Module-12

Composites

Contents

1) Particle reinforced composites, fiber reinforced composites, structural composites

Composite material- definition

- Conventional engineering materials are not able to serve some specific needs, especially of those related to new technologies.
- Need for materials with better properties, thus, growing.
- Combination of better properties can only be achieved with introduction of new materials.
- Composite material – can be defined as any multiphase material that is artificially made and exhibits a significant proportion of the properties of the constituent phases. The constituent phases of a composite are usually of macro sized portions, differ in form and chemical composition and essentially insoluble in each other.

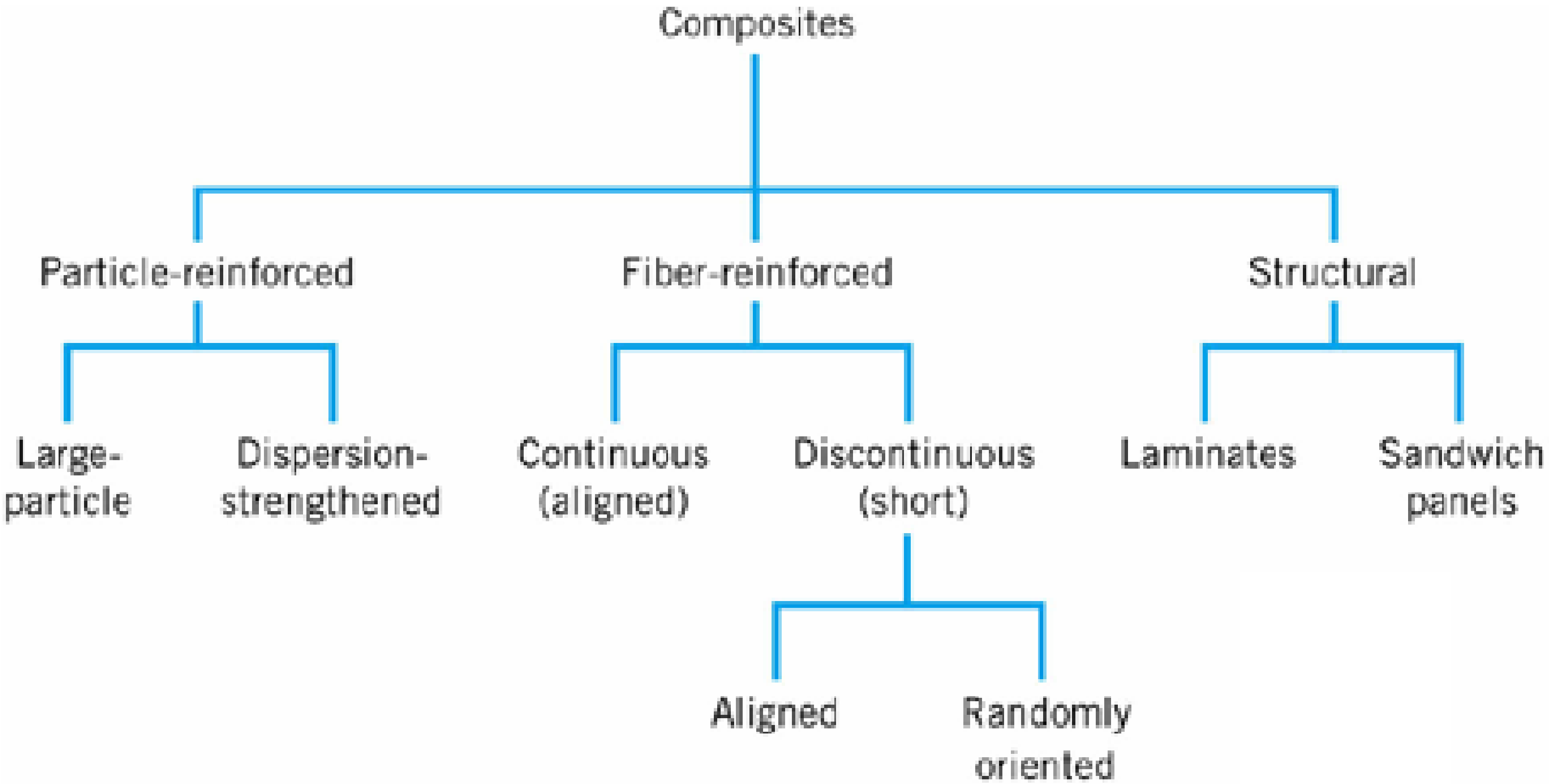
Classification of composites

- A composite is a material that consists of at least two distinct materials. Thus, number of composites are possible. For ease of recognition, they are classified based on two criteria.

- Based on <u>type of matrix material</u> as metal-matrix composites, polymer-matrix composites and ceramic-matrix composites.

- Based on <u>size-and-shape dispersed phase</u> as particle-reinforced composites, fiber-reinforced composites and structural composites.

Classification of composites (contd…)



Dispersion-strengthened composites

- In this composite, particles are of 0.01-0.1 μm in size.
- Strengthening occurs as a result of dislocation motion hindrance. It is similar to that of precipitation hardening in metals.
- Matrix bears the major portion of the applied load, while dispersoids obstruct the motion of dislocations.

E.g.: thoria (ThO_2) dispersed Ni-alloys (TD Ni-alloys) with high-temperature strength; SAP (sintered aluminium powder) – where aluminium matrix is dispersed with extremely small flakes of alumina (Al_2O_3).

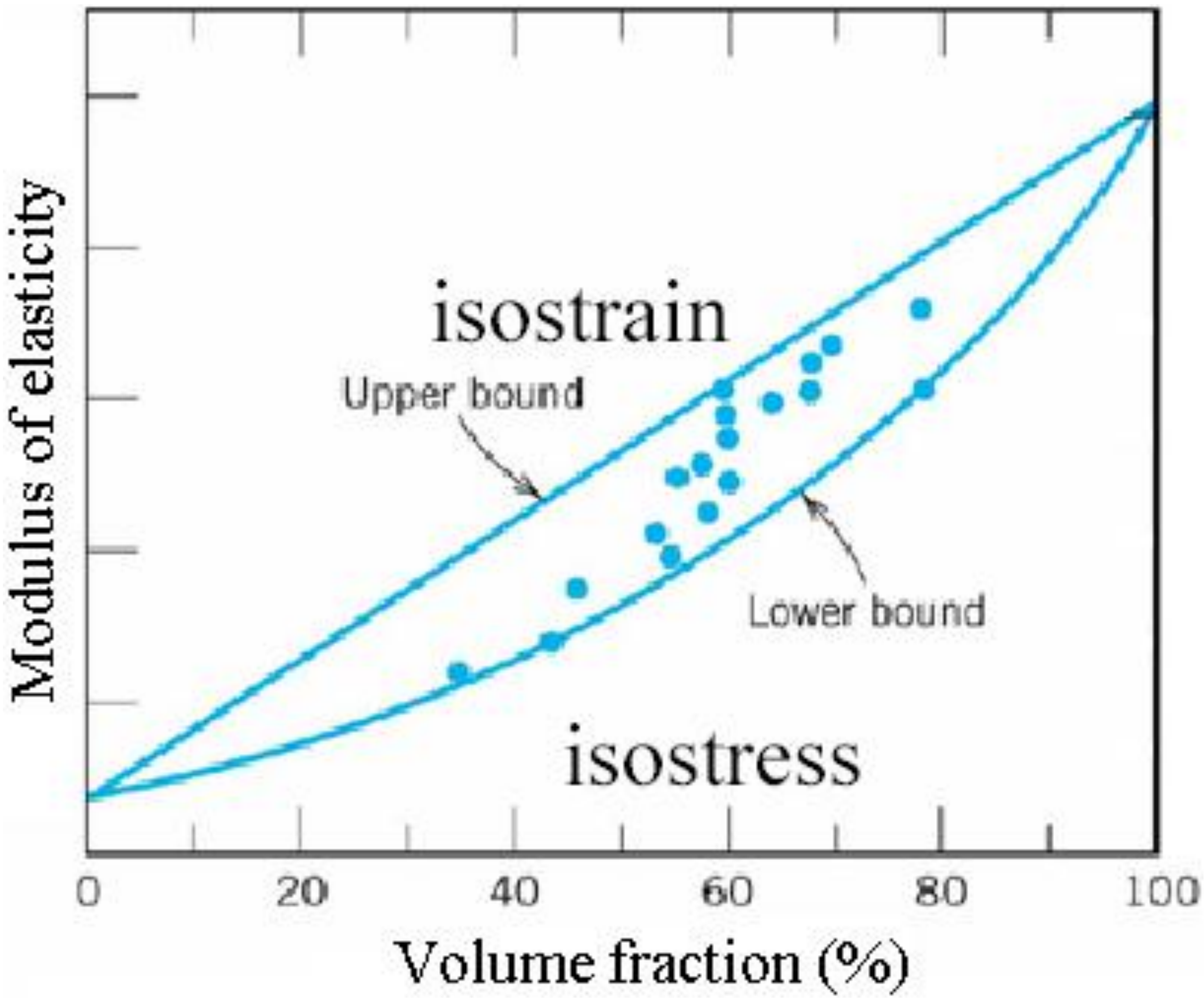
Particulate composites

- These composites contain large number of coarse particles.
- These composites are designed to produce combination of properties rather than increase the strength.
- Mechanical properties are characterized by rule-of-mixtures.
- Elastic modulus of these composites is given by the following bounds, derived from rule-of-mixtures:

$$E_c(u) = E_m V_m + E_p V_p$$

$$E_c(l) = \frac{E_m E_p}{E_p V_m + E_m V_p}$$

Particulate composites (contd…)



Particulate composites (contd…)

- Particulate composites are usually made of all three conventional engineering materials, namely – metals, polymers and ceramics.

  E.g.: tungsten carbide (WC) or titanium carbide (TiC) embedded cobalt or nickel based cutting tools.

  Aluminium alloy castings containing dispersed SiC particles are widely used for automotive applications including pistons and brake applications.

  Portland cement concrete where gravel and sand are particulates while the cement with water acts as binding matrix.

Fiber-reinforced composites

- These composite constituents are, usually, soft matrix embedded with harder fibers.
- Matrix serves as medium to transfer applied load to fibers, which carry most of the applied load. It also protects fibers from external environment.
- Fibers are either continuous and discontinuous. Continuous fibers provide best efficiency, however discontinuous fibers are used when manufacturing economics dictate the use of a process where the fibers must be in this form.
- Properties of these composites depend on many parameters: properties of matrix and fibers, fiber length and volume fraction, their orientation, and interface bond strength.

Fiber-reinforced composites (contd…)

- Effect of fiber length on composite strength:

- Some critical length (l_c) is necessary for effective strengthening and stiffening of the composite material, defined:

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

σ^*_f – ultimate/tensile strength of the fiber, d – diameter of the fiber, τ_c – interface bond strength.

- Fibers for which $l >> l_c$ (normally l >15 l_c) are termed as continuous, discontinuous or short fibers on the other hand.

Fiber-reinforced composites (contd…)

- Effect of fiber orientation and length:

- For continuous fiber composites under longitudinal loading conditions: assuming isostrain conditions, strength and elastic modulus of the composite is given by

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

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

$$E_{cl} = E_m V_m + E_f V_f = E_m (1 - V_f) + E_f V_f$$

Fiber-reinforced composites (contd…)

- Effect of fiber orientation and length:

- For continuous fiber composites under longitudinal loading conditions: assuming isostrain conditions, load sharing between matrix and fiber is given by

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

- For continuous fiber composites under transverse loading conditions: assuming isostress conditions, load sharing between matrix and fiber is given by

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

Fiber-reinforced composites (contd…)

- Effect of fiber orientation and length:

- For continuous fiber composites, longitudinal strength is given by

$$\sigma^*_{cl} = \sigma'_m (1 - V_f) + \sigma^*_f V_f$$

- For discontinuous but aligned fiber composites, longitudinal strength is given by

when $l > l_c$,
$$\sigma^*_{cd} = \sigma^*_f V_f (1 - \frac{l_c}{2l}) + \sigma'_m (1 - V_f)$$

when $l < l_c$
$$\sigma^*_{cd'} = \frac{l \tau_c}{d} V_f + \sigma'_m (1 - V_f)$$

Fiber-reinforced composites (contd…)

- Effect of fiber orientation and length:

- For discontinuous randomly orientated fiber composites, longitudinal strength is given by

  when *K* is fiber efficiency parameter.

$$E_{cl} = KE_m V_m + E_f V_f$$

Structural composites

- Two classes of structural composites are – laminar composites and sandwich structures.
- Laminar composites – consists of layers of materials. Many laminar composites are designed to increase corrosion resistance while retaining low cost, high strength or light weight.

  E.g.: thin coatings, thicker protective coatings, claddings, bimetallics, laminates.
- Sandwich structures – consists of thin layers joined to core in between. Neither the filler material nor the facing material is strong or rigid, but the composite possesses both properties.

Structural composites (contd…)

- The faces bear most of the in-plane loading and also any transverse bending stresses.
- Typical face materials include Al-alloys, fiber-reinforced plastics, titanium, steel and plywood.
- The core serves two functions – it separates the faces and resists deformations perpendicular to the face plane; provides a certain degree of shear rigidity along planes that are perpendicular to the faces.
- Typical materials for core are: foamed polymers, synthetic rubbers, inorganic cements, balsa wood.
- Sandwich structures are found in many applications like roofs, floors, walls of buildings, and in aircraft for wings, fuselage and tailplane skins.