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ENR116 Engineering Materials

Module 4 Non-metals and Corrosion

Dr David Steele
Unit Coordinator
School of Advanced Manufacturing and Mechanical Engineering

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Fibre-reinforced composites

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Intended Learning Outcomes

At the end of this section, students will be able to:-

- Describe the types of fibre-reinforced composites.
- Explain the effects of fibre alignment on the mechanical properties of the composite.

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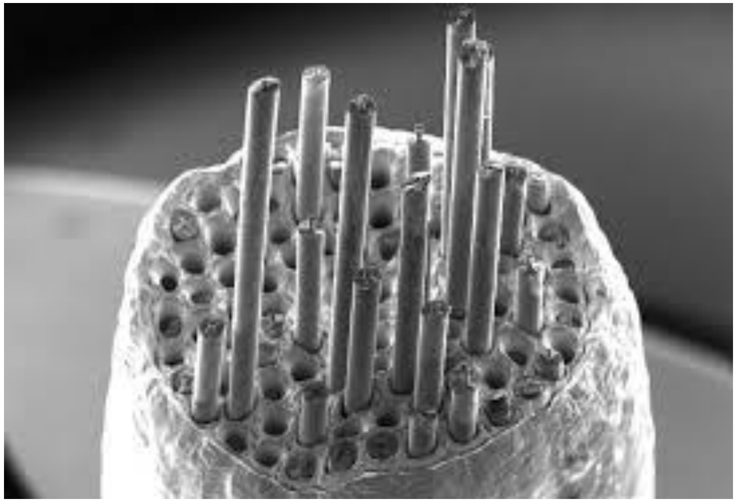
Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

Dispersed phase is in the form of a fibre:
Technologically, the most important of the composites.

May be continuous or discontinuous

Design goals of fibre-reinforced composites include high strength and/or stiffness on a weight basis.



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Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

Mechanical characteristics depend on:

- The properties of the fibre.
- The degree to which an applied load is transmitted to the fibres by the matrix phase.
- The magnitude of the interfacial bond between the fibre and matrix

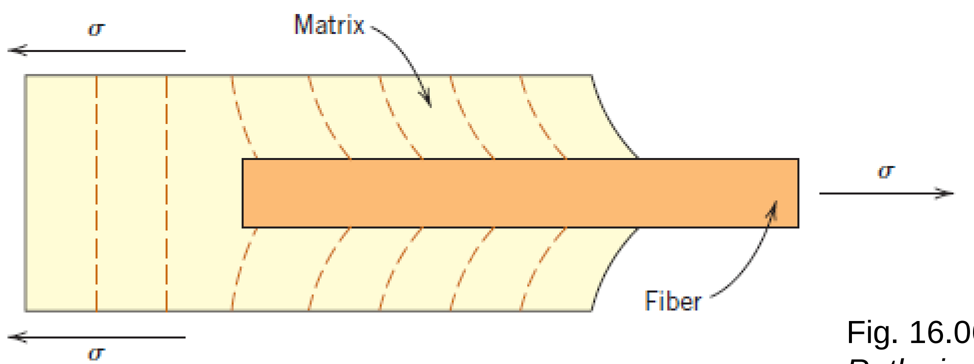

Fig. 16.06, *Callister & Rethwisch 8e*.

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Critical fibre length

Particle-reinforced | **Fibre-reinforced** | Structural

Critical fibre length; l_c

$$l_c = \frac{\sigma_f^* d}{2\tau_c}$$

l_c, critical length is dependent on the:

- d - fibre diameter
- σ_f^* - ultimate (or tensile) strength
- τ_c - fibre-matrix bond strength

For a number of glass and carbon fibre-matrix combinations, l_c is in the order of 1 mm (between 20 and 150 times the fibre diameter).

Continuous vs. discontinuous fibres

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$l >> l_c$

($l > 15\, l_c$) - continuous
(Below this, ‘discontinuous’)

Longer fibre - more effective reinforcement!

Fig. 16.07, *Callister & Rethwisch 8e*.

For a significant improvement in strength the fibres must be continuous.

Fiber Alignment

Adapted from Fig. 16.08, *Callister & Rethwisch 8e*.

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Continuous and Aligned Fibres

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Continuous and Aligned Fibre Composites, under a longitudinal load:

Mechanical properties depend on:

- The phase volume fractions.
- The direction in which stress or load is applied.

Properties of a composite having its fibres aligned are highly anisotropic (dependent on the direction in which they are measured).

Continuous and Aligned Fibres

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Composite failure is not catastrophic:

Fibres do not fracture at the same time.

Shortened fibres after fracture still have a reinforcement effect

Adapted from Fig. 16.09, *Callister & Rethwisch 8e*.

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Fibre reinforcement

Particle-reinforced | **Fibre-reinforced** | Structural

Consider the elastic behaviour of a continuous and oriented fibrous composite loaded in the direction of fibre alignment.

Assuming that the fibre-matrix interfacial bond is very good, total load sustained by the composite:

$$F_c = F_m + F_f$$

Eqn. 1

F_c - force carried by the composite
F_m - force carried by the matrix
F_f - force carried by the fibre phase

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Fibre reinforcement

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Since $F = \sigma A$,

$\sigma_c A_c = \sigma_m A_m + \sigma_f A_f$

$V_f = A_f / A_c$ volume fraction of the fibre phase.

$$\sigma_c = \sigma_m \frac{A_m}{A_c} + \sigma_f \frac{A_f}{A_c}$$

Eqn. 2

$$\sigma_c = \sigma_m V_m + \sigma_f V_f$$

Eqn. 3

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Fibre reinforcement

Particle-reinforced | Fibre-reinforced | Structural

Isostrain state means that:

$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$

Divide Eqn. 3 (for σ_c) by the strain:

$$\frac{\sigma_c}{\varepsilon_c} = \frac{\sigma_m}{\varepsilon_m} V_m + \frac{\sigma_f}{\varepsilon_f} V_f$$

If composite, matrix, and fibre deformations are all elastic, then:

$$\sigma_c / \varepsilon_c = E_c$$

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Longitudinal loading

Particle-reinforced | **Fibre-reinforced** | Structural

Modulus of elasticity of a continuous and aligned fibrous composite *in the direction of alignment* (*longitudinal direction*):

$$\mathbf{E_{cl} = E_m V_m + E_f V_f}$$

$$\text{Or....}\ E_{cl} = E_m(1 - V_f) + E_f V_f$$

For longitudinal loading the ratio of the load carried by the fibres to that carried by the matrix is:

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$$

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Transverse loading

Particle-reinforced | Fibre-reinforced | Structural

Elastic Behaviour - Transverse Loading

Load is applied at a 90^{o} angle to the direction of fibre alignment.

For this situation the stress to which the composite as well as both phases are exposed is the same:

$$\sigma_c = \sigma_m = \sigma_f = \sigma$$

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Transverse loading

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This is an isostress state:

$$\varepsilon_c = \varepsilon_m V_m + \varepsilon_f V_f$$

and, as

$$\varepsilon = \sigma / E$$

$$\frac{\sigma}{E_{ct}} = \frac{\sigma}{E_m} V_m + \frac{\sigma}{E_f} V_f$$

Eqn. 4

E_{ct} is the modulus of elasticity in the transverse direction.

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Transverse loading

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$$\frac{\sigma}{E_{ct}} = \frac{\sigma}{E_m} V_m + \frac{\sigma}{E_f} V_f$$

Eqn. 4

Dividing through by σ and reducing:

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m} = \frac{E_m E_f}{(1 - V_f) E_f + V_f E_m}$$

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Longitudinal Tensile Strength

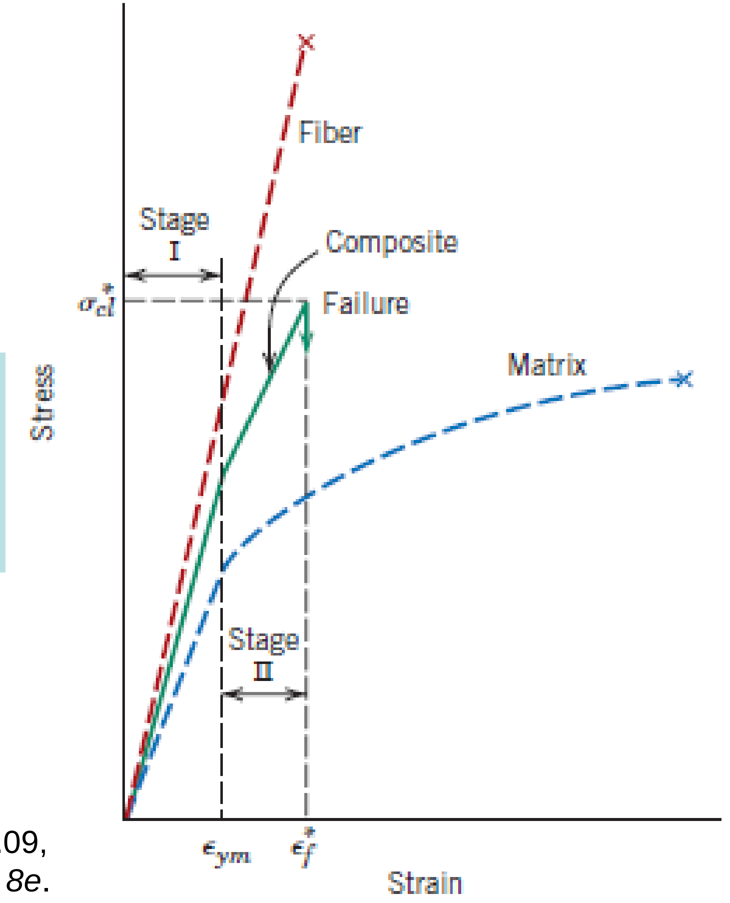
Particle-reinforced | **Fibre-reinforced** | Structural

Longitudinal Tensile Strength:

Strength is normally taken as the maximum stress.

$$\sigma_{cl}^{*} = \sigma_{m}^{'}(1 - V_f) + \sigma_f^{*} V_f$$

σ_m is the stress in the matrix at fibre failure.



Adapted from Fig. 16.09, *Callister & Rethwisch 8e*.

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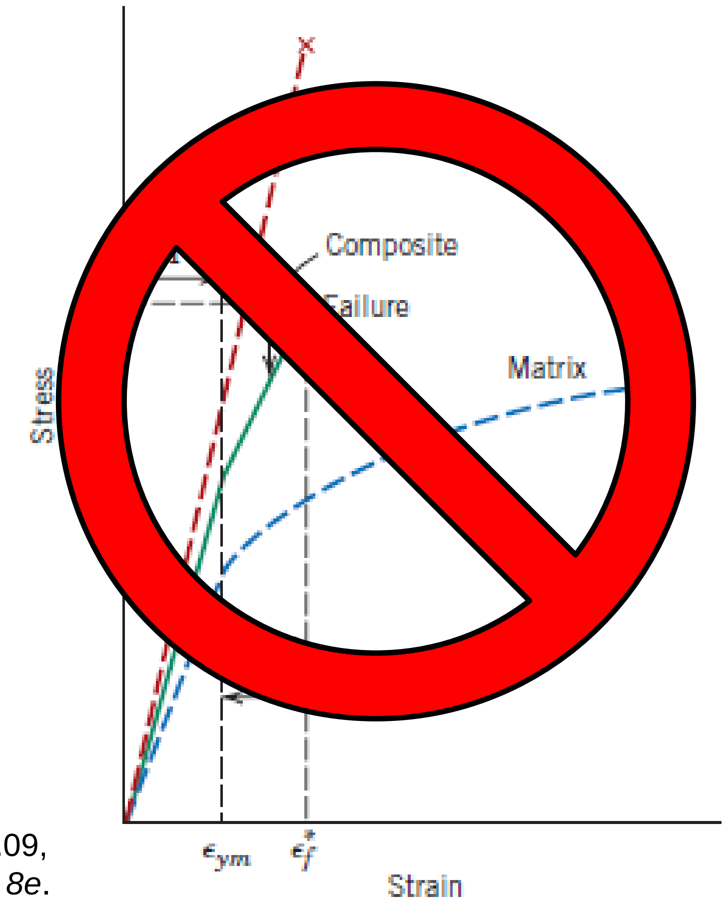
Transverse Tensile Strength

Particle-reinforced | **Fibre-reinforced** | Structural

Transverse Tensile Strength:

Will be ***much smaller*** than the longitudinal strength.

Important factors include;
properties of both the fibre and matrix,
the fibre-matrix bond strength,
and the presence of voids.



Adapted from Fig. 16.09,
Callister & Rethwisch 8e.

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Summary

- Fibre-reinforced composites can be:
  - continuous and aligned
  - discontinuous and aligned
  - discontinuous and random
- The improved mechanical properties of composites are influenced by the matrix-fibre bond strength and the fibre direction.

Thank you