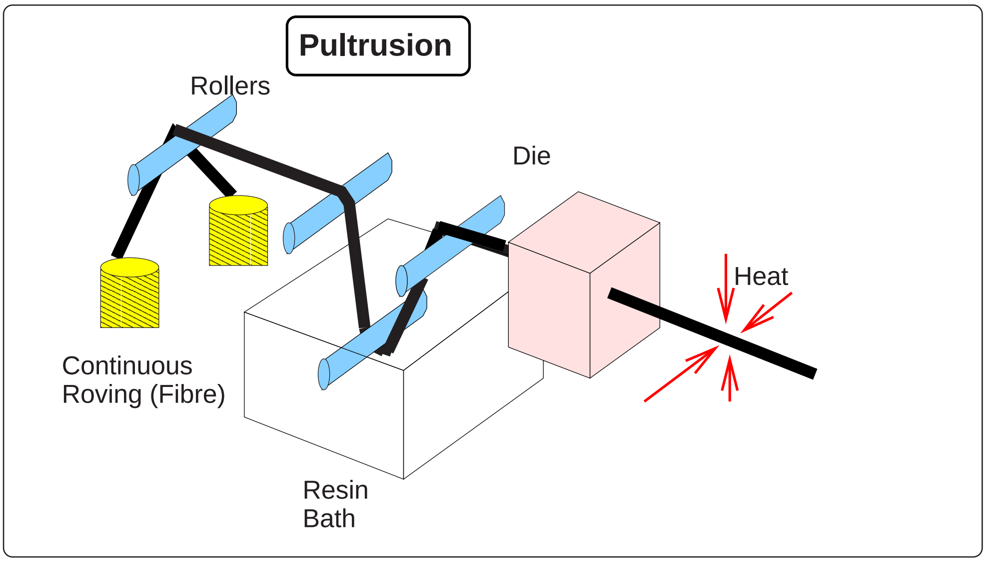
- Carbon
  - + Resists chemicals, moisture and fatigue
  - + High electrical & thermal conductivity
  - + Low thermal expansion
  - – Graphite ⇒ Black colour
  - – Highly anisotropic – requires careful manufacturing
  - – Expensive
- Oriented polymeric fibres (e.g. Kevlar®)
  - + Excellent mechanical properties
  - – Expensive
  - – Yellow
  - – Anisotropic

8 Fibre Reinforced Polymers – Fabrication

Various methods are used to fabricate components using composite materials

- Autoclave Curing
  - – Hand lay-up
  - – Hand spray-up
- Filament winding
- Pultrusion
- Braiding
- Injection moulding
- etc.,

9 Fibre Reinforced Polymers – Fabrication



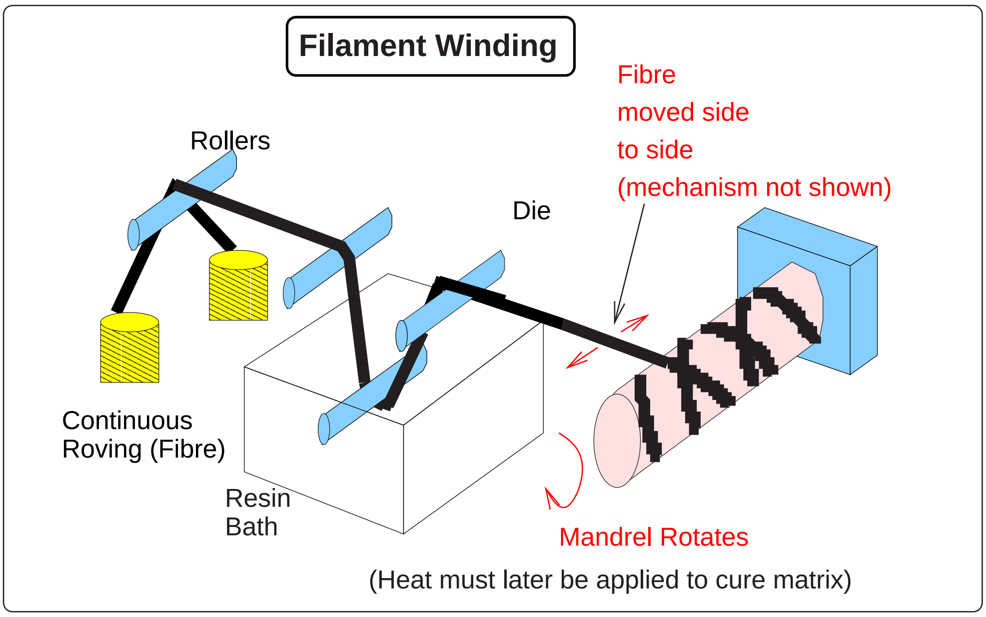


Diagram after Principles of Polymer Engineering, McCrum, N. G. et al; Wiley, 1998.

10 Fibre Reinforced Polymers – Fabrication

Photograph omitted.

Photo from Mechanics of Fibrous Composites, Herakovich, C. T.; Wiley, 1998.

11 Fibre Reinforced Polymers – Fabrication

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12 Fibre Reinforced Polymers – Fabrication

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13 Fibre Reinforced Composites – Fabrication

13.1 Laminates

Probably the most common type of fibre reinforced composite is the **laminate**.

- Multiple **laminae** stacked to form laminate
- Lamina ⇔ Layer ⇔ Ply
- Lamina = fibres + polymer-matrix
- Pre-preg layers already include matrix
  - Refrigeration to prevent curing
- Can assemble laminate by hand, place in autoclave to cure (under heat and pressure) and produce finished laminate
- Individual Lamina often unidirectional, but other arrangements possible too (e.g. woven).

14 Mechanics of Fibre Reinforced Composites

In all fabrication techniques, **fibre alignment** is a crucial part of the process.
Material properties are different depending on direction. Fibres are aligned to produce desired properties

- Uniaxial (all fibres parallel and in one direction)
- Angle Ply (fibres along more than one direction, e.g. $0°$, $45°$, $90°$, $-45°$, $0°$. Often layered).
- Cross Ply (direction of fibres alternates from layer to layer at right angles e.g. $0°$, $90°$, $0°$, $90°$.
- Random in-the-plane
- Random in 3 Dimensions

In general such materials are **anisotropic**. We will look first at how to describe anisotropic materials

Fibre reinforced polymers are the main focus of these lectures. In general such materials are **anisotropic**. We will look first at how to describe anisotropic materials. This will allow us to predict the behaviour of composite materials.

15 Mechanics of Fibre Reinforced Composites

15.1 Micro Mechanics

Looks at very detailed behaviour

- Properties of fibre
- Properties of matrix
- Fibre–Matrix interface

15.2 Macro Mechanics

Looks at average behaviour

- Structure = mix of Fibre and Matrix
- Properties = mix of component properties
- Make assumptions about interface

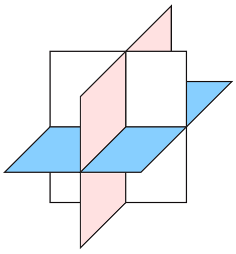
We will spend more time on Macro Mechanics

16 Theory of Anisotropic Materials

16.1 Isotropic and Anisotropic Materials

All about **symmetry**

- **Isotropic :** All directions are equivalent. E.g. solid block of polymer (e.g. nylon), or a block of annealed aluminium.
- **Anisotropic:** Very general term. Simply means that the material is “not isotropic”. May be only slightly anisotropic, or very.
- **Orthotropic:** 3 Orthogonal planes of material symmetry. (Orthogonal means at right angles, like orthographic projection). Intersections of these planes of symmetry are the principal axes of the material.



- **Transversely Isotropic:** Less general than orthotropic. Such materials have a plane of isotropy (normal to an axis of rotational symmetry).

Isotropic materials easier to deal with than anisotropic
The more anisotropic a material is, the more tricky it is

17 Theory of Anisotropic Materials

17.1 Symmetry and Coordinate Transformations

We define the symmetry of something by saying what coordinate transformations it is invariant under.

17.2 Orthotropic

Invariant under 3 $\perp$ **planes of mirror symmetry** Describe one mirror mathematically using a transformation like this

$$\beta_{ij} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \tag{1}$$

Mirror about the x_1–x_2 plane The other two are

$$\beta_{ij} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

17.3 Transversely Isotropic

Invariant under rotations about an
axis of symmetry. Rotation about the x_3 axis is described as

$$\beta_{ij} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Note that for a transversely isotropic material, its properties must be invariant under this transformation for **any value** of the angle θ. Less symmetric materials might be symmetric for particular values of θ.