BFF1113
Engineering Materials

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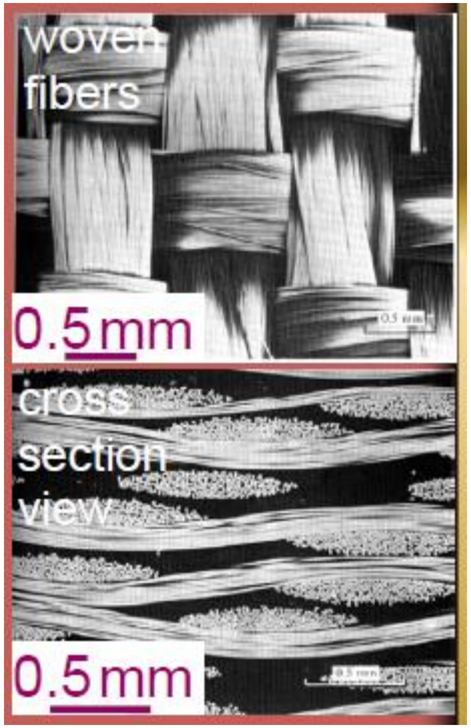
Course Guidelines:

1. Introduction to Engineering Materials
2. Bonding and Properties
3. Crystal Structures & Properties
4. Imperfection in Solids
5. Mechanical Properties of Materials
6. Physical Properties of Materials
7. Failure & Fundamental of Fracture
8. Metal Alloys
9. Phase Diagram
10. Phase Transformation – Heat Treatment
11. Processing and Application of Metals
12. Ceramic Materials
13. Polymer Materials
14. <u>Composite Materials</u>
15. Corrosion & Degradation of Materials
16. Environment and Sustainability

COMPOSITE



Chapter Outline

1. **Introduction**
2. **Matrix Phase**
   a) **Metal-matrix Composites**
   b) **Ceramic-matrix Composites**
   c) **Polymer-matrix Composite**
3. **Reinforcement Phase**
   a) **particle – reinforced composite**
   b) **fiber - reinforced composite**
   c) **structural-reinforced composite**
4. **Composite Applications**
5. **Composites Production Methods**

ISSUES TO ADDRESS...

- What is composite material?

- Why are composites used instead of metals, ceramics, or polymers?

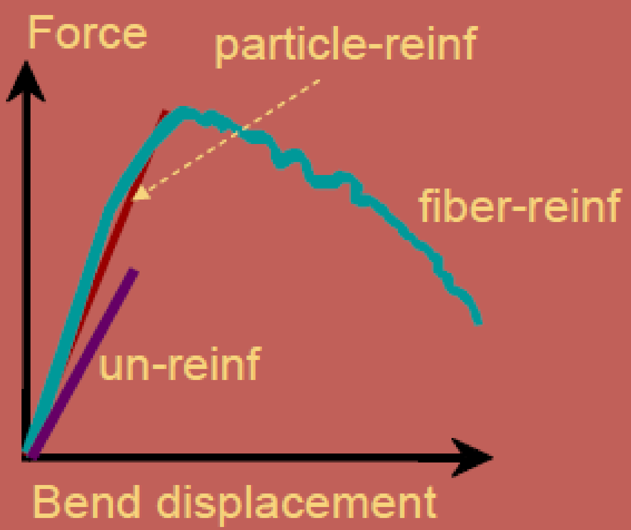
- What are some typical applications of composite materials?

Introduction to Composites

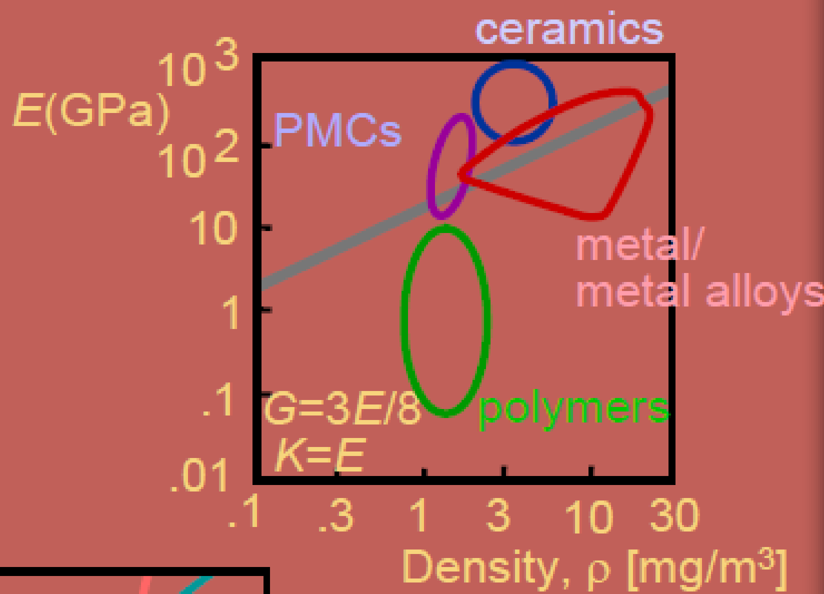
- Combine materials with the objective of getting a more desirable combination of properties
  - Ex: get flexibility & weight of a polymer plus the strength of a ceramic
- Principle of combined action
  - Mixture gives “averaged” properties

Composite Benefits

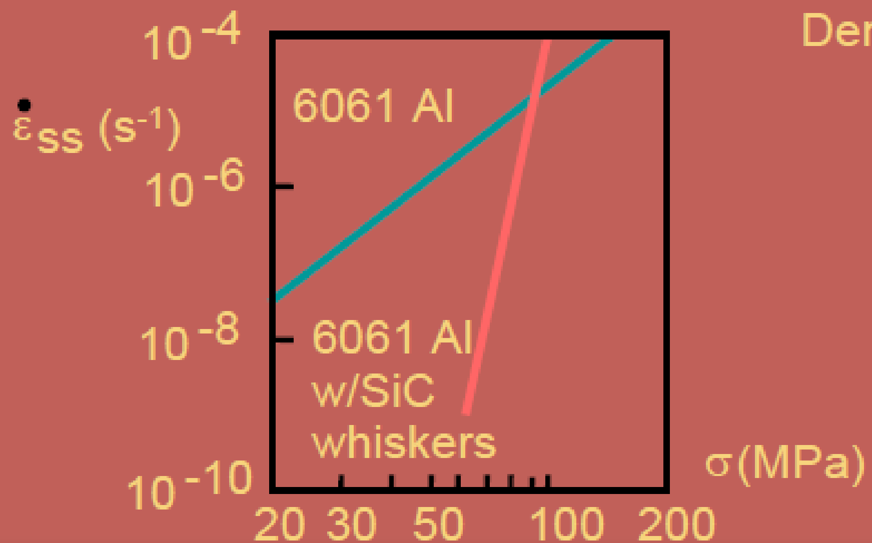
- CMCs: Increased toughness



- PMCs: Increased E/ρ Specific



- MMCs:
  Increased
  creep
  resistance



Matrix Materials

- Matrix in reinforced plastics has 3 principal functions:

1. Support the fibers in place and transfer the stresses to them
2. Protect the fibers against physical damage and the environment
3. Reduce the propagation of cracks in the composite

- Matrix materials are *thermoplastics* or *thermosets*

Reinforced Material

- Mechanical and physical properties of reinforced plastics depend on:

1. Type, shape, and orientation of the reinforcing material
2. Length of the fibers
3. Volume fraction (percentage) of the reinforcing material

Terminology/Classification

- Matrix:
  - -- The continuous phase
  - -- Purpose is to:
    - - transfer stress to other phases
    - - protect phases from environment
  - -- Classification: MMC, CMC, PMC

    metal → MMC, ceramic → CMC, polymer → PMC

- Dispersed phase:
  - -- Purpose: enhance matrix properties.
    - MMC: increase σ_y, *TS*, creep resist.
    - CMC: increase K_c
    - PMC: increase *E*, σ_y, *TS*, creep resist.
  - -- Classification: Particle, fiber, structural

Metal-matrix Composites

- Advantages of a *metal matrix (*over a *polymer matrix)* are higher elastic modulus, toughness, ductility and higher resistance
- Limitations: higher density and a greater difficulty in processing parts

Metal-matrix Composite Materials and Applications

Fiber	Matrix	Applications
Graphite	Aluminum	Satellite, missile, and helicopter structures
	Magnesium	Space and satellite structures
	Lead	Storage-battery plates
	Copper	Electrical contacts and bearings
Boron	Aluminum	Compressor blades and structural supports
	Magnesium	Antenna structures
	Titanium	Jet-engine fan blades
Alumina	Aluminum	Superconductor restraints in fission power reactors
	Lead	Storage-battery plates
	Magnesium	Helicopter transmission structures
Silicon carbide	Aluminum, titanium	High-temperature structures
	Superalloy (cobalt base)	High-temperature engine components
Molybdenum, tungsten	Superalloy	High-temperature engine components

EXAMPLE:

Aluminum-matrix Composite Brake Calipers

- Aluminum-matrix composite brake caliper using nano-crystalline alumina fiber reinforcement

Summary of Fiber and Material Properties for an Automotive Brake Caliper

Property	Alumina fiber	Aluminum-reinforced composite material
Tensile strength	3100 MPa	1.5 GPa
Elastic modulus	380 GPa	270 GPa
Density	3.9 g/cm^3	3.48 g/cm^3

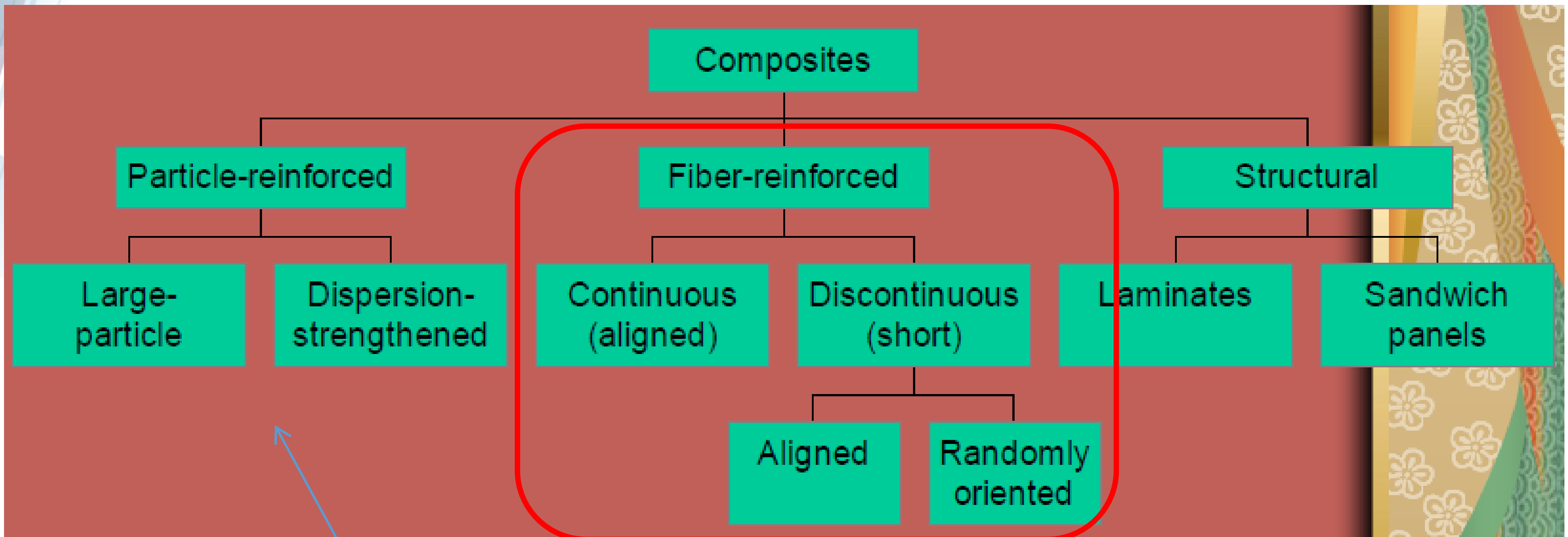
Ceramic-matrix Composites

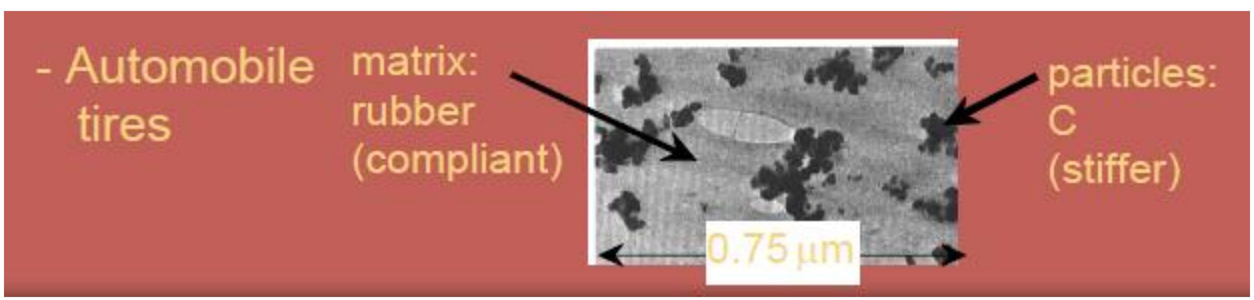
- *Ceramic-matrix composites* (CMC) are resistance to high temperatures and corrosive environments
- Ceramics are strong and stiff, they resist high temperatures, but they lack toughness
- Carbon/carbon-matrix composites retain much of their strength but lack oxidation resistance at high temperatures
- Used for automotive engine components

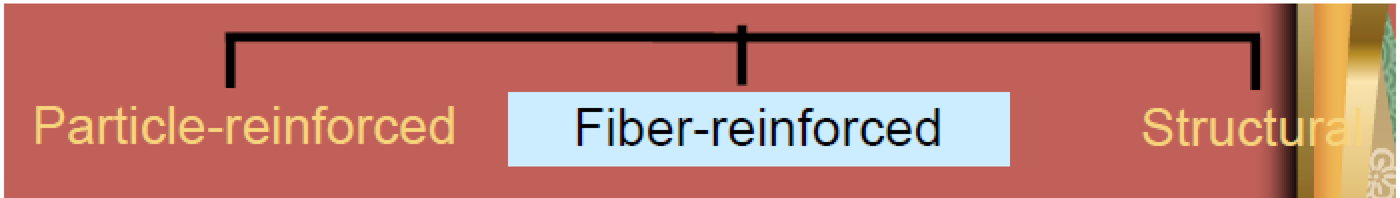
Polymer-matrix Composite (PMC)

- Also known as **Reinforced plastics** or **fiber reinforced plastics** (FRP)
- Glass, carbon, ceramics, aramids, and boron are the common reinforcing fibers
- When more than one type of fiber is used in a reinforced plastic, it is called a **hybrid**
    - Have better properties but are more costly

Reinforcement Phase







Glass fiber, carbon fiber, graphite fiber, ceramic fiber, polymer, boron fiber, whisker.

Glass Fibers

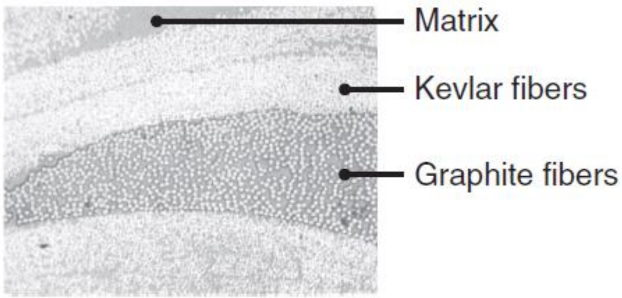
- Least expensive of all fibers
- Composite material is called **glass-fiber reinforced plastic (GFRP)**

Carbon Fibers

- More expensive, low density, high strength and high stiffness
- Product is called **carbon-fiber reinforced plastic (CFRP)**
- Difference between *carbon* and *graphite* depends on the material purity and processed temperature
- Classified by their elastic modulus: *low*, *intermediate*, *high*, and *very high modulus*
- All carbon fibers are made by **pyrolysis** of organic **precursors**
- Pyrolysis is the process of inducing chemical changes by heat

Conductive Graphite Fibers

- Enhance the electrical and thermal conductivity of reinforced plastic components



Ceramic Fibers

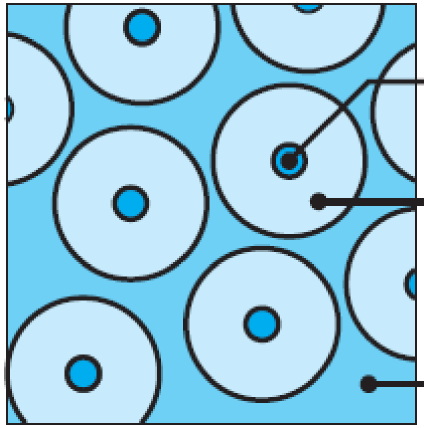
- Have low elongation, low thermal conductivity and good chemical resistance

Polymer Fibers

- Fibers may be made of nylon, rayon, acrylics, or aramids, most common are **aramid fibers**
- Aramids, such as **Kevlar**, are tough and have very high specific strength

Boron Fibers

- Fibers consist of boron deposited onto tungsten or carbon fibers
- High strength and stiffness in tension and compression and resistance to high temperatures
- Due to high density of tungsten, they are heavy and expensive



Other Fibers

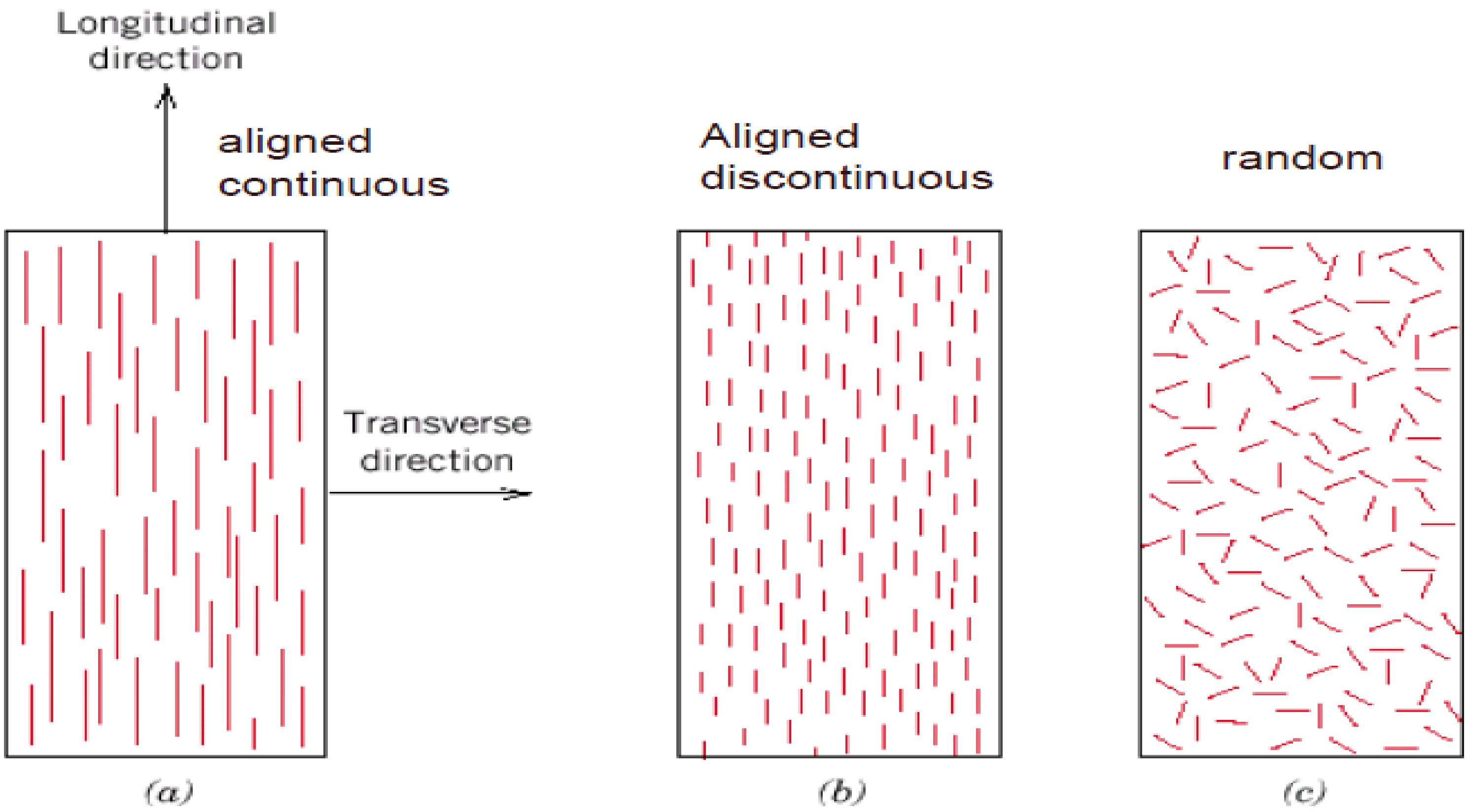
- **Whiskers** used as reinforcing fibers, they are tiny needle-like single crystals
- High aspect ratios (ratio of fiber length to its diameter)
- Small size and free of imperfections / high crystal perfection –extremely strong, strongest known very expensive
- Ex: graphite, SiN, SiC

Fiber Size and Length

- Fibers are very strong and stiff in tension
- Fibers are classified:

1. **Short** (**discontinuous**)
2. **Long** (**continuous**)

Note: Better overall composite properties are realized when the fiber distribution is uniform



Influence of fiber length

- Critical fiber length for effective stiffening & strengthening:

fiber strength in tension

fiber diameter

$$\text{fiber length}(l_c) = \frac{\sigma_f d}{2\tau_c}$$

shear strength of fiber-matrix interface

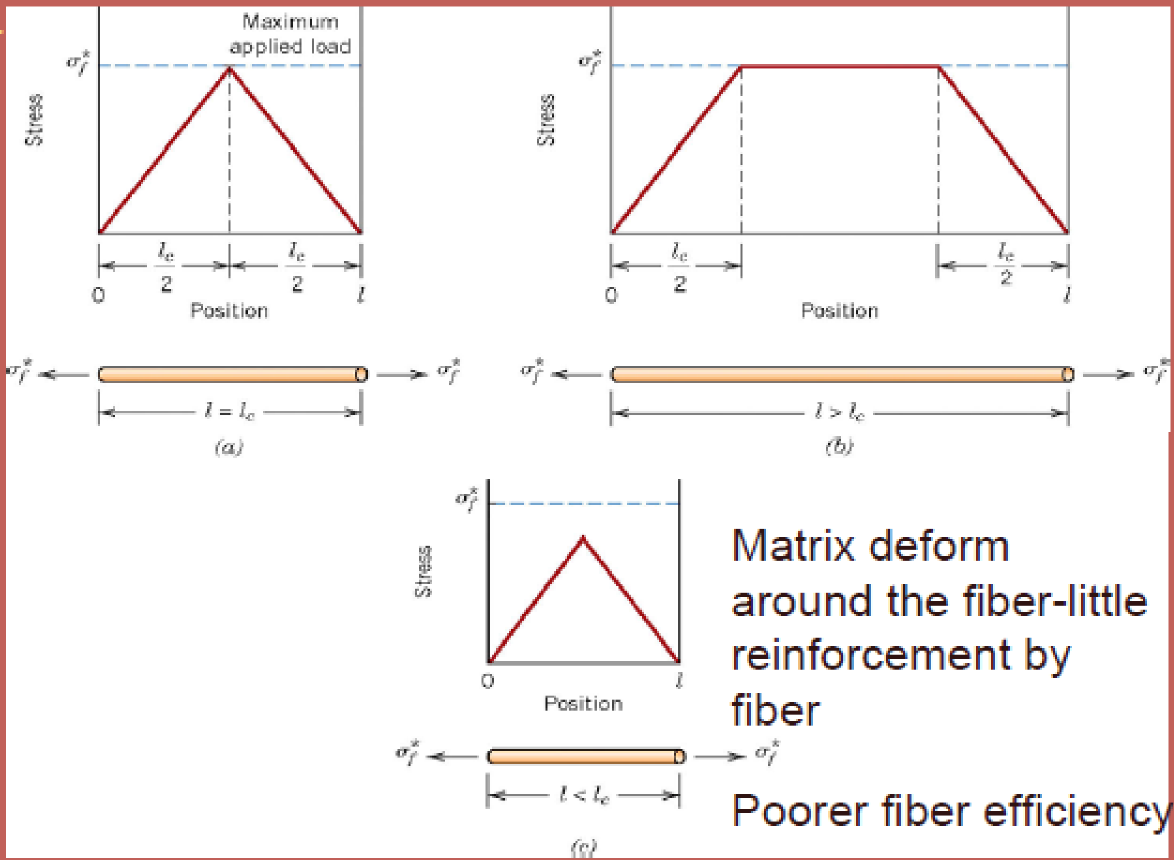
Fiber length increase-reinforcement active • Why? Longer fibers carry stress more efficiently!

When $l > 15l_c$

Applied stress =fibre strength

Better fiber efficiency

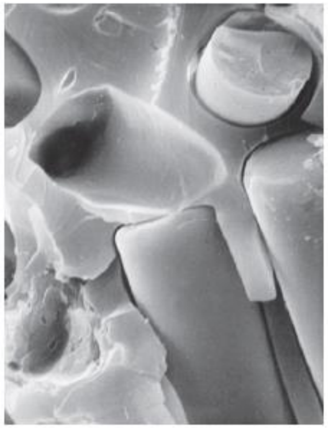
Max fiber load is achieved only at centre of fiber

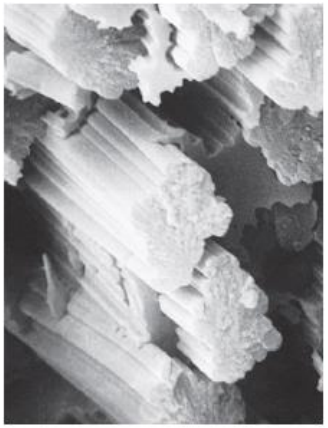


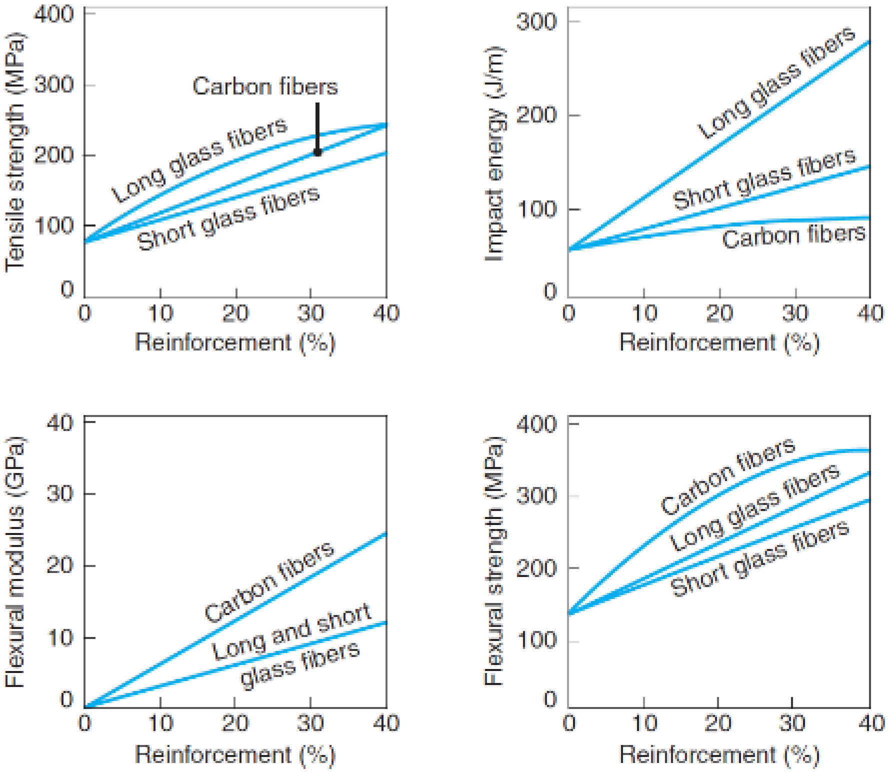
Matrix deform around the fiber-little reinforcement by fiber

Poorer fiber efficiency

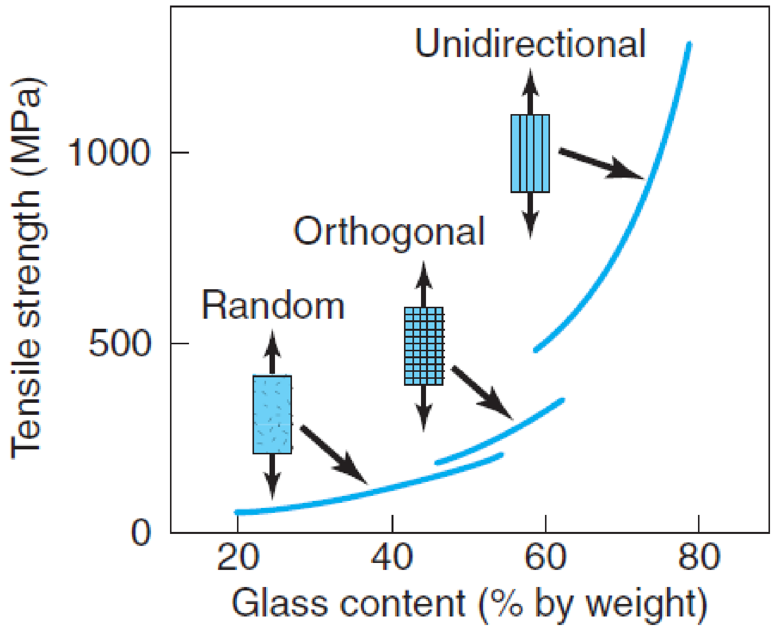
- Physical properties of reinforced plastics depend on the type and amount of reinforcement
- Weak interfacial bonding causes **fiber pullout** and **delamination** of the structure
- Glass fibers are treated with **silane** for improved wetting and bonding







- Highest stiffness and strength in reinforced plastics are when the fibers are aligned in the direction of the tension force.



Strength and Elastic Modulus of Reinforced Plastics

- Total load, P_c , on the composite is

$$P_c = P_f + P_m$$

P_f = fibre load
P_m = matrix load

- Which can be written as

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

- Using x to represents the volume fraction,

$$\sigma_c = x\sigma_f + (1-x)\sigma_m$$

- Elastic modulus of the composite is

$$E_c = xE_f + (1-x)E_m$$

EXAMPLE

Calculation of Stiffness of a Composite and Load Supported by Fibers

Assume that a graphite–epoxy reinforced plastic with longitudinal fibers contains 20% graphite fibers. The elastic modulus of the fibers is 300 GPa, and that of the epoxy matrix is 100 GPa. Calculate the elastic modulus of the composite

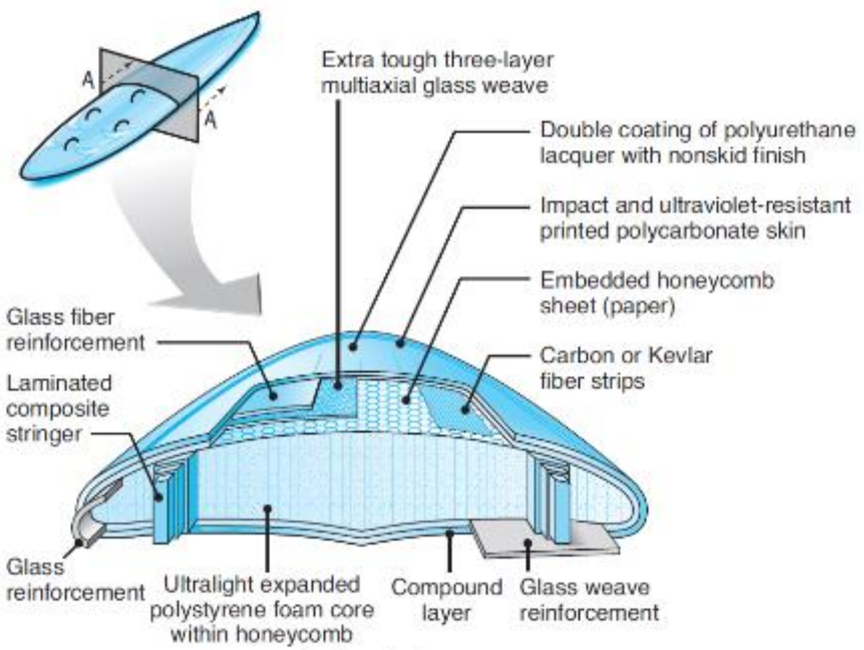
Solution

We have

$$E_c = 0.2(300) + (1 - 0.2)(100) = 140 \text{ GPa}$$

Applications of Reinforced Plastics

- Glass or carbon fiber reinforced hybrid plastics are for high-temperature applications
- Reinforced plastics is used for weight reduction in product design



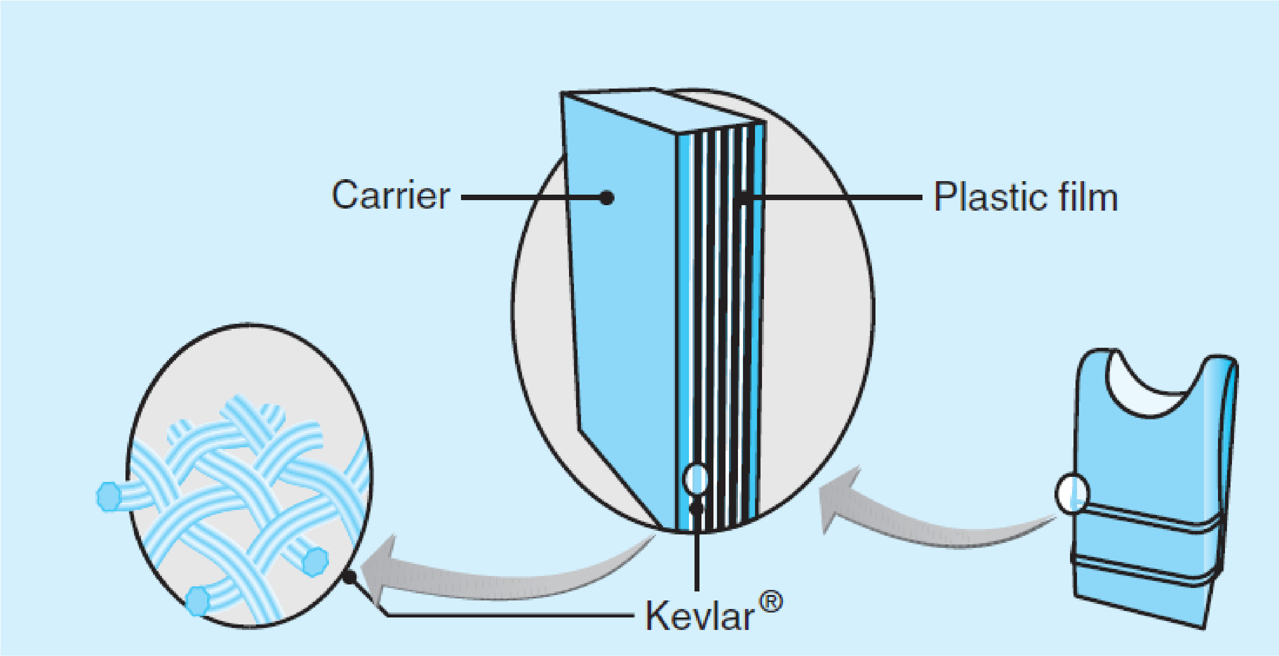
Section A–A

Applications of Reinforced Plastics

EXAMPLE

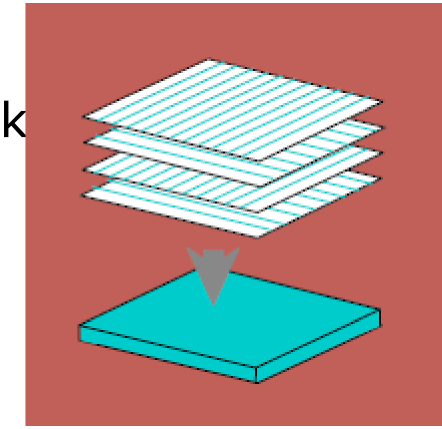
Composite Military Helmets and Body Armor

- Body armor uses layers of woven fibers

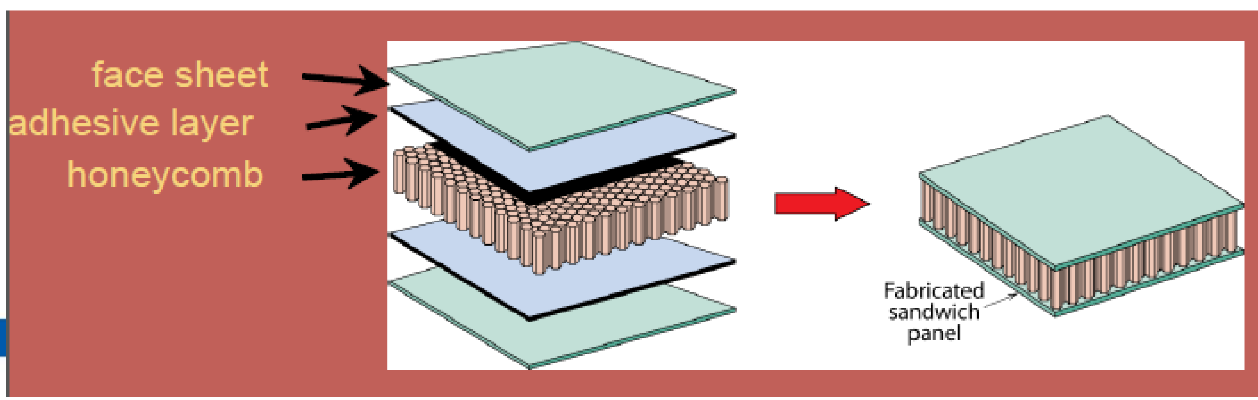


Particle-reinforced | Fiber-reinforced | **Structural**

- ❖ Laminar composite:
  - composed of 2 dimensional sheet which are stack and cemented--stacking sequence
  - benefit: balanced, in-plane stiffness

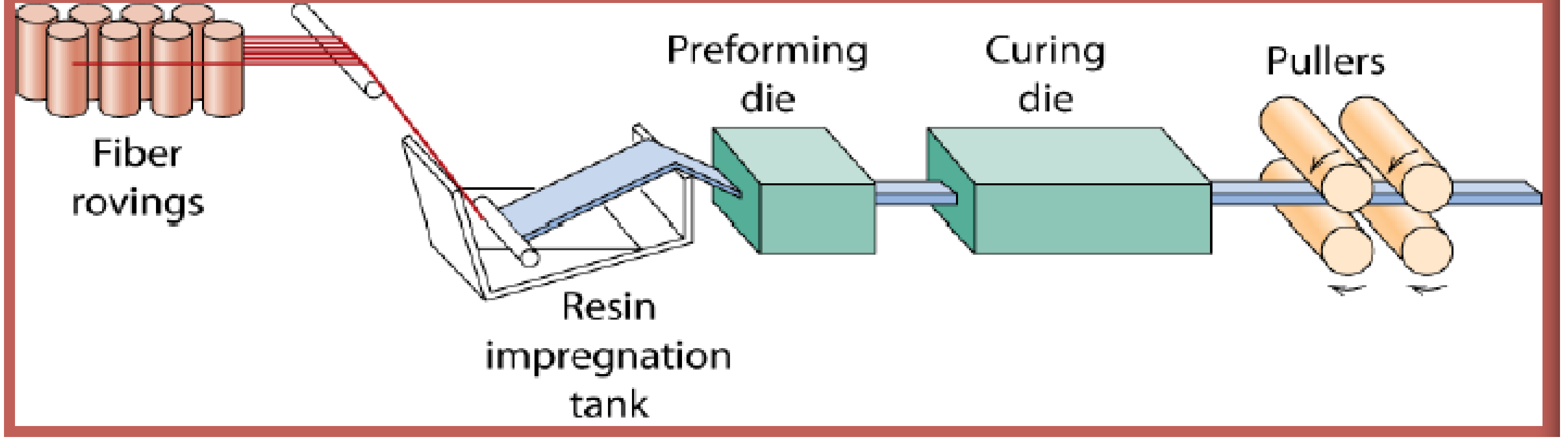


- ❖ **Sandwich panels:**
  - consist of 2 outer sheets (strong material) that are separated by thicker core (lightweight and low elastic modulus materials)
  - low density, honeycomb core
  - benefit: small weight, large bending stiffness



Composite Production Methods 1

- **Pultrusion**
  - **Continuous fibers impregnated in resin**
  - **pulled through steel die to preform desired shape**
  - **followed by passing through curing die (precision machined). This die is heated to cure the resin matrix.**
  - **A pulling device draws the stock through die**



https://www.youtube.com/watch?v=aXq1hrzne2k

Composite Production Methods-II

Filament Winding

- Continuous fiber accurately positioned in predetermined pattern to form hollow shape
- The fiber are fed through resin bath and then continuously wound onto a mandrel using automated winding equipment
- Curing in oven
- Removal of mandrel