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Engineering Composite Materials (MatE 6314)

Introduction to Composite and Classification

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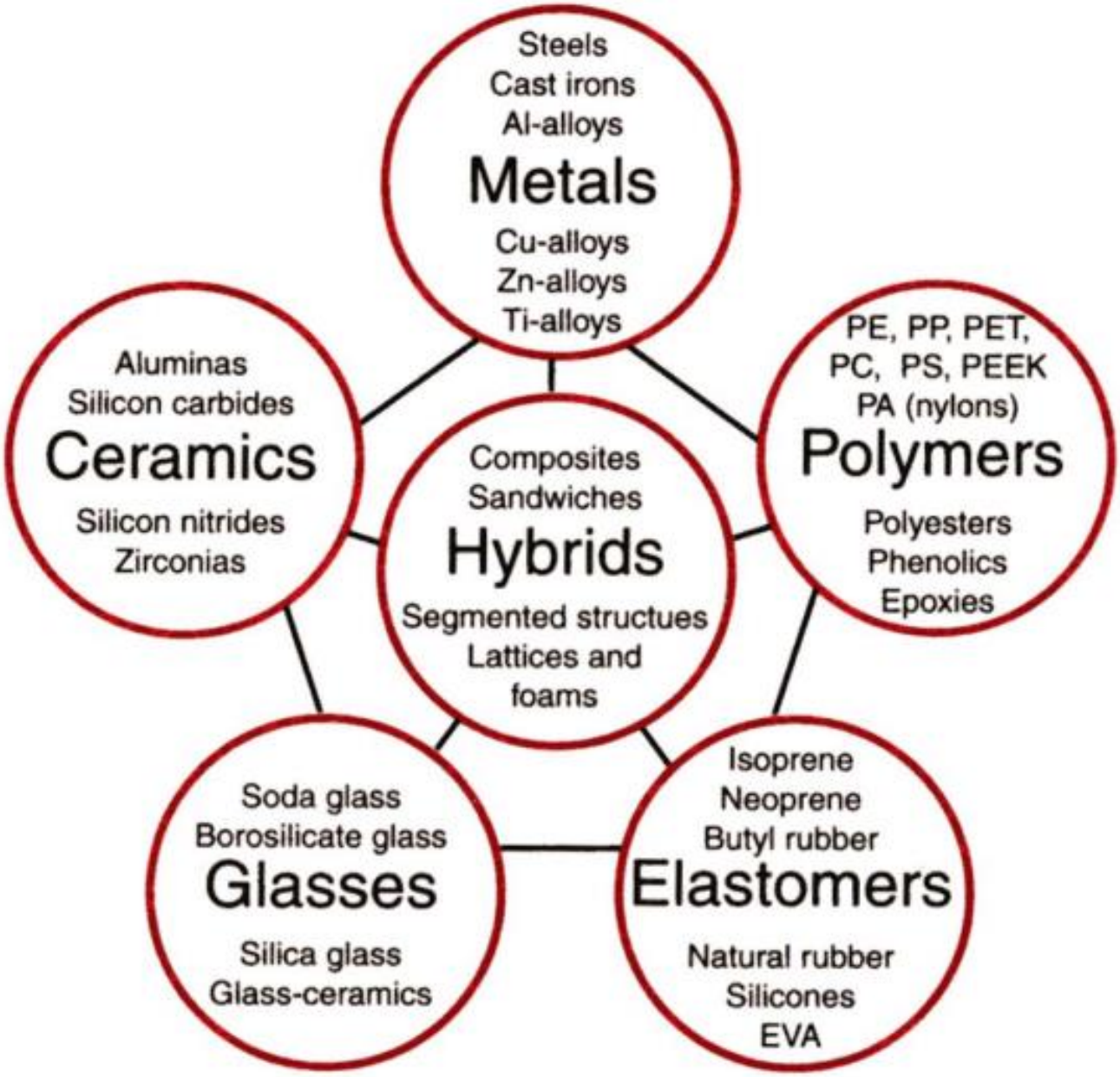
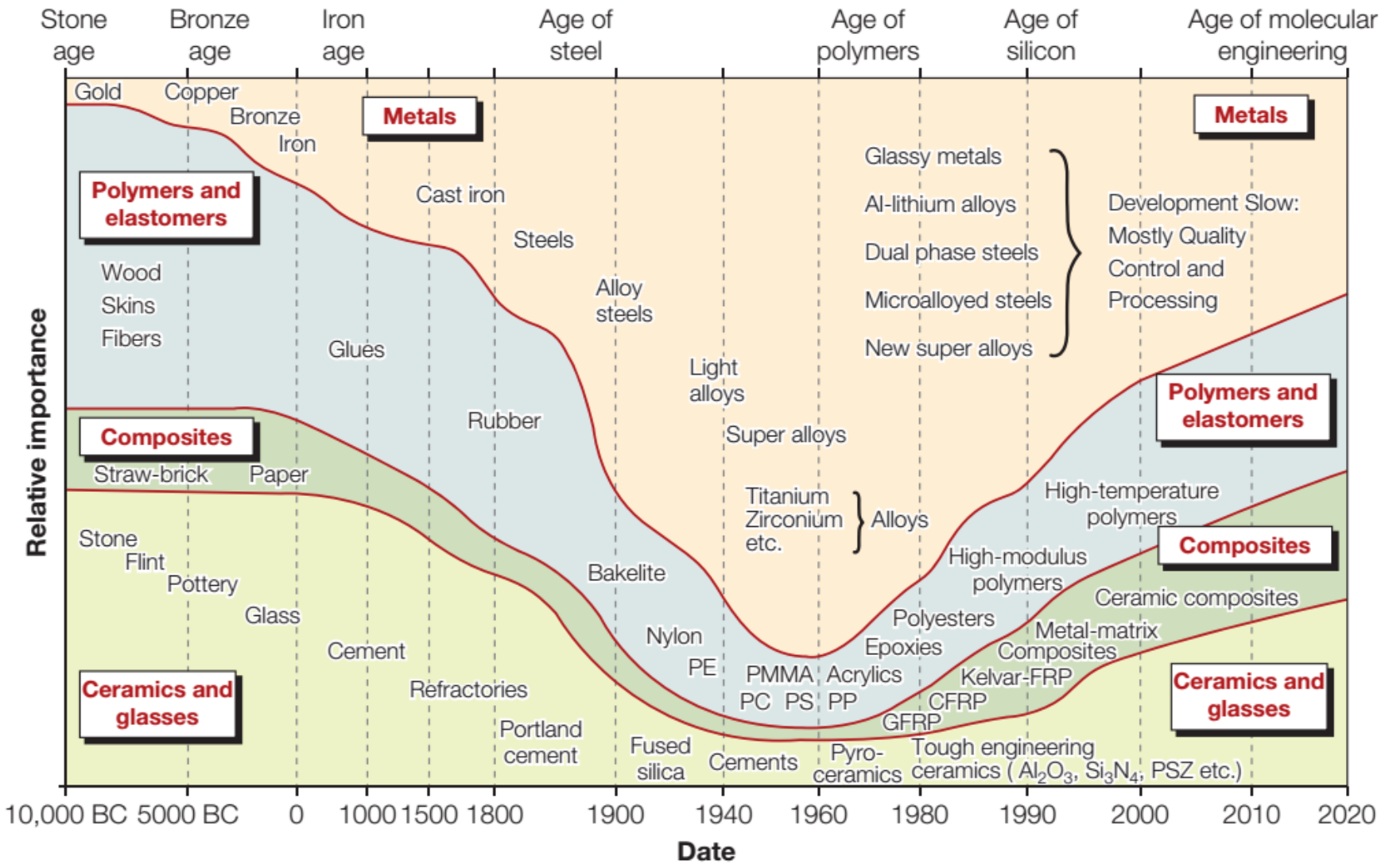
Engineering Materials



The evolution of Engineering Materials with time



Evolution and relevance of materials in the human history

Michael F. Ashby, "Materials selection in mechanical design. 4th Edition - Elsevier (2010)

Composite Materials: Definitions

- Two or more materials, macroscopically different in aspect (morphology), whose combination produces a new material with new properties (mechanical, magnetic, electrical, thermal, optical, etc.) that depend on the constituent properties

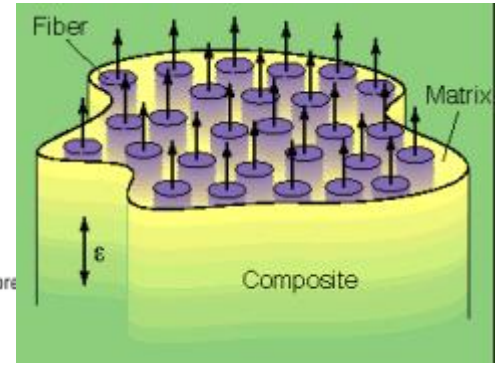
- Composite materials are like sandwiches. A good sandwich contains a variety of ingredients to yield a taste that no single ingredient could provide by itself

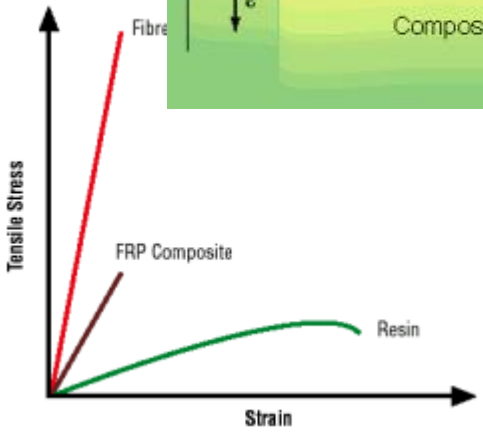
- Similarly, composite materials are those which are formed from two or more materials producing properties or characteristics that could not be obtained from any one material

Considering mechanical reinforcement of the aimed composites:

Composites consist of one or more discontinuous phases embedded in a continuous phase.

The discontinuous phase is usually harder and stronger than the continuous phase and is called the **reinforcemen** or reinforcing material, whereas the continuous phase is termed the **matrix**.





Composite Materials

Are Composite materials new?

Already thousands of years ago mud and straw were combined to make bricks that have been used to build houses, monuments and towns.

Thanks to the presence of the straw, the mud does not cracks during desiccation and contributes to a brick with improved mechanical properties,

Composite Materials

Are Composites materials new?

The word 'composites' has a modern ring

But using the high strength of fibers to stiffen and strengthen a cheap matrix material is probably older than the wheel. ...

Almost all natural materials which must bear load--wood, bone, muscle-are composites. ...

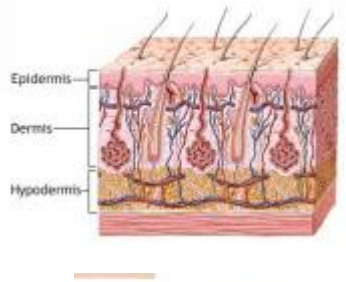
The composite industry, however, is new. It has grown rapidly in the past 30 years with the development of *fibrous composites*...

Composite Materials

Are Composites materials new?

Examples of Composites materials

- Straw-bricks
- Concrete (cement + gravel)
- Wood (cellulose + lignin)
- Human body (muscles + bones)
- Tires
- Transportation
- Plywood
- Sports good …



Composite Materials - Outlines

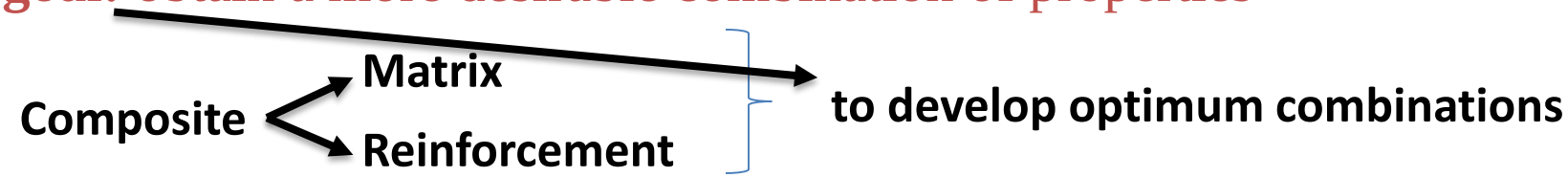
- **Introduction: Definition and characteristics of composite**
- **Composite materials: composites in nature and beyond, applications...**
- **Classification: according to type of matrix and reinforcement**
  - **Metal Matrix Composites (MMC)**
  - **Ceramic Matrix Composites (CMC)**
  - **Polymer Matrix Composites (PMC)**
  - **Particulate Composites**
  - **Fibrous Composites**
  - **Structural Composites**
  - **Hybrid Composites**
    - Particle reinforced composite materials
    - Fiber reinforced composite materials: types of fibers
    - Structural composite materials (laminates and sandwich structures)
- **Fiber-Matrix Adhesion : Interphase and Interface**
- **Composite micromechanics and mechanics theory**
- **Applications and fabrication techniques of composite materials**
- **Case studies and design project**

Composite Materials

Classification of composites

Composite material: a material composed of two or more distinct phases (matrix phase + dispersed phase) and having bulk properties significantly different form those of any of the constituents

Design goal: obtain a more desirable combination of properties



Matrix phase

- The primary phase, having a continuous phase/character
- Matrix is usually more ductile and less hard phase
- It holds the dispersed phase and shares a load with it
- Embeds, surrounds, and supports the reinforcements

Dispersed (reinforcing) phase

- The second phase/phases embedded in the matrix in a discontinuous form
- Usually stronger than the matrix, therefore it is called reinforcing phase

Composite Materials

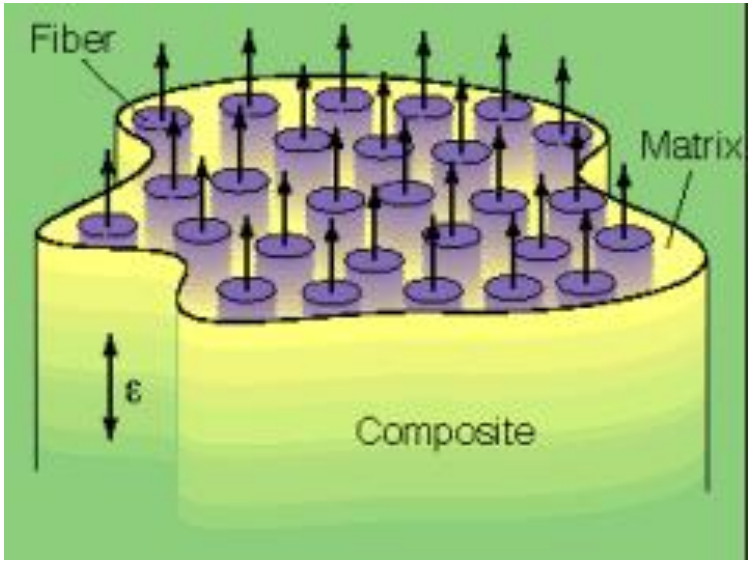
Matrix Phase: Functions

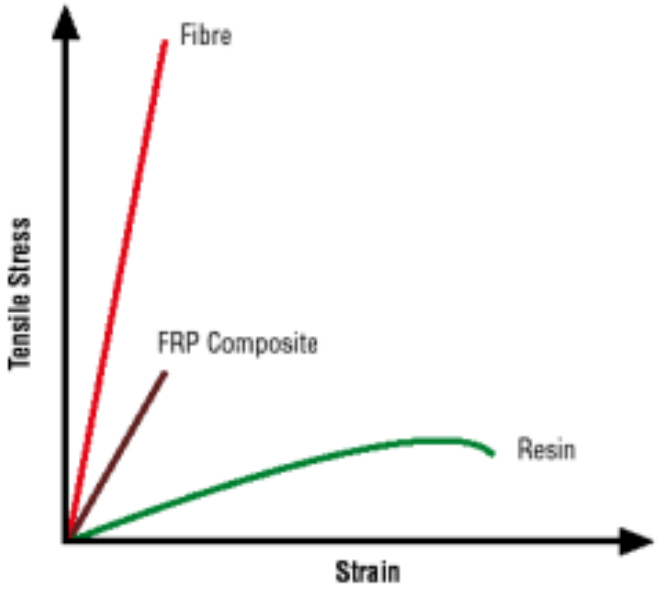
- Holds the fibers together
- Protects the fibers from environment
- Protects the fibers from abrasion (with each other)
- Helps to maintain the distribution of fibers
- Transmit force between fibers
- Distributes the loads evenly between fibers
- Arrest cracks from spreading between fibers
- Holds fibers in proper orientation
- Enhances some of the properties of the resulting material and structural component (that fiber alone is not able to impart)

Composite Materials

Reinforcement Phase: Functions

- Contribute desired properties
- Load carrying
- Transfer the strength to matrix





Composite Materials

Classification of composites→ based on Matrix materials

MMC, CMC, PMC

- **Metal Matrix Composites (MMC)**
- **Ceramic Matrix Composites (CMC)**
- **Polymer Matrix Composites (PMC)**

1. Metal Matrix Composites (MMC)

✓ Composed of a metallic matrix (Al, Mg, Fe, Co, Cu) and a dispersed ceramic (oxides, carbides) or metallic (Pb, W, Mo) phase

✓ fibers or particles surrounded by a matrix of metal;
✓ the matrix is a ductile metal
✓ the reinforcement improve specific stiffness, strength, abrasion resistance, creep resistance, thermal conductivity, and stability

Composite Materials

….Metal Matrix Composites (MMC)…

- ✓ The matrix materials: super-alloys, alloys of Al, Mg, Ti, and Cu,
- ✓ Reinforcement: in the form of particulates, both continuous and discontinuous fibers, and whiskers

- Continuous fiber: include C, SiC, B, Al_2O_3, and the refractory metals
- Discontinuous reinforcements: consist primarily of SiC whiskers, chopped fibers of Al_2O_3 and C, and particulates of SiC and Al_2O_3

- ✓ **Processing of MMC:** synthesis (i.e., introduction of reinforcement into the matrix), followed by a shaping (forging, extrusion, rolling…)

- ✓ **Applications**: Automobile, aerospace industry, …

- ✓ *Higher operating T,*
- ✓ *But much more expensive than PMCs*

Composite Materials

2. Ceramic Matrix Composites (CMC)

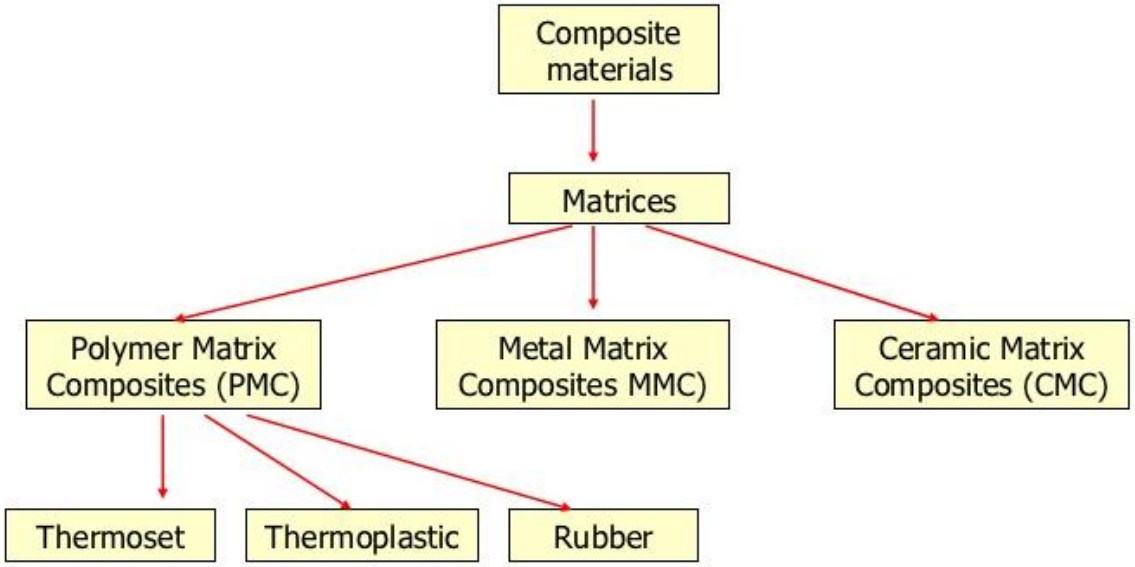
- Composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase)
- When particulates, fibers, or whiskers of one ceramic material embedded into a matrix of another ceramic
- CMCs are non - brittle refractory materials designed for applications in severe environments (often combining high T, high stress levels and corrosive atm.)
- CMC materials have extended fracture toughness→ results from interactions between advancing cracks and dispersed phase particles

*Walter Krenkel, '**Ceramic Matrix Composites: Fiber Reinforced Ceramics and their Applications**', 2008 Wiley-VCH Verlag GmbH & Co. KGaA*

Composite Materials

3. Polymer Matrix Composites (PMC)

- ✓ Consisting of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase
- ✓ Provides strength and stiffness that are lacking in the matrix
- ✓ Composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (PC), PVC, Nylon, PS); and embedded glass, carbon, steel or Kevlar fibers (dispersed phase)



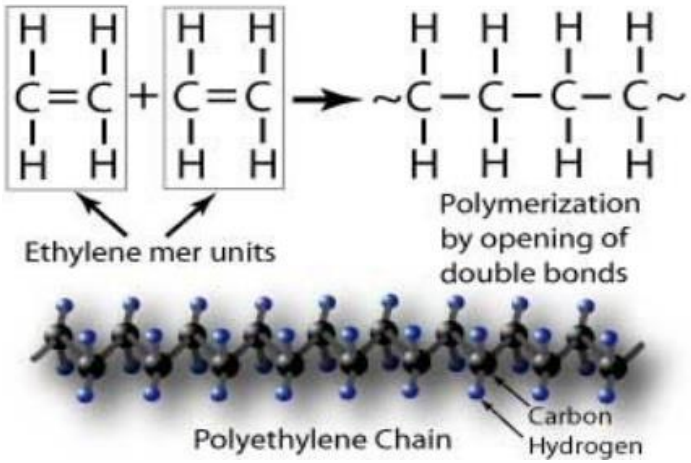
***Assignment 1 (5%)*: Prepare a 2 pages review/report on: Monomer, Polymer; Polymerization; linear, branched, cross-linked polymers; thermosetting & thermoplastic polymers; elastomers**

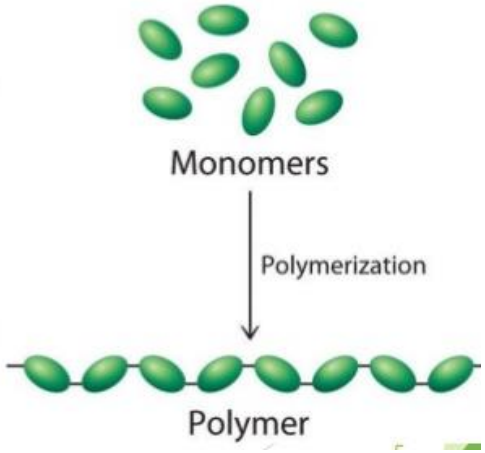
Please do it neatly! Avoid any kind of copy-paste

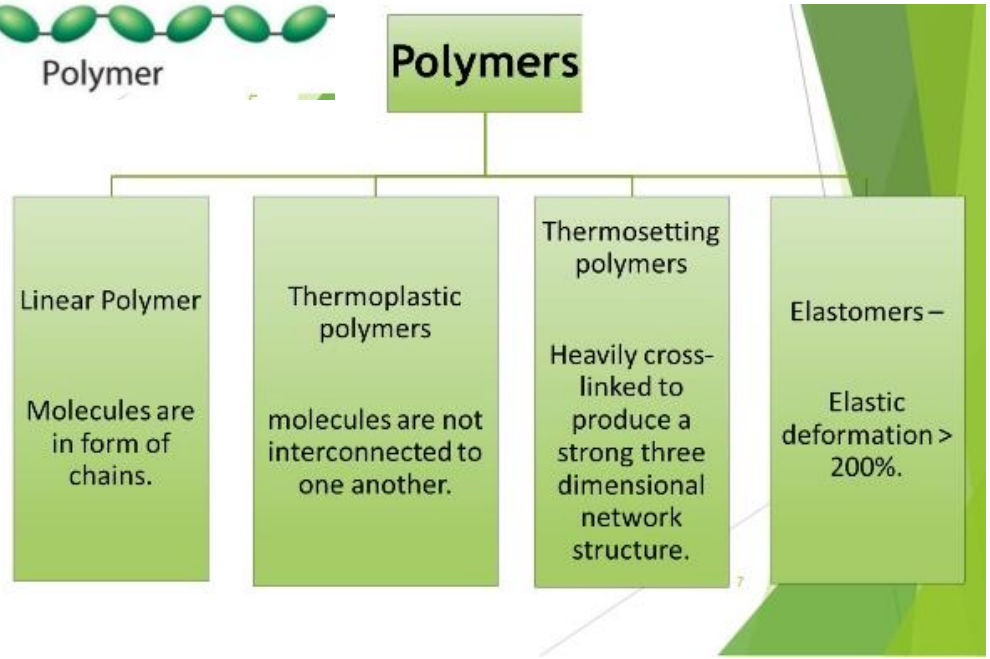
Composite Materials

…Polymer & Polymer Matrix Composites (PMC)…

Polymer: a large molecule (macromolecule) composed of repeating structural units (monomer) connected by covalent chemical bonds







Composite Materials

…Polymer Matrix Composites (PMC)…

- ✓ PMCs are very popular due to their low cost and simple fabrication methods
- ✓ Reinforcement of polymers by strong fibrous network permits fabrication of PMC characterized by the following properties:

  - High tensile strength;
  - High stiffness;
  - High Fracture Toughness;
  - Good abrasion resistance;
  - Good corrosion resistance;
  - Low cost

- ✓ According to the reinforcement material the following groups of PMC are used:

  Fiber glasses – Glass Fiber Reinforced Polymers;

  Carbon Fiber Reinforced Polymer Composites;

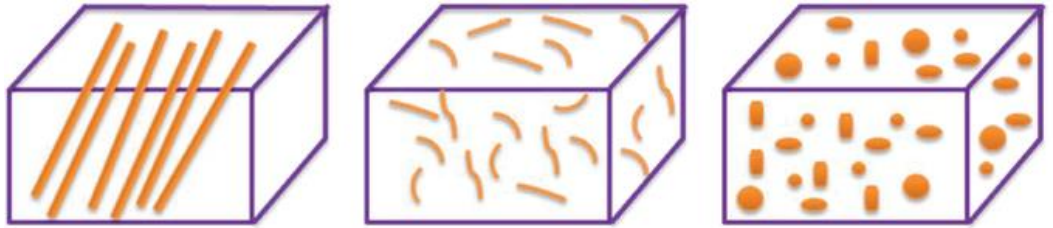
  Kevlar (aramid) fiber reinforced polymers.

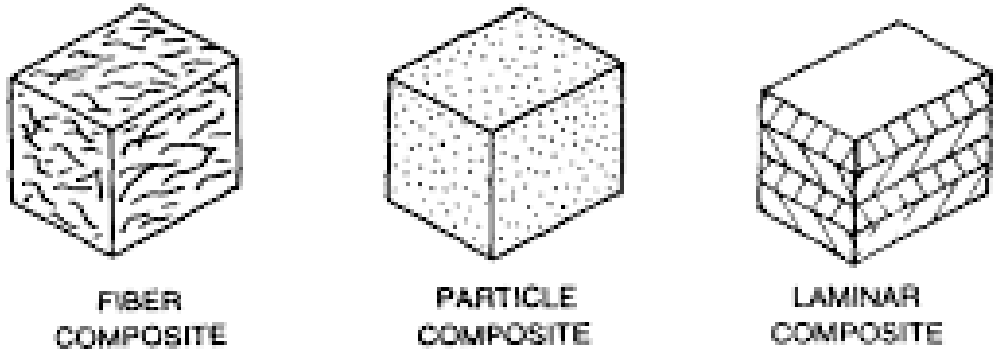
Composite Materials

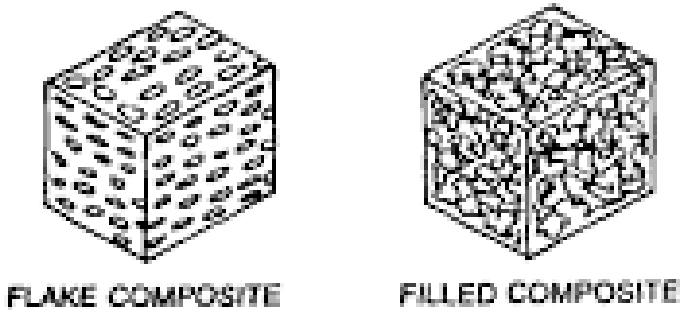
Classification of composites→ based on reinforcement materials

Some composites involve fibers, while others rely on particles, including elongated particles (whiskers) and flat particles (flakes)

- **Particulate Composites**
- **Fibrous Composites**
- **Structural Composites**







Composite Materials

Classification of composites→ based on reinforcement materials

1. Particulate-Reinforced Composites

Consists of matrix reinforced by a dispersed phase in form of particles

- Composites with random orientation of particles
- Composites with preferred orientation of particles.

Sub-classifications of particle-reinforced composites

- large-particle composite
- dispersion-strengthened composites

} The distinction is based upon reinforcement or strengthening mechanism

- polymeric materials + fillers
- concrete: cement (the matrix)+ sand & gravel (the particulates)

- Metals and metal alloys strengthened and hardened by the uniform dispersion fine particles (metallic, non-metallic, oxides…)
  e.g. Al-Al_2O_3 system

Composite Materials

Examples of Particulate Reinforced Composites

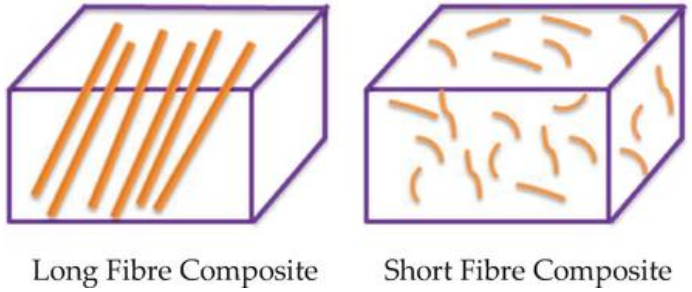
System	Application	Ingredients
Paint	Spreadable surface coating	Mixture of solvent, opaque particles, and polymer such as an acrylic emulsion
Ink	Printing on paper	Small graphite particles in a mixture of solvent and polymer
Porcelain	Dishes, dental crowns, electrical insulators	Mixture of oxide ceramic crystals and glass phases
Electrical contacts	Make-break circuit switches	Arc resistant refractory phase (W, WC, Mo) and high electrical conductivity phase (Ag, Cu)
Heat sinks	Redistribution of heat in computers, rocket engines, high intensity lighting	High conductivity phase (Cu, Ag) with low thermal expansion phase (W, Mo, WC)
Brake pads	Transformation of kinetic energy into heat to stop mechanical systems	Mixtures of graphite, polymers, metals, and ceramics
Electromagnetic shields	Absorption of radio wave interference in devices such as computers	Polypropylene or other polymers with electrically conductive dispersed conductors of nickel and graphite
Permanent magnets	Flexible magnets for use in headphones, stereo speakers, electric motors	Polymer mixed with high capacity magnetic compound
Correction fluid	Opaque cover up for typographical errors or drawing mistakes on paper	White titania (TiO_2) particles dispersed in a solvent-softened polymer
Cemented carbide	Provide hard surfaces for drawing, machining, drilling, shearing, extrusion of metals	Interlocked network of hard carbide (WC) particles in a tough metal matrix (Co)
Wear resistant aluminum	Air conditioner rotors, endurance horseshoes, sporting equipment	Mixture of hard silicon carbide (SiC) particles in aluminum alloy matrix
Inertial weights	Selective mass to balance gyroscopes, aircraft wings, helicopter rotors, vibrators, fishing, and golf club weights	Composite consisting of mostly tungsten (W) mixed with transition metals, such as Cu, Fe, Ni, Mn, Co
Low toughness projectiles	Lead-free frangible ammunition where the bullet has sufficient strength for firing but disintegrates on target impact	Variants include tungsten (W) bonded with nylon or copper (Cu) bonded with tin (Sn)
Foamed ceramic	Insulation for high temperature heating pipes with low thermal conductivity up to 1000 °C	High porosity foamed hydrous calcium silicate with a density near 0.2 g/cm^3

Randall M. German, Particulate Composites Fundamentals and Applications

Composite Materials

Classification of composites→ based on reinforcement materials

2. Fibrous -Reinforced Composites

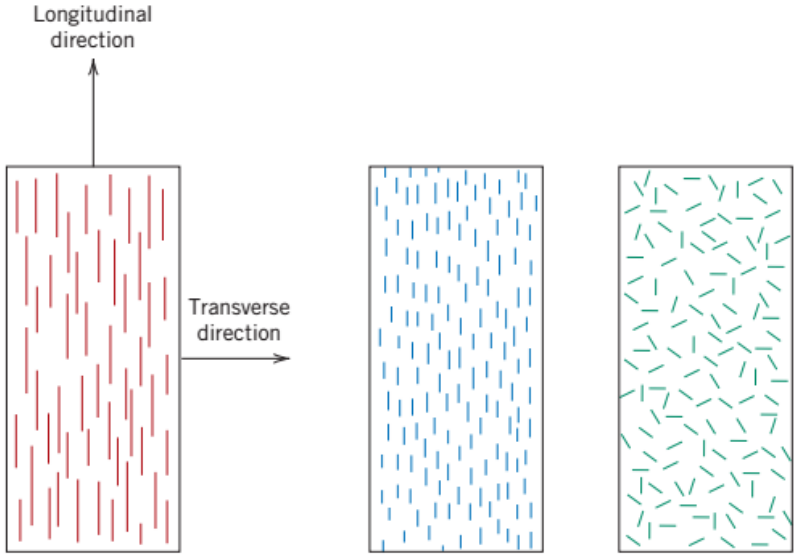


1. Short-fiber reinforced composites: a matrix reinforced by a dispersed phase in form of discontinuous fibers

- Composites with random orientation of fibers
- Composites with preferred orientation of fibers

2. Long-fiber reinforced composites: dispersed phase in form of continuous fibers

- Unidirectional orientation of fibers
- Bidirectional orientation of fibers (woven)



- ✓ Continuous and aligned,
- ✓ Discontinuous and aligned, and
- ✓ Discontinuous and randomly oriented

Composite Materials

Classification of composites→ based on reinforcement materials

3. Structural Composites

- ✓ Composed of both homogeneous and composite materials,
- ✓ The properties depend on the properties of the constituent materials and geometrical design of the structural elements

Two types :

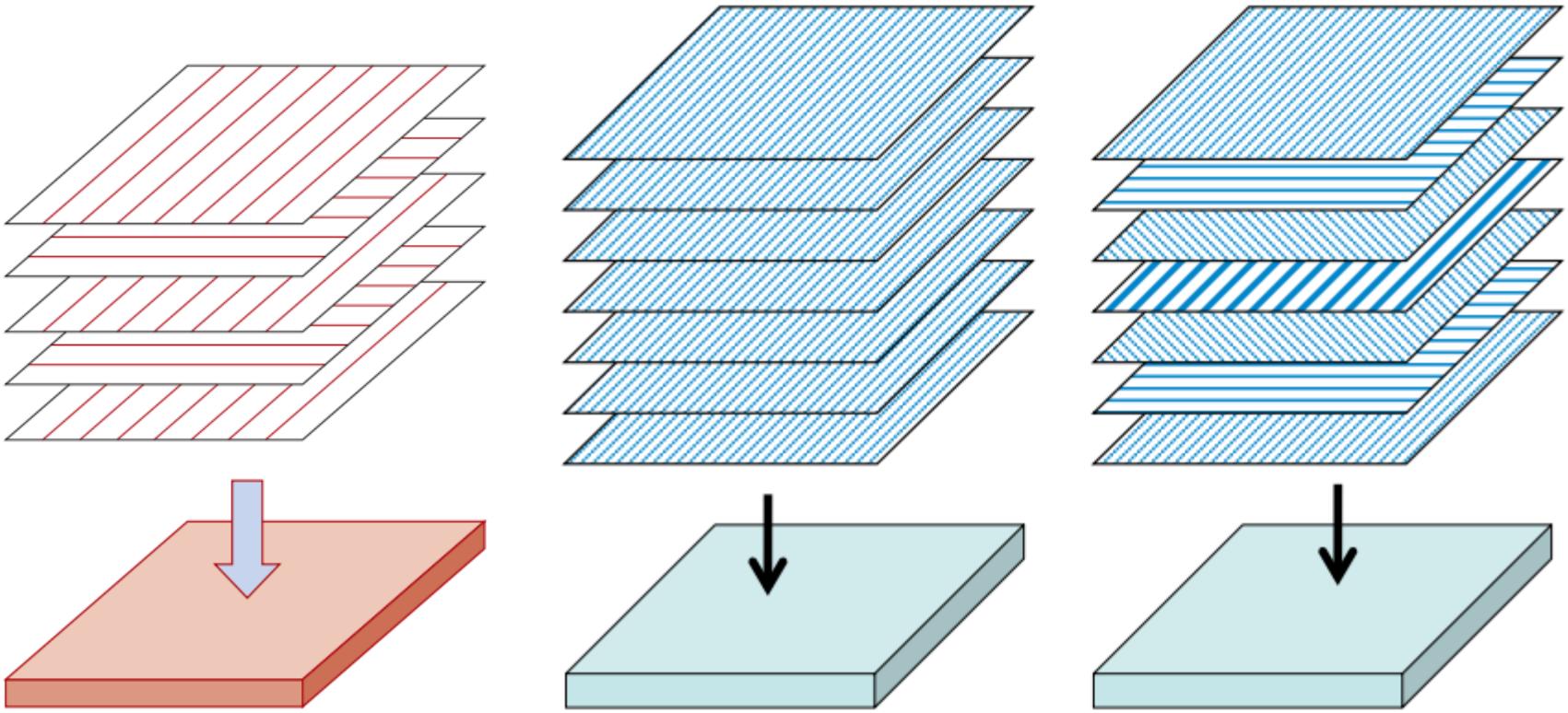
- laminated composites
- sandwich structures

Composite Materials

3. Structural Composites…

1. Laminate-Reinforced Composites←→Laminar composite

- material layers stacked together by the matrix;
- 2D sheets or panels that have a preferred high-strength direction
- Orientations: combined (0, 90, +/-45^{o})→ to achieve the desired strength & stiffness
- The strength and stiffness varies greatly with the orientation



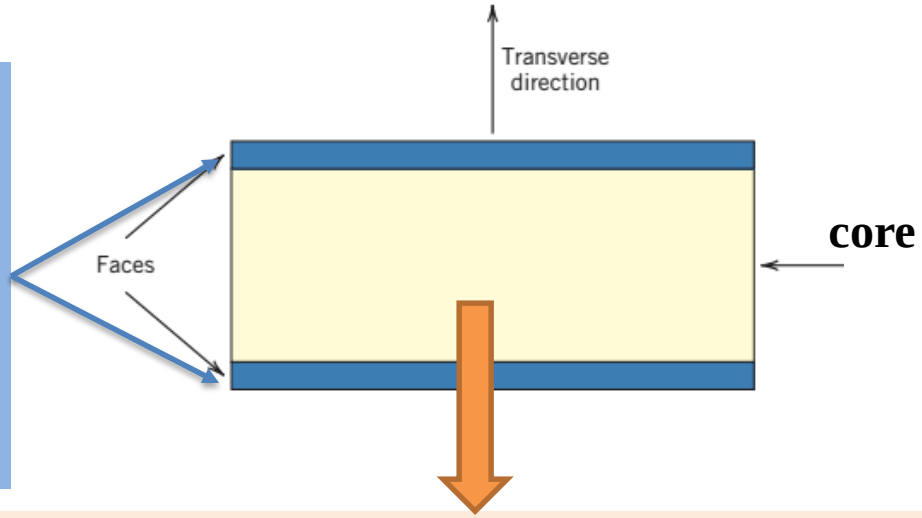
Composite Materials

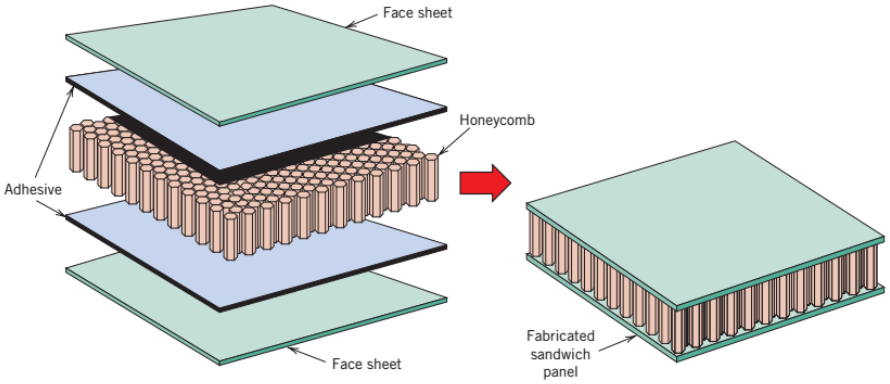
Structural Composites

2. Sandwich Composites---sandwich panels

Consists of two outer **sheets/faces** separated by and bonded to a thicker **core**

- made of a relatively stiff & strong material, typically Al alloys, fiber-reinforced plastics, Ti, steel, or plywood; they impart high stiffness and strength to the structure
- must be thick enough to withstand tensile and compressive stresses result from loading





- The core material is lightweight, and has a low modulus of elasticity
- Core materials fall within either rigid polymeric foams (i.e., phenolics, epoxy, polyurethanes), wood, and honeycombs
- It provides continuous support for the faces

Composite Materials

Hybrid Composites

- Obtained by using two or more different kinds of fibers in a single matrix;
- Have a better all around combination of properties than composites containing only a single fiber type

E.g.: **carbon fiber** and **glass fibers** incorporated into a polymeric resin

- **Are strong and relatively stiff and**
- **Provide a low-density reinforcement;**
- **However, they are expensive**

- **are inexpensive**
- **lack the stiffness of carbon**

- **The hybrid is stronger and tougher,**
- **Has a higher impact resistance, and**
- **may be produced at a lower cost**