MEMEC02

ENGINEERING MATERIALS & METALLURGY

UNIT-V: Composites

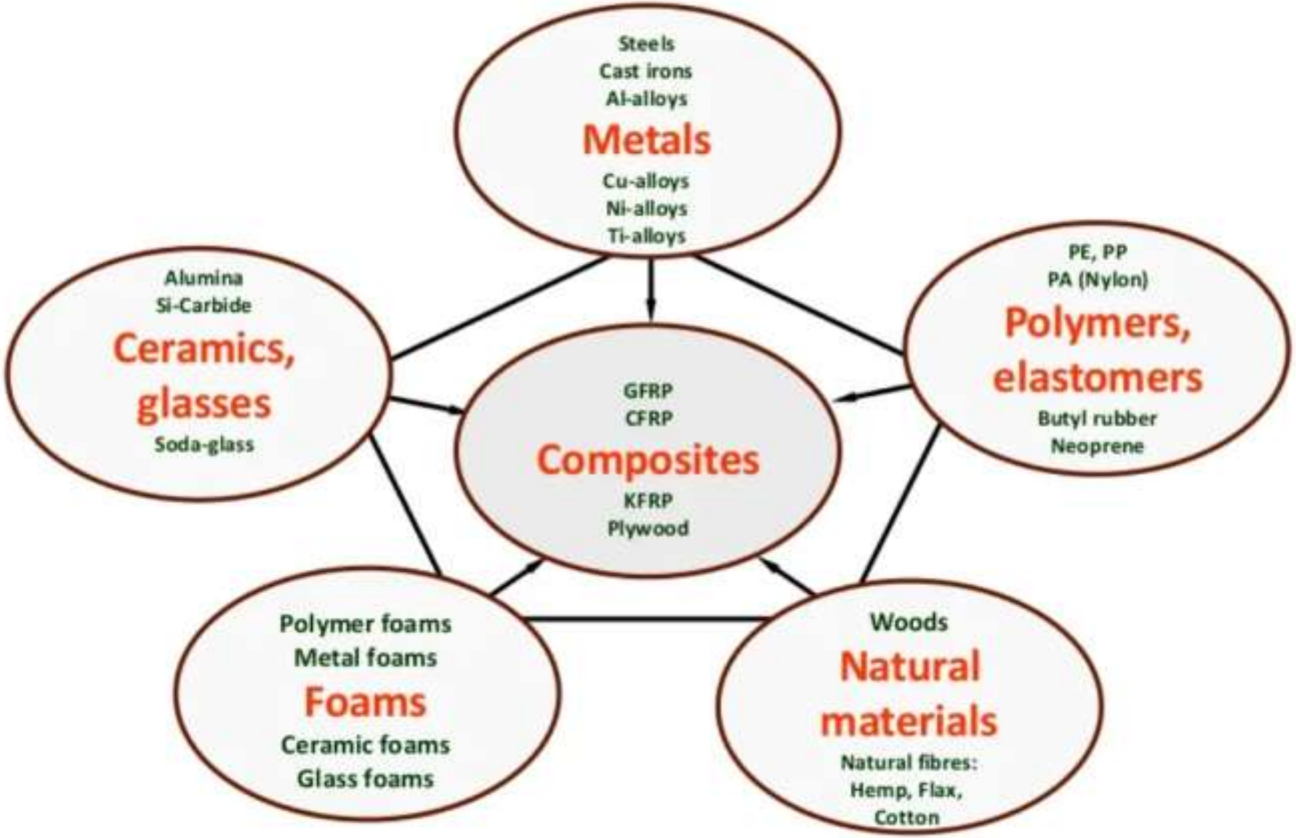
Department of Mechanical Engineering
Netaji Subhas University of Technology

Unit-V Composites

Composites: Classification, Micro-mechanics of the fiber and particle reinforced composites, strength, stiffness and factors affecting, failure modes.

Other Materials: Brief description of other industrial materials, smart materials and nano-materials and other industrial materials of industrial applications.

The world of materials



Advantages of Composites

- Light in weight
- Strength-to-weight and Stiffness-weight are greater than steel or aluminum
- Fatigue properties are better than common engineering metals
- Composites cannot corrode like steel
- Possible to achieve combinations of properties attainable with metals, ceramics, or polymers alone

WHAT IS A COMPOSITE MATERIAL?

A materials system **composed of two or more physically distinct phases** whose combination produces aggregate properties that are different from those of its constituents.

or

Two or more chemically distinct materials which when combined have improved properties over the individual materials. Composites could be natural or synthetic.

Composites

A ***judicious*** combination of two or more materials that produces a ***synergistic*** effect.

A material system composed of two or more physically distinct phases whose combination produces aggregate properties that are different from those of its constituents.

To obtain a more desirable combination of properties (principle of combined action)

e.g., low density and high strength

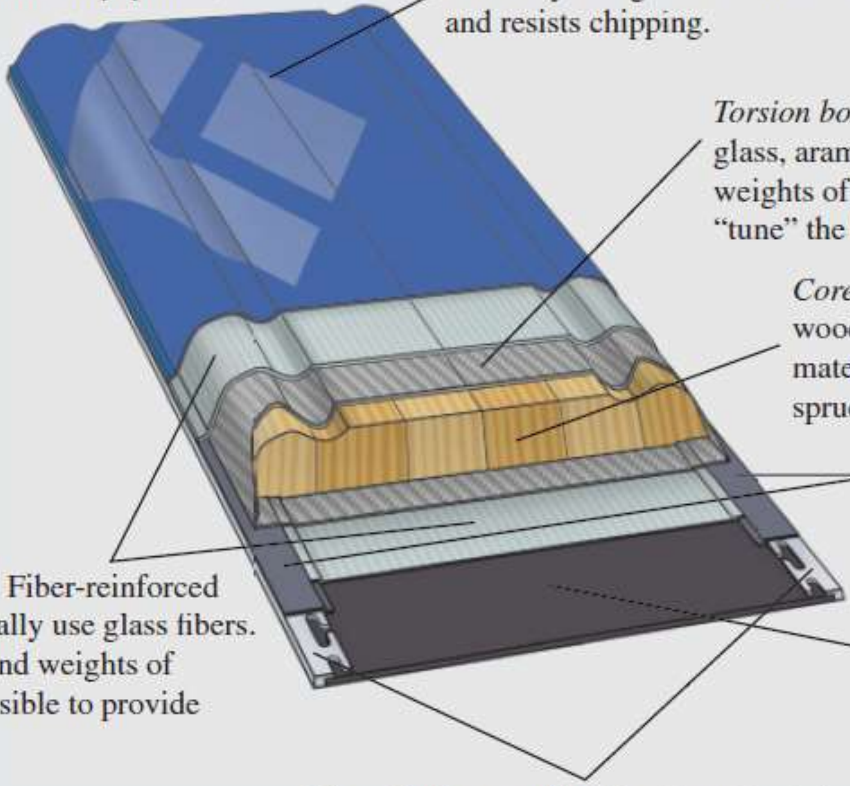


Fig: One relatively complex composite structure is the modern ski. This illustration, a cross section of a high performance snow ski, shows the various components.

Importance of Composite Materials

- Composites can be **very strong and stiff**, yet very **light in weight**, so **ratios of strength -to - weight** and s**tiffness -to - weight** are several times greater than steel or aluminum.

- Fatigue properties are generally better than for common engineering metals.

- Toughness is often greater too

- Composites can be designed that do not corrode like steel

- Possible to achieve combinations of properties not attainable with metals, ceramics, or polymers

Properties of Composite Material

In selecting a composite material, an optimum combination of properties is usually sought, rather than one particular property

- Fuselage and wings of an aircraft must be lightweight and be strong, stiff, and tough

- Several fiber reinforced polymers possess this combination of properties

  Example: natural rubber alone is relatively weak; adding significant amounts of carbon black to NR increases its strength dramatically.

One Possible Classification of Composite Materials

1. **Traditional composites** – composite materials that occur in nature or have been produced by civilizations for many years
   Examples: wood, concrete, asphalt

1. ***Synthetic composites*** - modern material systems normally associated with the manufacturing industries, in which the components are first produced separately and then combined in a controlled way to achieve the desired structure, properties, and part geometry .

Components in a Composite Material

Nearly all composite materials consist of two phases:

1. **Primary phase** - forms the ***matrix*** within which the secondary phase is imbedded

1. **Secondary phase** - imbedded phase sometimes referred to as a ***reinforcing agent***, because it usually serves to strengthen the composite

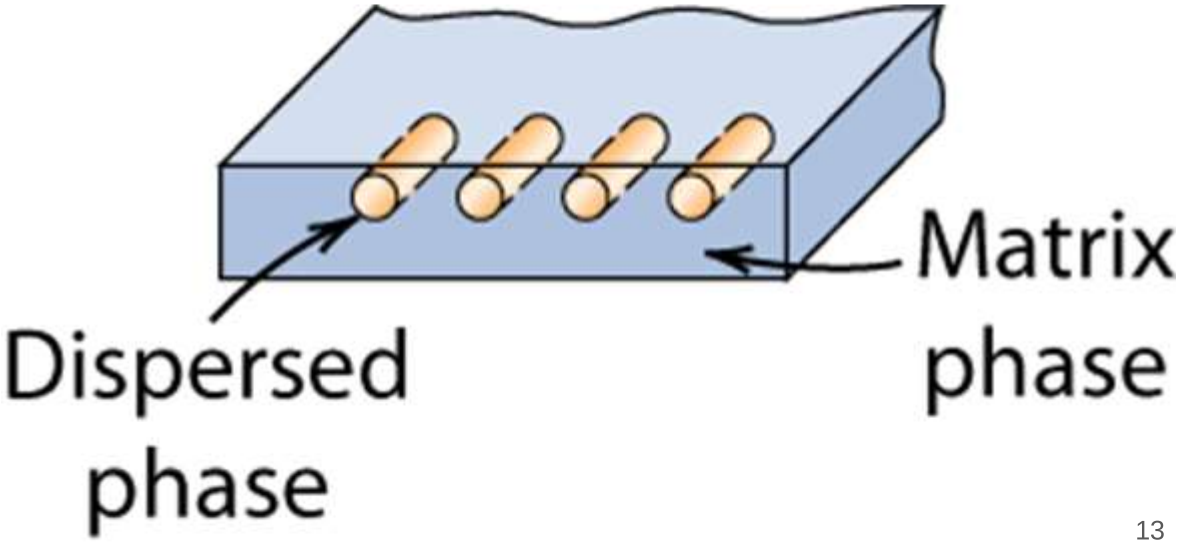
The reinforcing phase may be in the form of **fibers, particles**, or various other geometries

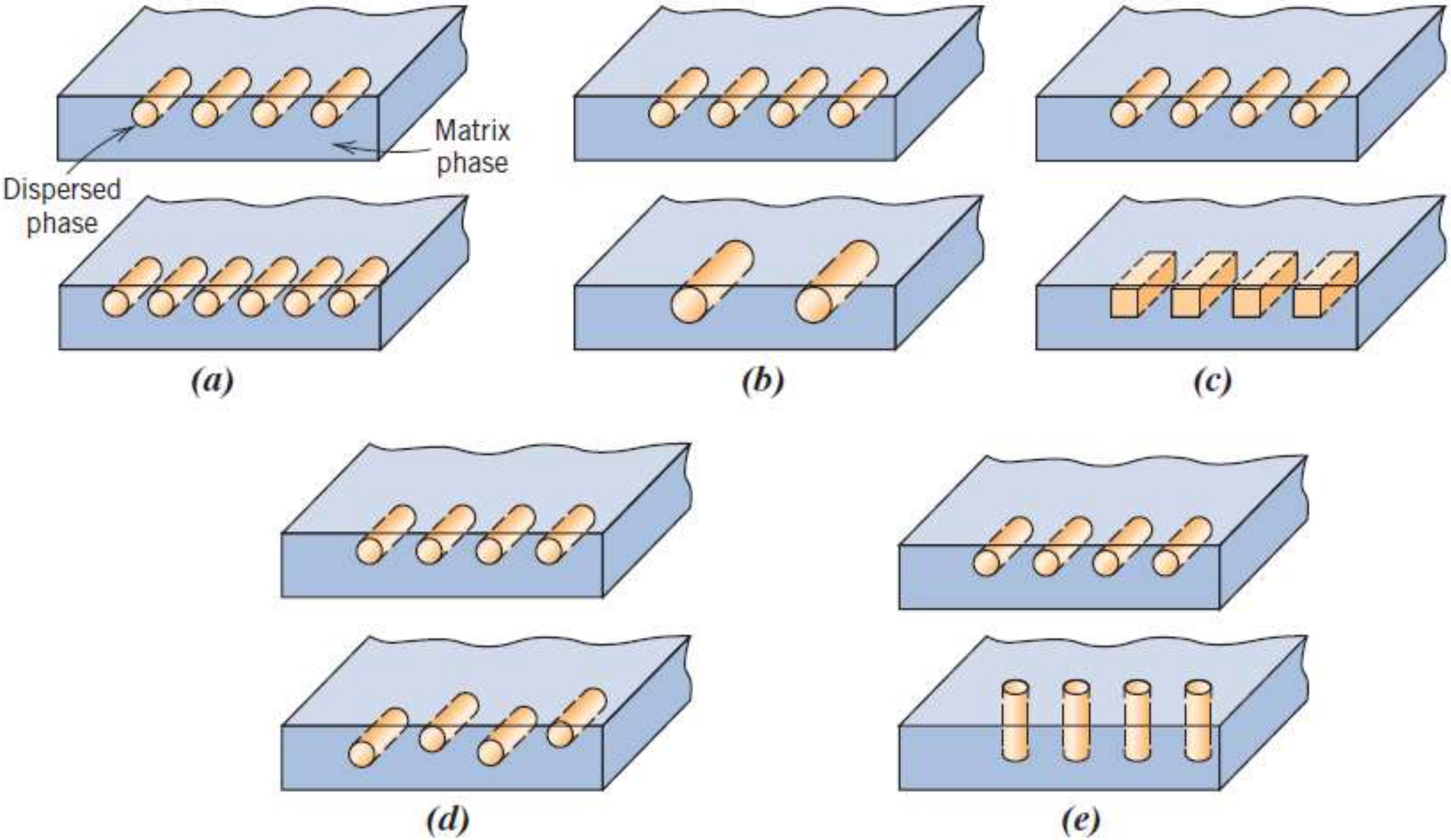
Possible combinations of two-component composite materials.

Secondary phase (reinforcement)	Primary Phase (matrix): Metal	Ceramic	Polymer
Metal	Powder metal parts infiltrated with a second metal	NA	Plastic molding compounds Steel-belted radial tires
Ceramic	Cermets[a] Fiber-reinforced metals	SiC whisker-reinforced Al_2O_3	Plastic molding compounds Fiberglass-reinforced plastic
Polymer	Powder metal parts impregnated with polymer	NA	Plastic molding compounds Kevlar-reinforced epoxy
Elements (C, B)	Fiber-reinforced metals	NA	Rubber with carbon black B or C fiber-reinforced plastic

-- Matrix - is continuous

-- Dispersed - is discontinuous and surrounded by matrix





Schematic representations of the various geometrical and spatial characteristics of particles of the dispersed phase that may influence the properties of composites: (a) concentration, (b) size, (c) shape, (d) distribution, and (e) orientation.

Functions of Matrix

- Binds Fibre
- Act as medium
- Protect fiber
- Prevent Propagation of cracks

Essentials of matrix phase

- It should be ductile
- Bonding strength should be high
- Corrosion resistant

Classification of dispersed phase

The dispersed phase can be fibre particle etc.

- **Fibres**:
  1. Glass fibres
  2. Carbon fibres
  3. Aramid fibres(Aromatic)
- **Particles** (metallic or non metallic)
- **Flakes** : 2-d particles
- **Whiskers**: thin crystals with high impact ratio e.g. graphite, silicon carbide etc.

Functions of the Matrix Material (Primary Phase)

- Provides the bulk form of the part or product made of the composite material.

- Holds the imbedded phase in place, usually enclosing and often concealing it.

- When a load is applied, the matrix shares the load with the secondary phase,in some cases deforming so that the stress is essentially born by the reinforcing agent.

The Reinforcing Phase (Secondary Phase)

- Function is to reinforce the primary phase
- Imbedded phase is most commonly one of the following shapes:
  - Fibers
  - Particles
  - Flakes
- In addition, the secondary phase can take the form of an infiltrated phase in a skeletal or porous matrix
  - Example: a powder metallurgy part infiltrated with polymer

Factors in Creating Composites

- Matrix material
- Reinforcement material
  - Concentration
  - Size
  - Shape
  - Distribution
  - Orientation

Glass fiber Reinforced Composites (GFRC/GFRP)

Contains glass fibre as reinforcing phase in a polymer matrix

Glass fiber

- Continuous or discontinuous
- Dia b/w 3-20 microns

Lim: Not very stiff and rigid

Application: Automobile and marine bodies, storage containers, plastic pipes, industrial flooring

Carbon Fibre Reinforced Polymer Composites (CFRP/CFRPC)

- Contains carbon fibre as reinforcing phase in a polymer matrix

Advantages

- High specific strength and specific modulus
- Higher strength at elevated temperatures
- Not affected by moisture or acids

Applications

- Aerospace applications
- Sports and recreational equipments
- Pressure vessels

Aramid fibre reinforced polymer composites

- Aramid-polyamide-kevlar or nomex

Advantages

- High toughness and impact resistance
- Resistance to creep and ad fatigue failure

Applications

- Bullet proof vests and armor
- Sports goods, missile cases
- Pressure vessels, clutch lining and gaskets

Metal Matrix Composites (MMCs)

- Metals with low density and low temperature toughness are preferred as matrix metal
- Aluminium, titanium, magnesium and their alloys

Advantages

- Higher operating temperatures
- Non flammability and creep resistance
- Greater resistance to degradation by organic fluids

Applications

- Aerospace application
- Gas turbine blades
- Electrical contacts

Ceramic Matrix Composites (CMCs)

- Primary objective for developing CMCs was to enhance the toughness while retaining the high temperature properties

- High melting temperature and good resistance to oxidation

- But law tensile strength, impact resistance and shock resistance

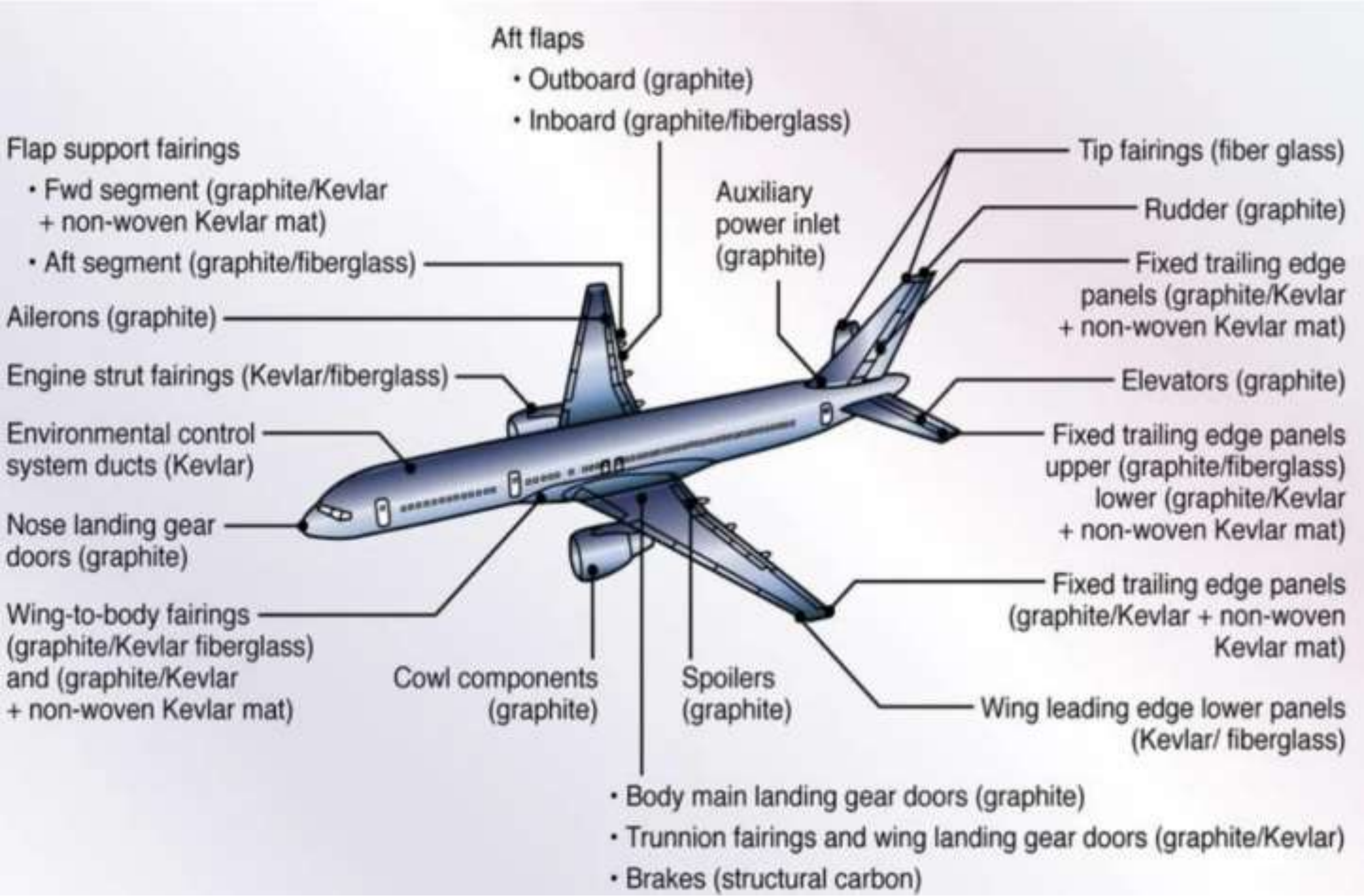
- Example: Small particles of partially stabilized Zirconia are disperses within a matrix material Al_2O_3

Applications

- Aircraft and aerospace applications
- Automotive applications
- Marine applications
- Sporting industries
- Biomaterials
- Industrial Applications

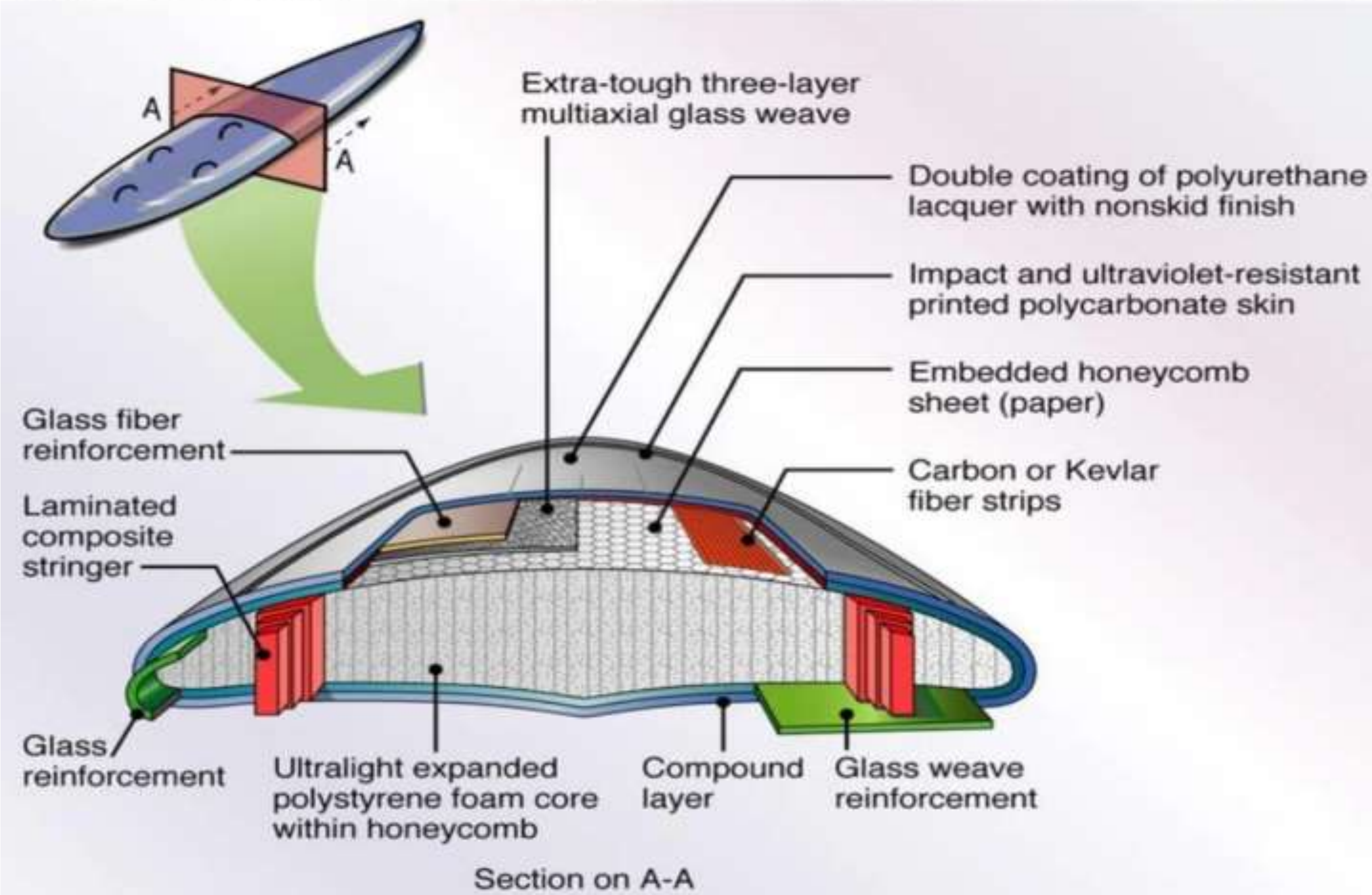
Application of advanced composite materials in Boeing 757-200 commercial aircraft.

Source: Courtesy of Boeing Commercial Airplane Company.

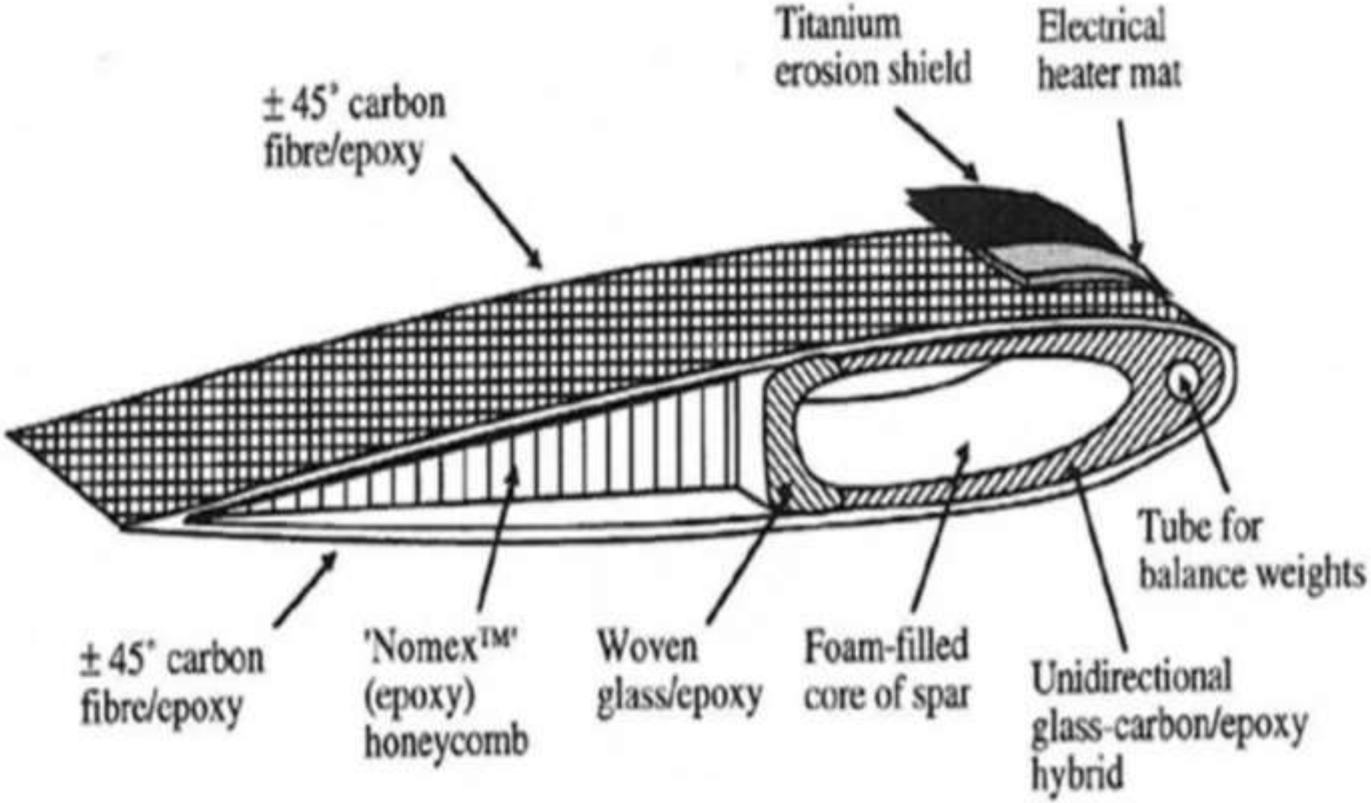


Cross-section of a composite sailboard.

Source: K. Easterline, *Tomorrow's Materials* (2nd ed.), p. 133. Institute of Metals, 1990.



Helicopter rotor blade



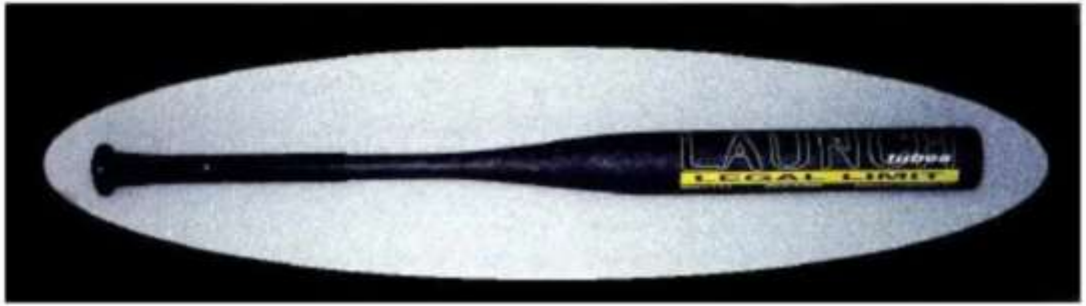
Schematic section through a typical composite construction for a helicopter rotor blade. (Courtesy of Westland Helicopters.)


Wing Panel

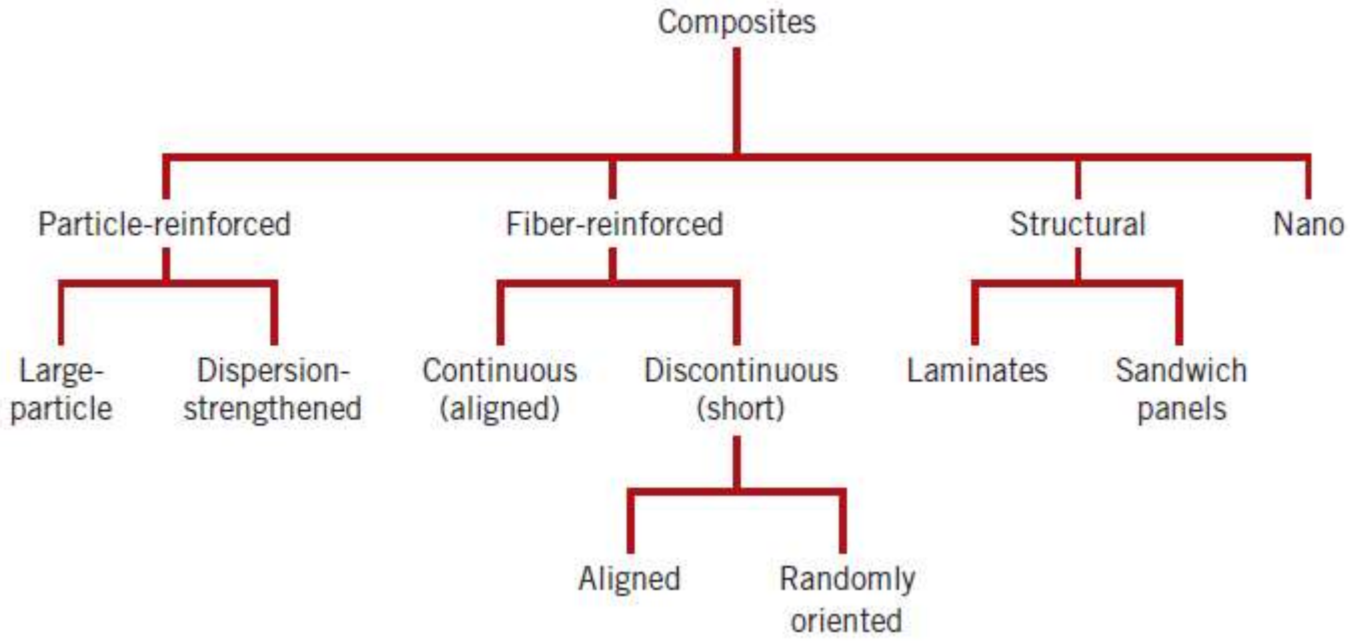

Automotive structure


Aerospace parts

Sporting goods



Classification of Composites



A classification scheme for the various composite types

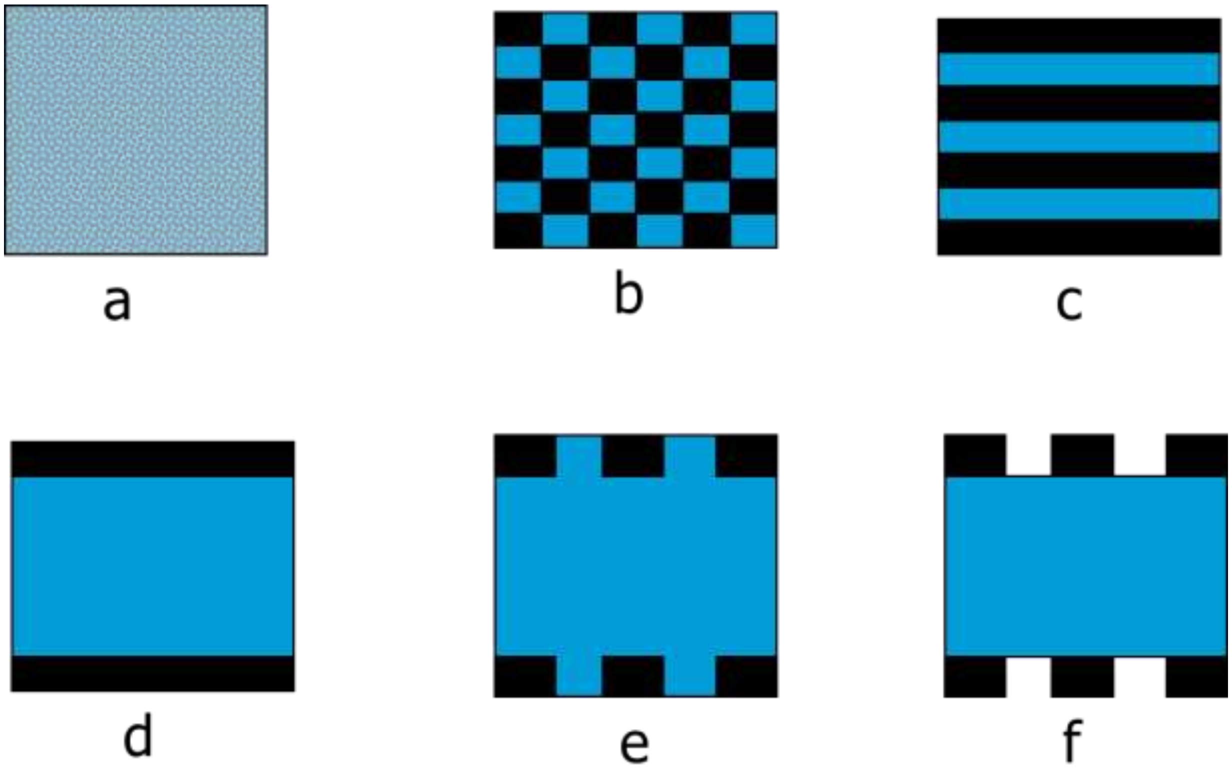
Classification of Composite Materials by Matrix

- Ceramic matrix composites (CMC):
  - Silicon carbide-silicon carbide (SiC-SiC)
  - Same material both matrix and filler BUT filler different form such as whickers, chopped fibers or strands to achieve preferred properties.

Hybrid Composites

Incorporation of two or more fibres within a single matrix resulted in formation of **hybrid composite.**

Hybrids: configuration



HYBRID COMPOSITES

Hybrid materials are composites consisting of two constituents at the nanometer or molecular level.

Commonly one of these compounds is inorganic and the other one organic in nature. Thus, they differ from traditional composites where the constituents are at the macroscopic (micrometer to millimeter) level.

Mixing at the microscopic scale leads to a more homogeneous material that either show characteristics in between the two original phases or even new properties.

Particle-Reinforced Composites

- Large-particle and dispersion-strengthened composites are the two subclassifications of particle-reinforced composites.

- The distinction between these is based on the reinforcement or strengthening mechanism.

- The term large is used to indicate that particle–matrix interactions cannot be treated on the atomic or molecular level; rather, continuum mechanics is used.

LARGE-PARTICLE COMPOSITES

- Familiar large-particle composite is concrete, which is composed of cement (the matrix) and sand and gravel (the particulates).

- Particles can have quite a variety of geometries, but they should be of approximately the same dimension in all directions (equiaxed).

- For effective reinforcement, the particles should be small and evenly distributed throughout the matrix.

- Furthermore, the volume fraction of the two phases influences the behavior; mechanical properties are enhanced with increasing particulate content.

The rule-of-mixtures

Two mathematical expressions have been formulated for the dependence of the elastic modulus on the volume fraction of the constituent phases for a two-phase composite.

These rule-of-mixtures equations predict that the elastic modulus should fall between an upper bound represented by

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

and a lower bound, or limit,

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

In these expressions, E and V denote the elastic modulus and volume fraction, respectively, and the subscripts c, m, and p represent composite, matrix, and particulate phases, respectively.

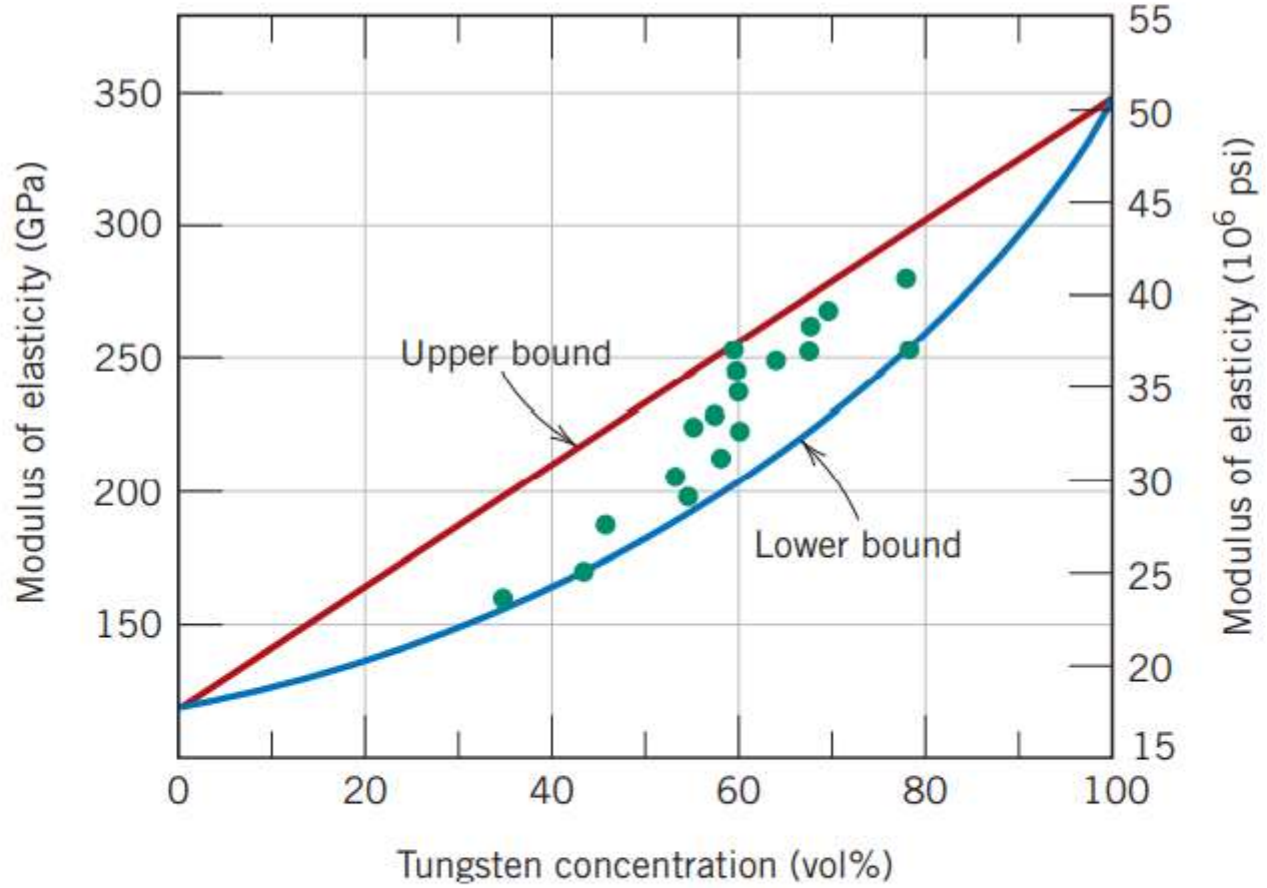


Figure : Modulus of elasticity versus volume percent tungsten for a composite of tungsten particles dispersed within a copper matrix. Upper and lower bounds are according to Equations, respectively; experimental data points are included.

The cermets

- The cermets are examples of **ceramic–metal composites**.

- The most common cermet is **cemented carbide**, which is composed of extremely hard particles of a refractory carbide ceramic such as **tungsten carbide (WC)** or **titanium carbide (TiC)** embedded in a matrix of a metal such as **cobalt** or **nickel**.

- These composites are used extensively as **cutting tools** for hardened steels.

- The hard carbide particles provide the cutting surface but, being extremely brittle, are not capable of withstanding the cutting stresses.

- Toughness is enhanced by their inclusion in the ductile metal matrix, which isolates the carbide particles from one another and prevents particle-to-particle crack propagation.

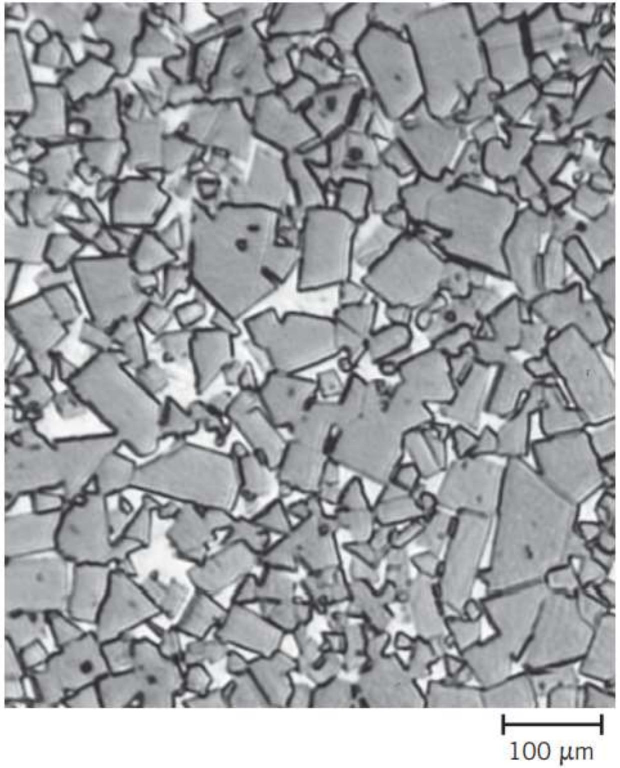


Figure Photomicrograph of a WC–Co cemented carbide. Light areas are the cobalt matrix; dark regions are the particles of tungsten carbide. 100×.

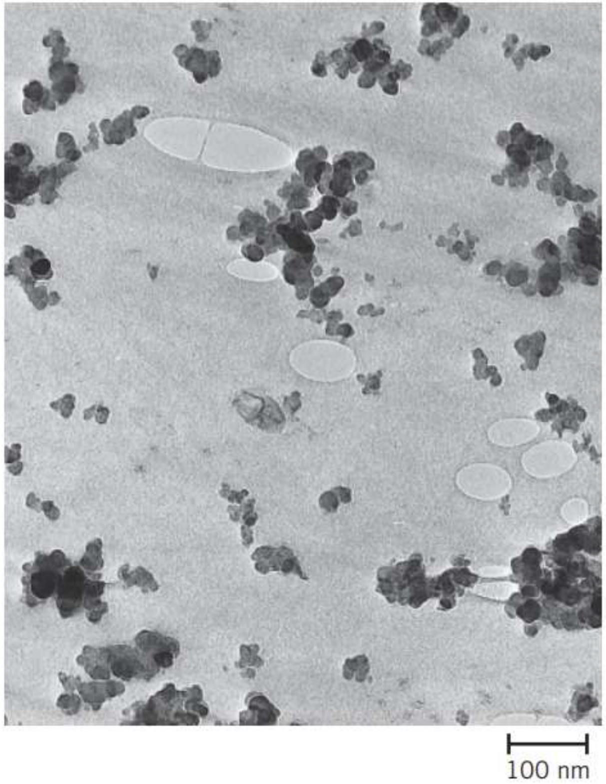


Figure Electron micrograph showing the spherical reinforcing carbon black particles in a synthetic rubber tire tread compound. The areas resembling water marks are tiny air pockets in the rubber. 80,000×.

Concrete

- Concrete is a common large-particle composite in which both matrix and dispersed phases are ceramic materials.

- The two most familiar concretes are those made with Portland and asphaltic cements, in which the aggregate is gravel and sand.

- Asphaltic concrete is widely used primarily as a paving material, whereas Portland cement concrete is employed extensively as a structural building material.

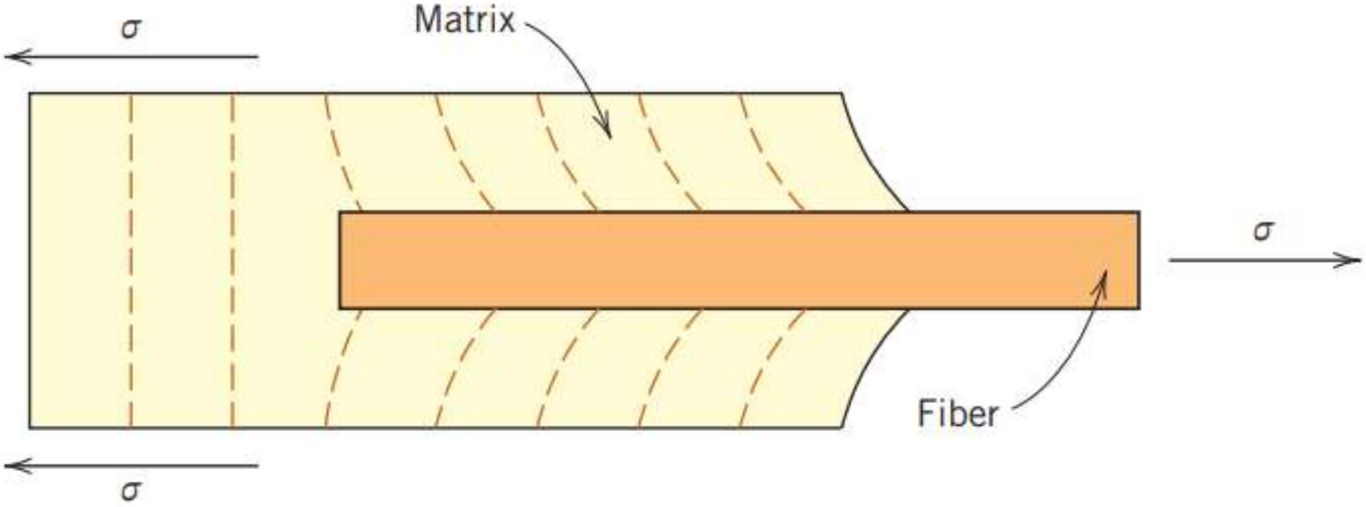
Fiber-Reinforced Composites

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

These characteristics are expressed in terms of specific strength and specific modulus parameters, which correspond, respectively, to the ratios of tensile strength to specific gravity and modulus of elasticity to specific gravity.

Fiber-reinforced composites with exceptionally high specific strengths and moduli have been produced that use low-density fiber and matrix materials.

INFLUENCE OF FIBER LENGTH



The deformation pattern in the matrix surrounding a fiber that is subjected to an applied tensile load.

Cont..

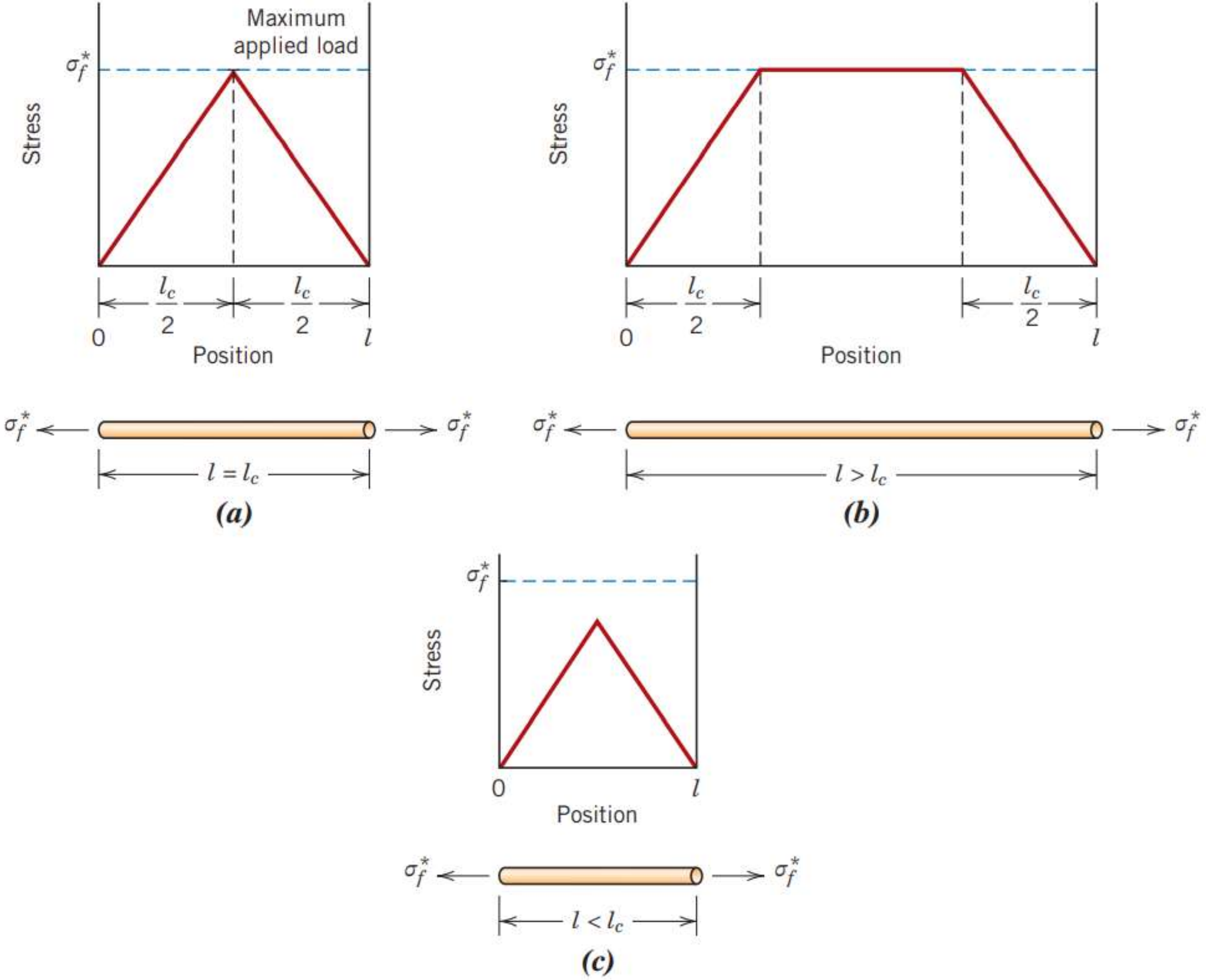
- Some critical fiber length is necessary for effective strengthening and stiffening of the composite material.

- This critical length lc is dependent on the fiber diameter d and its ultimate (or tensile) strength σ*f and on the fiber–matrix bond strength (or the shear yield strength of the matrix, whichever is smaller) τc according to

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

- For a number of glass and carbon fiber–matrix combinations, this critical length is on the order of 1 mm, which ranges between 20 and 150 times the fiber diameter.

Stress–position profiles when the fiber length l (a) is equal to the critical length l_c, (b) is greater than the critical length, and (c) is less than the critical length for a fiber-reinforced composite that is subjected to a tensile stress equal to the fiber tensile strength σ_f^*.



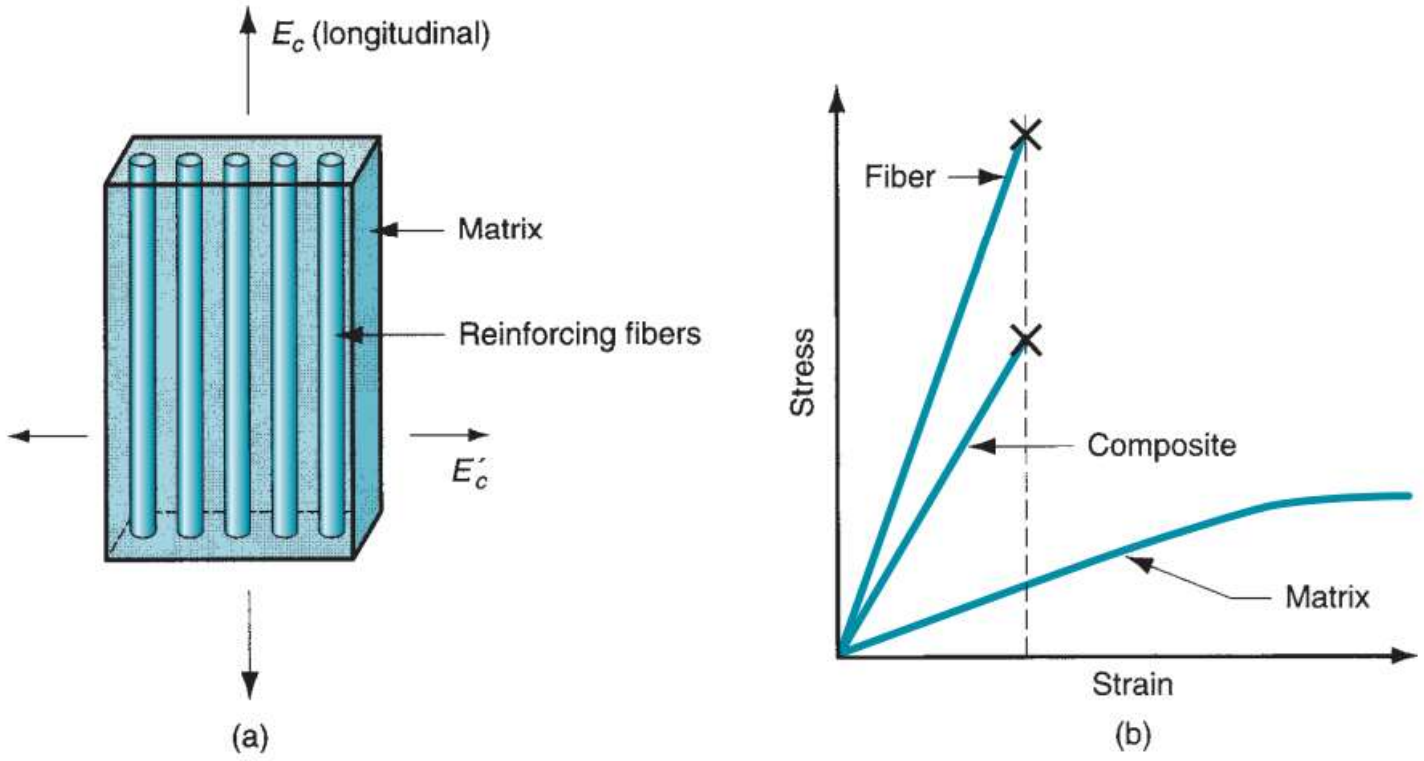
INFLUENCE OF FIBER ORIENTATION AND CONCENTRATION

- The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites.

- With respect to orientation, two extremes are possible:
  - (1) a parallel alignment of the longitudinal axis of the fibers in a single direction, and
  - (2) a totally random alignment.

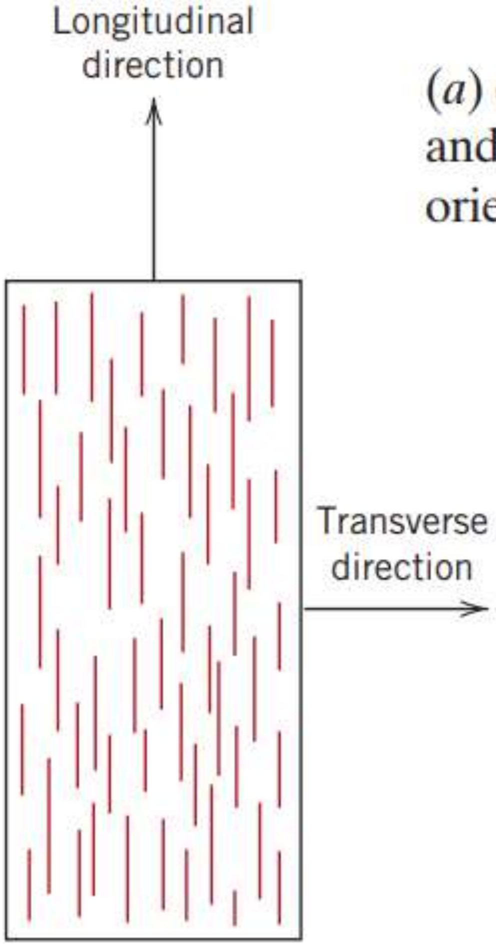
- Continuous fibers are normally aligned (Figure a), whereas discontinuous fibers may be aligned (Figure b), randomly oriented (Figure c), or partially oriented.

- Better overall composite properties are realized when the fiber distribution is uniform.

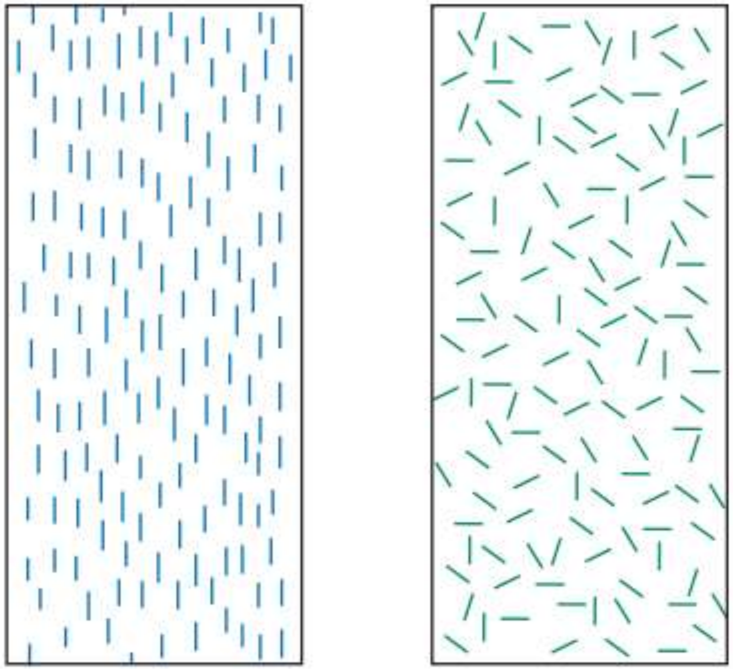


(a) Model of a fiber-reinforced composite material showing direction in which elastic modulus is being estimated by the rule of mixtures. (b) Stress–strain relationships for the composite material and its constituents. The fiber is stiff but brittle, while the matrix (commonly a polymer) is soft but ductile. The composite's modulus is a weighted average of its components' moduli. But when the reinforcing fibers fail, the composite does likewise

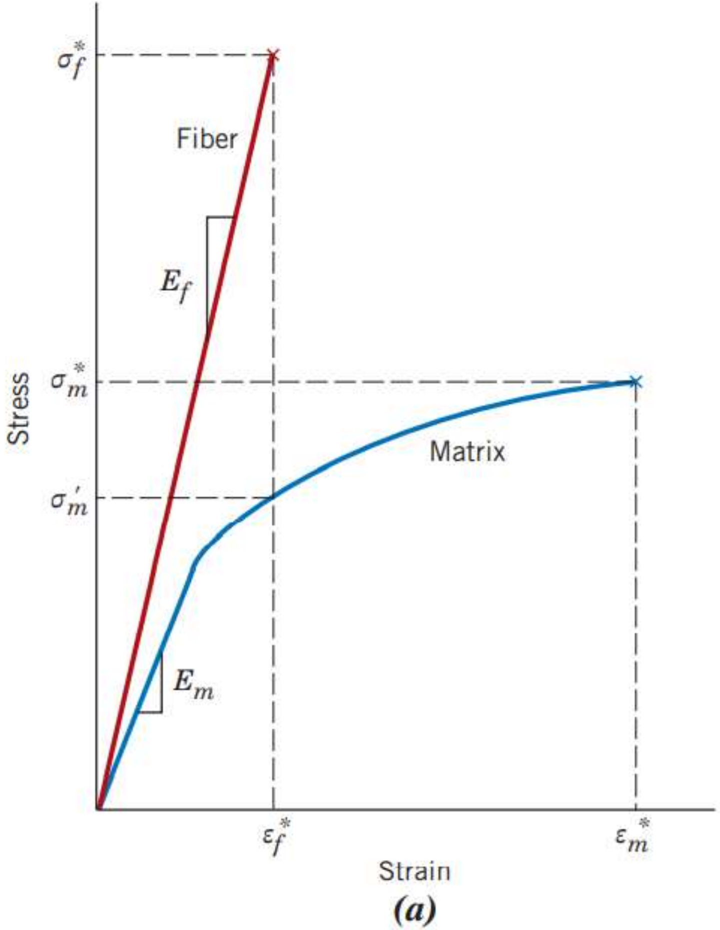
Schematic representations of (*a*) continuous and aligned, (*b*) discontinuous and aligned, and (*c*) discontinuous and randomly oriented fiber–reinforced composites.

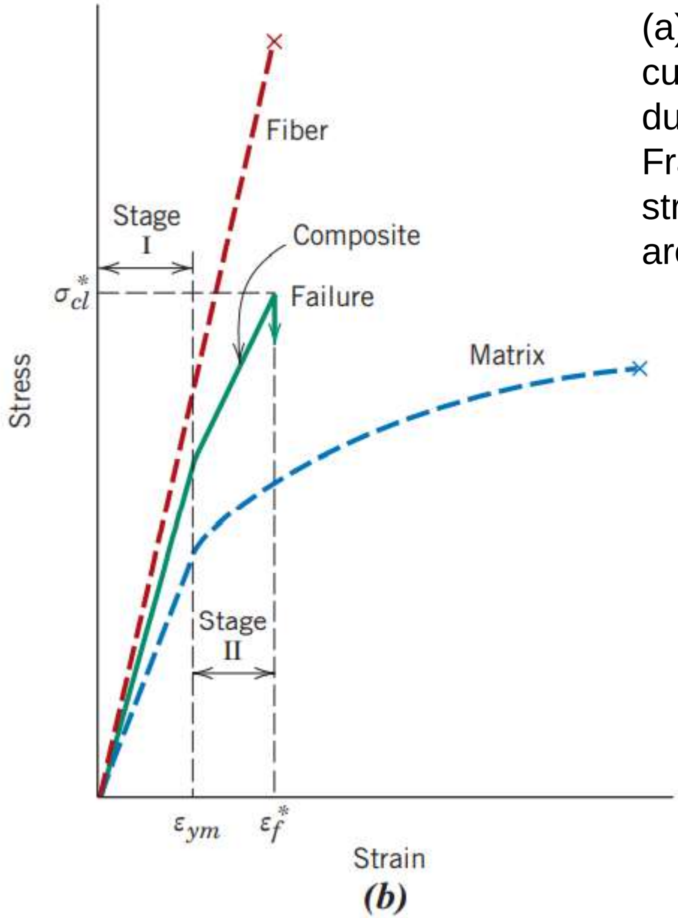


(*a*)



(*b*) (*c*)





(a) Schematic stress–strain curves for brittle fiber and ductile matrix materials. Fracture stresses and strains for both materials are noted.

(b) Schematic stress–strain curve for an aligned fiber–reinforced composite that is exposed to a uniaxial stress applied in the direction of alignment; curves for the fiber and matrix materials shown in part (a) are also superimposed

Elastic Behavior—Longitudinal Loading

- Let us now consider the elastic behavior of a continuous and oriented fibrous composite that is loaded in the direction of fiber alignment.

- First, it is assumed that the fiber–matrix interfacial bond is very good, such that deformation of both matrix and fibers is the same (an isostrain situation).

- Under these conditions, the total load sustained by the composite Fc is equal to the sum of the loads carried by the matrix phase F_m and the fiber phase F_f, or

$$F_c = F_m + F_f$$

Cont..

- From the definition of stress, Equation, F = σA; thus expressions for Fc, Fm, and Ff in terms of their respective stresses (σ c, σ m, and σf) and cross-sectional areas (A_c, A_m, and A_f) are possible. Substitution of these into Equation, yields

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

- Dividing through by the total cross-sectional area of the composite, A_c, we have

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

- where A_m/A_c and A_f/A_c are the area fractions of the matrix and fiber phases, respectively. If the composite, matrix, and fiber phase lengths are all equal, A_m/A_c is equivalent to the volume fraction of the matrix, V_m, and likewise for the fibers, $V_f = A_f / A_c$

Cont..

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

The above equation becomes

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

The previous assumption of an isostrain state means that

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

and when each term in Equation σ_c is divided by its respective strain,

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

Cont..

Furthermore, if composite, matrix, and fiber deformations are all elastic, then $\sigma_c / \varepsilon_c = E_c$, $\sigma_m / \varepsilon_m = E_m$, and $\sigma_f / \varepsilon_f = E_f$, the Es being the moduli of elasticity for the respective phases. Substitution into Equation yields an expression for the modulus of elasticity of a continuous and aligned fibrous composite in the direction of alignment (or longitudinal direction), E_{cl}, as

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

or

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

because the composite consists of only matrix and fiber phases; that is, $V_m + V_f = 1$.

E_{cl} is equal to the volume-fraction weighted average of the moduli of elasticity of the fiber and matrix phases. Other properties, including density, also have this dependence on volume fractions.

It can also be shown, for longitudinal loading, that the ratio of the load carried by the fibers to that carried by the matrix is

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

Example-1

A continuous and aligned glass fiber–reinforced composite consists of 40 vol% glass fibers having a modulus of elasticity of 69 GPa (10 × 106 psi) and 60 vol% polyester resin that, when hardened, displays a modulus of 3.4 GPa (0.5 × 106 psi).

(a) Compute the modulus of elasticity of this composite in the longitudinal direction.

(b) If the cross-sectional area is 250 mm^2 (0.4 in^2.) and a stress of 50 MPa (7250 psi) is applied in this longitudinal direction, compute the magnitude of the load carried by each of the fiber and matrix phases.

(c) Determine the strain that is sustained by each phase when the stress in part (b) is applied.

Solution

(a) The modulus of elasticity of the composite is calculated using Equation 16.10a:

$$E_{cl} = (3.4 \text{ GPa})(0.6) + (69 \text{ GPa})(0.4)$$
$$= 30 \text{ GPa } (4.3 \times 10^6 \text{ psi})$$

(b) To solve this portion of the problem, first find the ratio of fiber load to matrix load, using Equation 16.11; thus,

$$\frac{F_f}{F_m} = \frac{(69 \text{ GPa})(0.4)}{(3.4 \text{ GPa})(0.6)} = 13.5$$

or $F_f = 13.5\ F_m$.

In addition, the total force sustained by the composite F_c may be computed from the applied stress σ and total composite cross-sectional area A_c according to

$$F_c = A_c\sigma = (250 \text{ mm}^2)(50 \text{ MPa}) = 12{,}500 \text{ N } (2900 \text{ lb}_f)$$

However, this total load is just the sum of the loads carried by fiber and matrix phases; that is,

$$F_c = F_f + F_m = 12{,}500\ \mathrm{N}\ (2900\ \mathrm{lb_f})$$

Substitution for F_f from the preceding equation yields

$$13.5\ F_m + F_m = 12{,}500\ \mathrm{N}$$

or

$$F_m = 860\ \mathrm{N}\ (200\ \mathrm{lb_f})$$

whereas

$$F_f = F_c - F_m = 12{,}500\ \mathrm{N} - 860\ \mathrm{N} = 11{,}640\ \mathrm{N}\ (2700\ \mathrm{lb_f})$$

(c) The stress for both fiber and matrix phases must first be calculated. Then, by using the elastic modulus for each [from part (a)], the strain values may be determined.

For stress calculations, phase cross-sectional areas are necessary:

$$A_m = V_m A_c = (0.6)(250\ \text{mm}^2) = 150\ \text{mm}^2\ (0.24\ \text{in.}^2)$$

and

$$A_f = V_f A_c = (0.4)(250\ \text{mm}^2) = 100\ \text{mm}^2\ (0.16\ \text{in.}^2)$$

Thus,

$$\sigma_m = \frac{F_m}{A_m} = \frac{860\ \text{N}}{150\ \text{mm}^2} = 5.73\ \text{MPa}\ (833\ \text{psi})$$

$$\sigma_f = \frac{F_f}{A_f} = \frac{11{,}640\ \text{N}}{100\ \text{mm}^2} = 116.4\ \text{MPa}\ (16{,}875\ \text{psi})$$

Finally, strains are computed as

$$\varepsilon_m = \frac{\sigma_m}{E_m} = \frac{5.73\ \text{MPa}}{3.4 \times 10^3\ \text{MPa}} = 1.69 \times 10^{-3}$$

$$\varepsilon_f = \frac{\sigma_f}{E_f} = \frac{116.4\ \text{MPa}}{69 \times 10^3\ \text{MPa}} = 1.69 \times 10^{-3}$$

Therefore, strains for both matrix and fiber phases are identical, which they should be, according to Equation in the previous development.

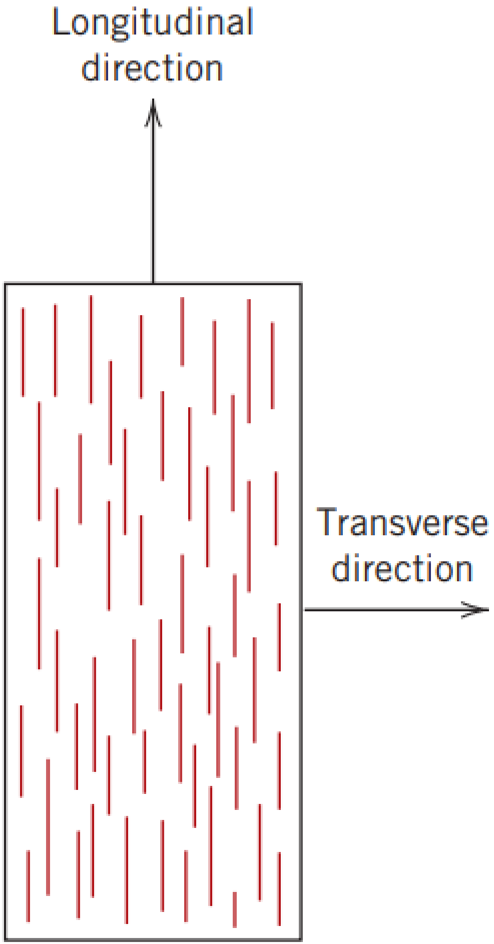
Elastic Behavior—Transverse Loading

A continuous and oriented fiber composite may be loaded in the transverse direction; that is, the load is applied at a 90° angle to the direction of fiber alignment as shown in Figure (a). For this situation the stress σ to which the composite and both phases are exposed is the same, or

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

This is termed an isostress state. The strain or deformation of the entire composite ε_c is

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



(a)

but, because $\varepsilon = \sigma/E$,

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

where E_{ct} is the modulus of elasticity in the transverse direction. Now, dividing through by σ yields

$$\boxed{\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}}$$

which reduces to

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

Example-2

Compute the elastic modulus of the composite material described in Example Problem 1, but assume that the stress is applied perpendicular to the direction of fiber alignment.

Solution

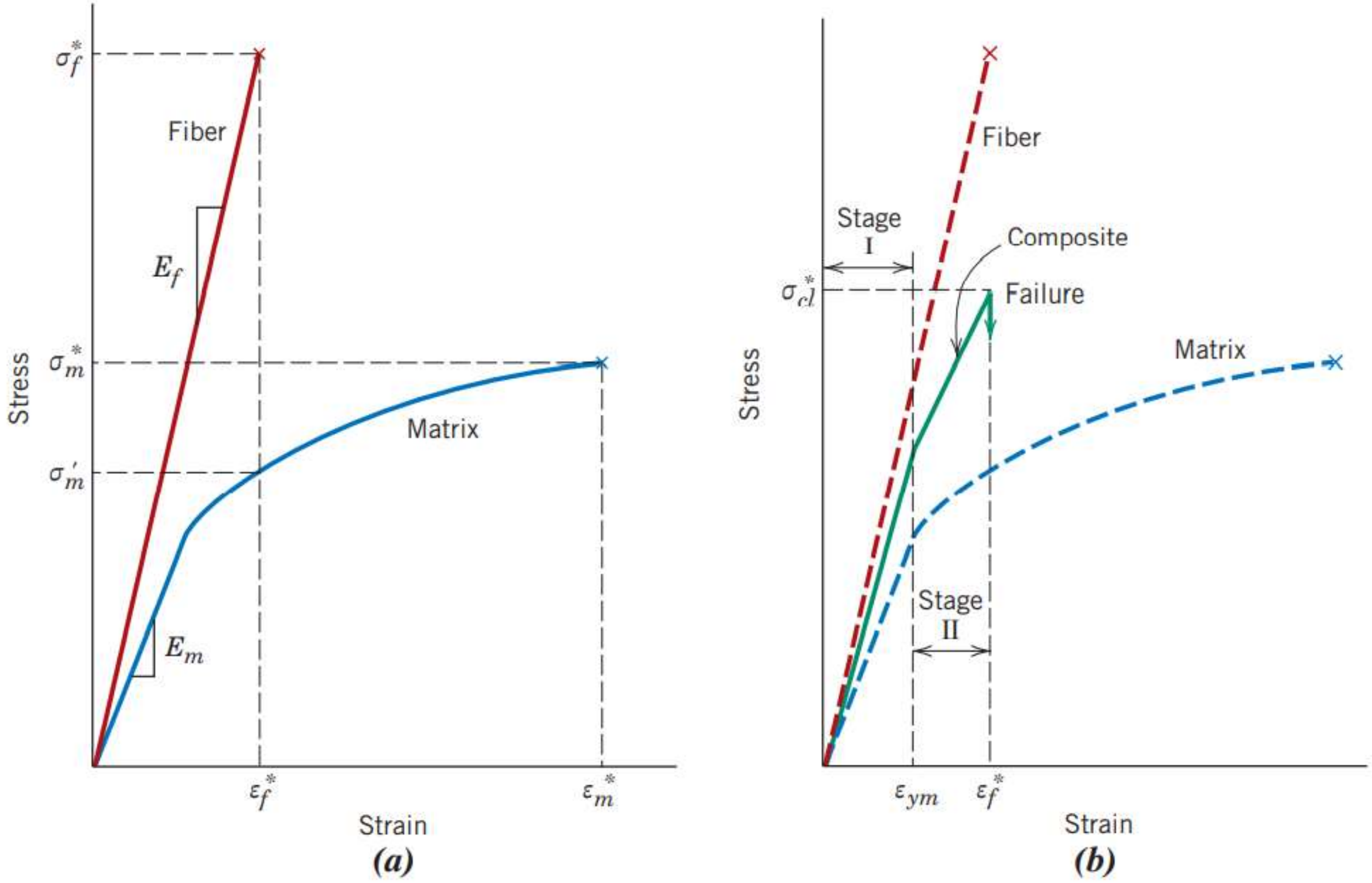
According to Equation

$$E_{ct} = \frac{(3.4\ \text{GPa})(69\ \text{GPa})}{(0.6)(69\ \text{GPa}) + (0.4)(3.4\ \text{GPa})}$$

$$= 5.5\ \text{GPa}\ (0.81 \times 10^6\ \text{psi})$$

This value for E_{ct} is slightly greater than that of the matrix phase but, from Example Problem 1a, only approximately one-fifth of the modulus of elasticity along the fiber direction (E_{cl}), which indicates the degree of anisotropy of continuous and oriented fiber composites.

Longitudinal Tensile Strength



Cont..

Typical Longitudinal and Transverse Tensile Strengths for Three Unidirectional Fiber–Reinforced Composites.

Material	*Longitudinal Tensile Strength (MPa)*	*Transverse Tensile Strength (MPa)*
Glass–polyester	700	47–57
Carbon (high modulus)–epoxy	1000–1900	40–55
Kevlar–epoxy	1200	20

[a]The fiber content for each is approximately 50 vol%.

Cont..

- Failure of this type of composite material is a relatively complex process, and several different failure modes are possible.

- The mode that operates for a specific composite depends on fiber and matrix properties and the nature and strength of the fiber–matrix interfacial bond.

- If we assume that $\varepsilon_f^* < \varepsilon_m^*$ (Figure (a)), which is the usual case, then fibers will fail before the matrix. Once the fibers have fractured, most of the load that was borne by the fibers will be transferred to the matrix.

- This being the case, it is possible to adapt the expression for the stress on this type of composite, into the following expression for the longitudinal strength of the composite, σ_{cl}^*:

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

Transverse Tensile Strength

- The strengths of continuous and unidirectional fibrous composites are highly anisotropic, and such composites are normally designed to be loaded along the high strength, longitudinal direction.

- However, during in-service applications, transverse tensile loads may also be present.

- Under these circumstances, premature failure may result inasmuch as transverse strength is usually extremely low—it sometimes lies below the tensile strength of the matrix.

- Thus, the reinforcing effect of the fibers is negative.

Example-3

The following table lists four hypothetical aligned fiber–reinforced composites (labeled A through D), along with their characteristics. On the basis of these data, rank the four composites from highest to lowest strength in the longitudinal direction, and then justify your ranking.

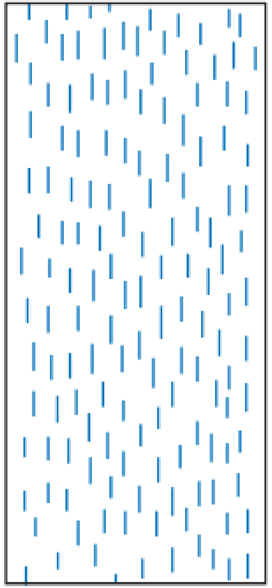
Composite	***Fiber Type***	***Volume Fraction Fibers***	***Fiber Strength (MPa)***	***Average Fiber Length (mm)***	***Critical Length (mm)***
A	Glass	0.20	3.5×10^3	8	0.70
B	Glass	0.35	3.5×10^3	12	0.75
C	Carbon	0.40	5.5×10^3	8	0.40
D	Carbon	0.30	5.5×10^3	8	0.50

Discontinuous and Aligned-Fiber Composites

- Even though reinforcement efficiency is lower for discontinuous than for continuous fibers, discontinuous and aligned-fiber composites (Figure b) are becoming increasingly important in the commercial market.

- Chopped-glass fibers are used most extensively; however, carbon and aramid discontinuous fibers are also used.

- These short-fiber composites can be produced with moduli of elasticity and tensile strengths that approach 90% and 50%, respectively, of their continuous-fiber counterparts.



(b)

Cont..

- For a discontinuous and aligned-fiber composite having a uniform distribution of fibers and in which $l > l_c$, the longitudinal strength (σ_{cd}^*) is given by the relationship

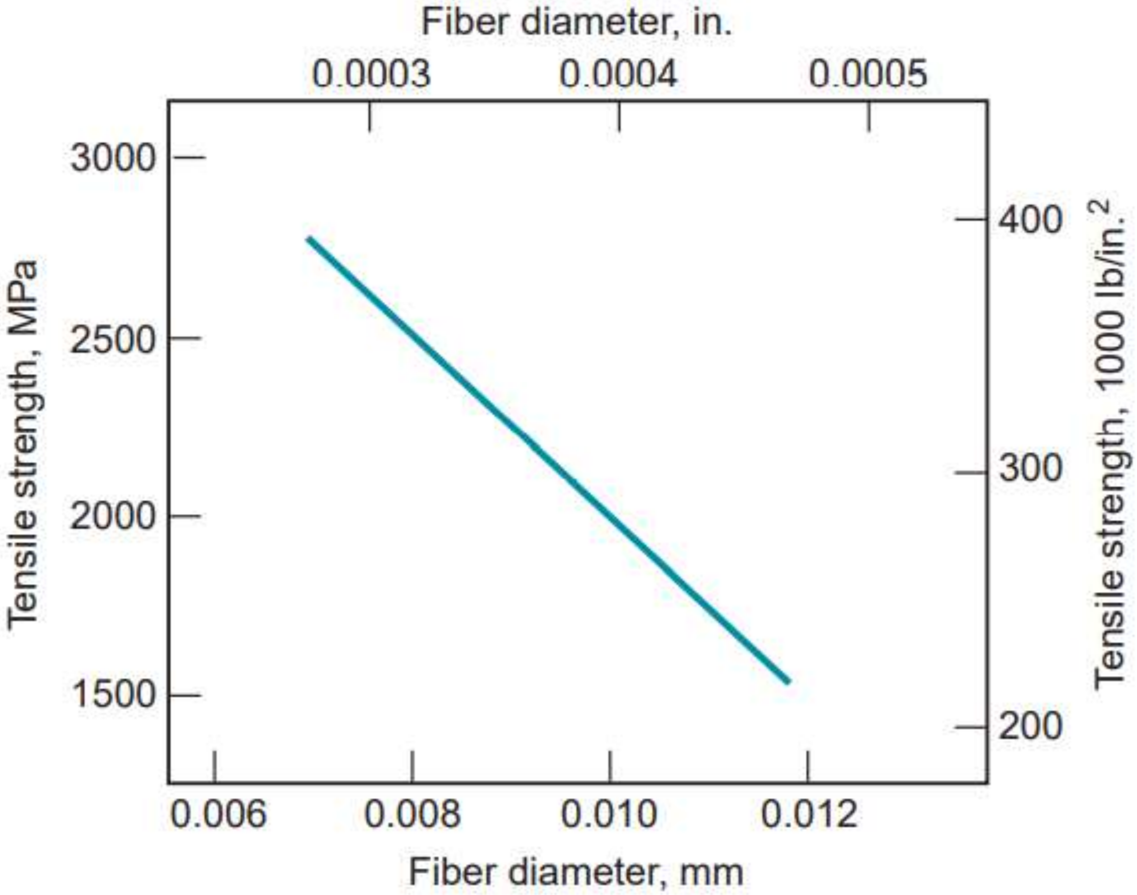
$$\sigma_{cd}^* = \sigma_f^* V_f \left(1 - \frac{l_c}{2l}\right) + \sigma_m'(1 - V_f)$$

- where σ_f^* and σ'_m represent, respectively, the fracture strength of the fiber and the stress in the matrix when the composite fails (Figure (a)).

- If the fiber length is less than critical ($l < l_c$), then the longitudinal strength ($\sigma_{cd}^{*\prime}$) is given by

$$\sigma_{cd'}^* = \frac{l\tau_c}{d} V_f + \sigma_m'(1 - V_f)$$

where d is the fiber diameter and τ_c is the smaller of either the fiber–matrix bond strength or the matrix shear yield strength



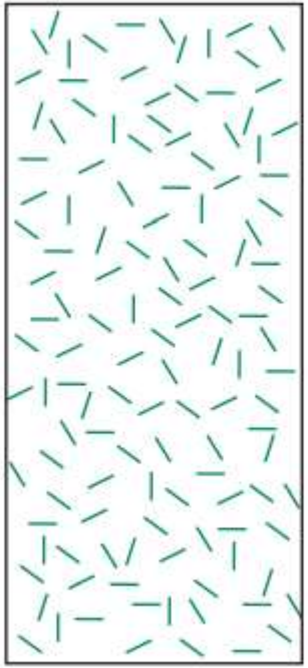
Relationship between tensile strength and diameter for a carbon fiber.

Discontinuous and Randomly Oriented–Fiber Composites

Normally, when the fiber orientation is random, short and discontinuous fibers are used; reinforcement of this type is schematically demonstrated in Figure (c).

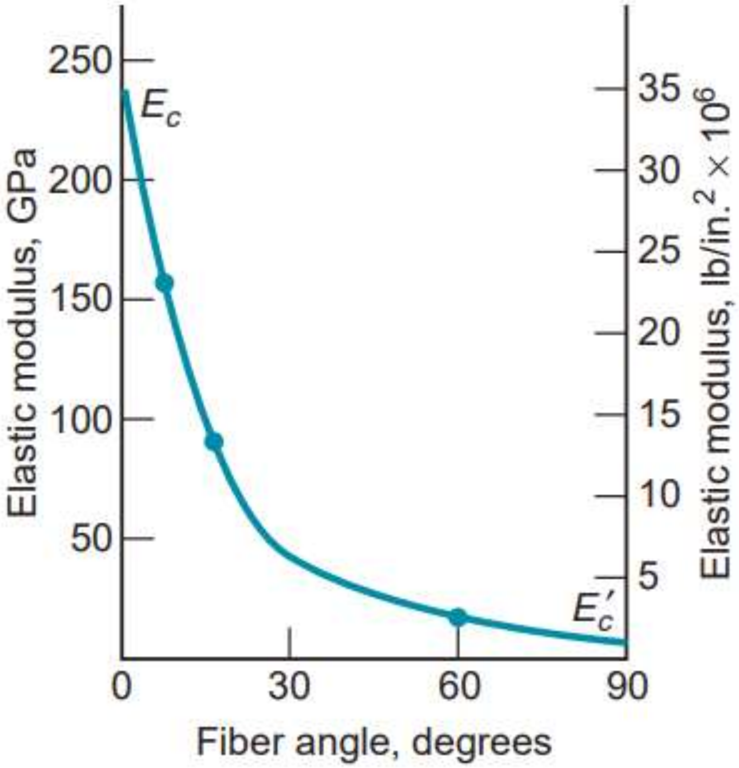
Under these circumstances, a rule-of-mixtures expression for the elastic modulus similar to Equation may be used, as follows:

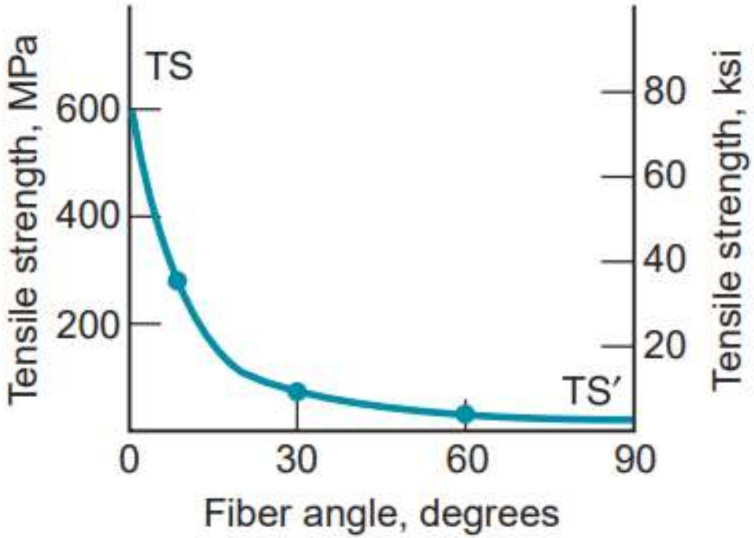
$$E_{cd} = KE_fV_f + E_mV_m$$



(c)

In this expression, K is a fiber efficiency parameter that depends on Vf and the E_f/E_m ratio. Its magnitude will be less than unity, usually in the range 0.1 to 0.6. Thus, for random fiber reinforcement (as with oriented-fiber reinforcement), the modulus increases with increasing volume fraction of fiber.



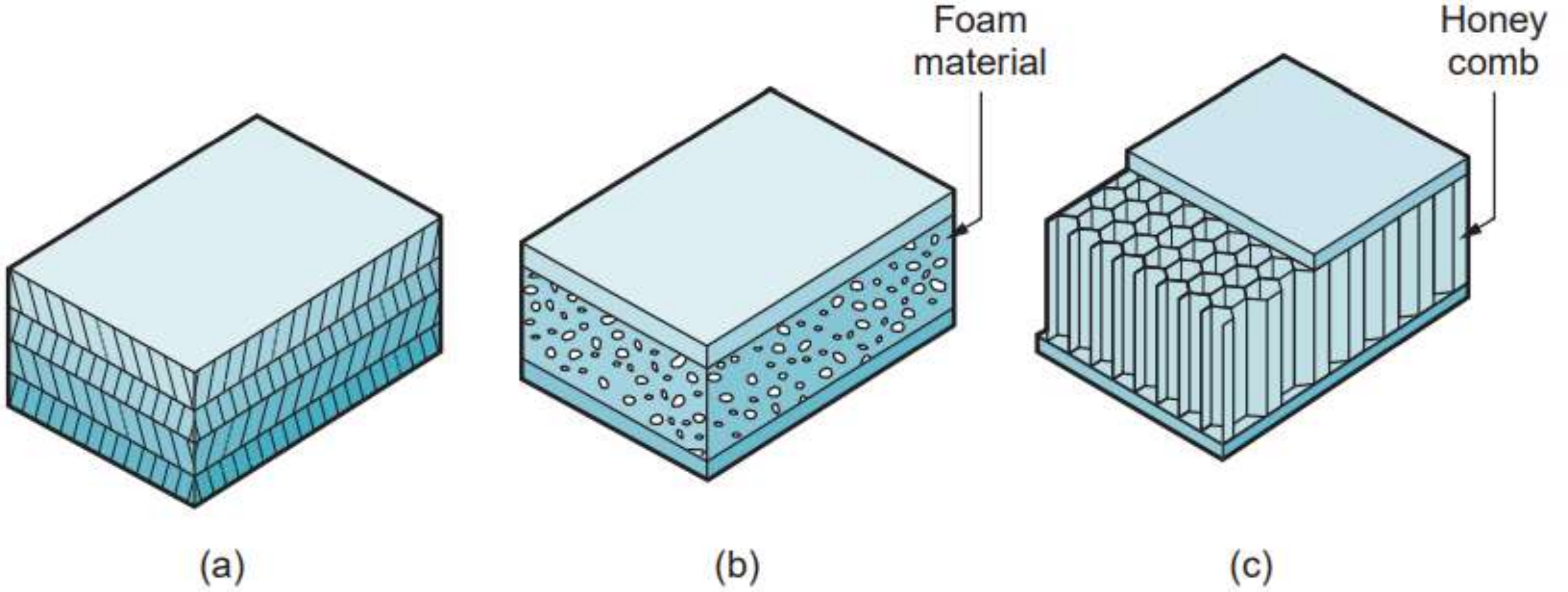


Variation in elastic modulus and tensile strength as a function of direction of measurement relative to longitudinal axis of carbon fiber-reinforced epoxy composite.

OTHER COMPOSITE STRUCTURES

- Our model of a composite material described above is one in which a reinforcing phase is imbedded in a matrix phase, the combination having properties that are superior in certain respects to either of the constituents alone.

- However, composites can take alternative forms that do not fit this model, some of which are of considerable commercial and technological importance.
  - A laminar composite structure
  - A sandwich structure
  - A foamed material
  - A honeycomb



Laminar composite structures: (a) conventional laminar structure; (b) sandwich structure using a foam core, and (c) honeycomb sandwich structure.

- **A laminar composite structure** consists of two or more layers bonded together to form an integral piece, as in Figure 9.7(a). The layers are usually thick enough that this composite can be readily identified—not always the case with other composites. The layers are often of different materials, but not necessarily. Plywood is such an example; the layers are of the same wood, but the grains are oriented differently to increase overall strength of the laminated piece.

- **The sandwich structure** is sometimes distinguished as a special case of the laminar composite structure. It consists of a relatively thick core of low-density material bonded on both faces to thin sheets of a different material.

- The low-density core may be **a foamed material**, as in Figure (b), or **a honeycomb**, as in (c). The reason for using a sandwich structure is to obtain a material with high strength-to-weight and stiffness-to-weight ratios

Examples of laminar composite structures.

Laminar Composite	Description (reference in text if applicable)
Automotive tires	A tire consists of multiple layers bonded together; the layers are composite materials (rubber reinforced with carbon black), and the plies consist of rubber-impregnated fabrics
Honeycomb sandwich	A lightweight honeycomb structure is bonded on either face to thin sheets, as in Figure (c).
Fiber-reinforced polymers	Multilayered fiber-reinforced plastic panels are used for aircraft, automobile body panels, and boat hulls
Plywood	Alternating sheets of wood are bonded together at different orientations for improved strength.
Printed circuit boards	Layers of copper and reinforced plastic are used for electrical conductivity and insulation, respectively
Snow skis	Skis are laminar composite structures consisting of multiple layers of metals, particle board, and phenolic plastic.
Windshield glass	Two layers of glass on either side of a sheet of tough plastic

Other Materials

Smart Materials

Nano Materials

Smart Materials

- Smart or intelligent materials are materials that have to respond to stimuli and environmental changes and to activate their functions according to these changes

- The stimuli like temperature, pressure, electric flow, magnetic flow, light, mechanica, etc can originate internally or externally.

Properties of Smart Materials

- Sensing materials and devices
- Actuation materials and devices
- Control devices and techniques
- Self-detection, self-diagnostic
- Self-corrective, self-controlled, self-healing
- Shock absorbers, damage arrest

Components of Smart Systems

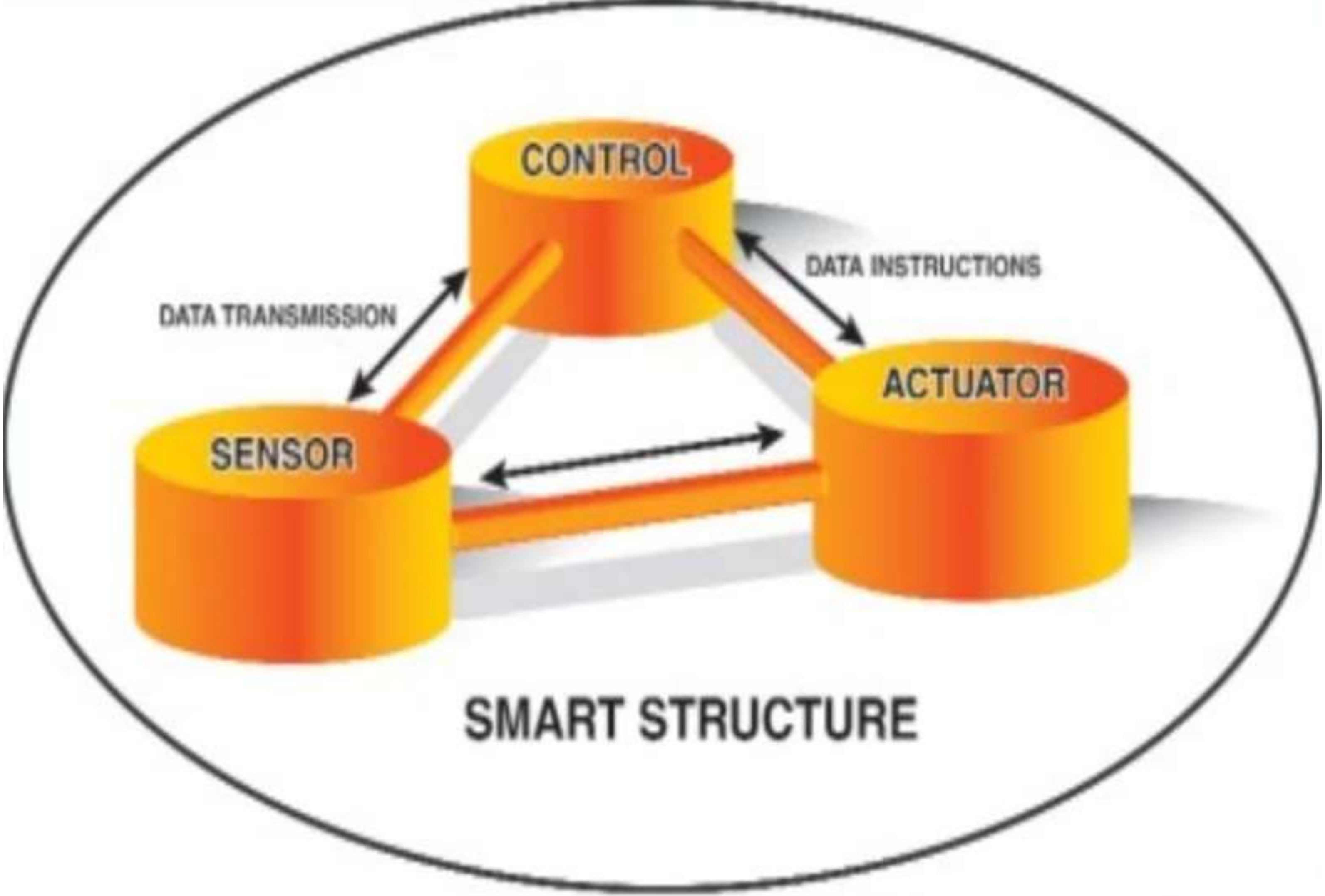
- **Data Acquisition (**tactile sensing): The aim of this component is to collect the required data needed for an appropriate sensing and mentoring of the structure. E.g. Fiber optic sensing

- **Data Transmission** (Sensory nerves): The purpose of this part is to forward the raw data to the local and/or central command and control units.

- **Command and Control unit** (brain): The role of this unit is to manage and control the whole system by analyzing the data, reaching the appropriate conclusion, and determining the actions required.

- **Data Instruction (**motor nerves): The function of this part is to transmit the decisions and the associated instructions back to the members of the structure.

- **Action Devices(**muscles): The purpose of this part is to take action by triggering the controlling devices units

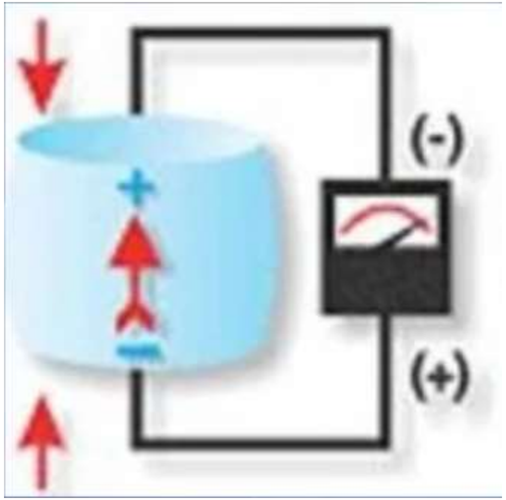

CONTROL
DATA INSTRUCTIONS
DATA TRANSMISSION
ACTUATOR
SENSOR
SMART STRUCTURE

Classification of Smart materials

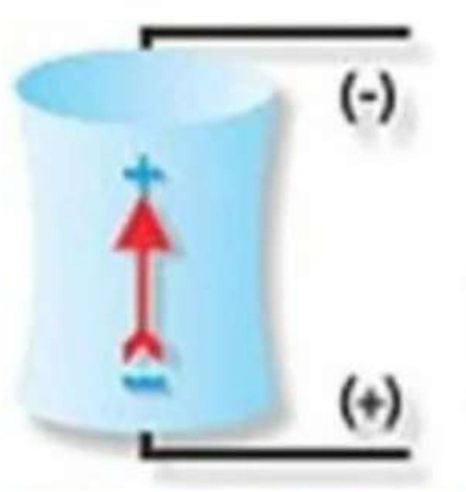
- Piezoelectric materials
- Rheological materials
- Thermoresponsive materials
- Electrochromic materials
- Fullerenes
- Biomimetic materials
- Smart gels

Piezoelectric Materials

When subjected to an electric change or a variation in voltage, piezoelectric material will undergo some mechanical change, and vice versa. These events are called the direct and converse effects



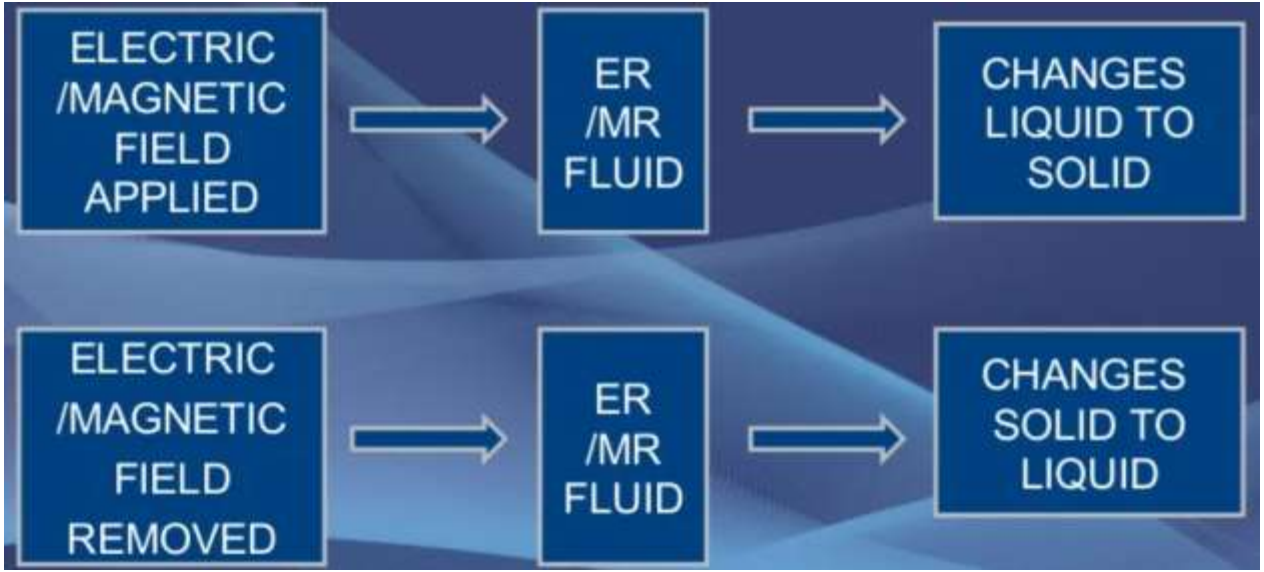
Direct effect



Reverse Effect

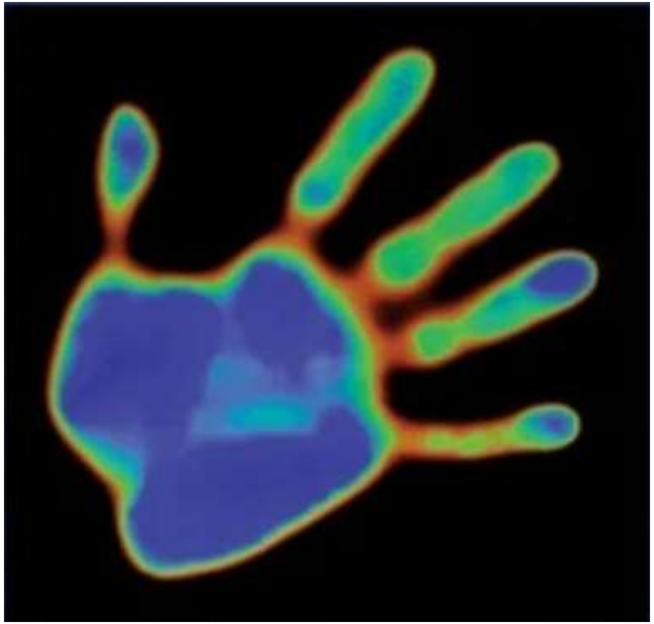
Rheological Materials

These are in liquid phase which can change state instantaneously through the application of an electric current or magnetic field. These fluids may find applications in brakes, shock absorbers and dampers for vehicle seats.



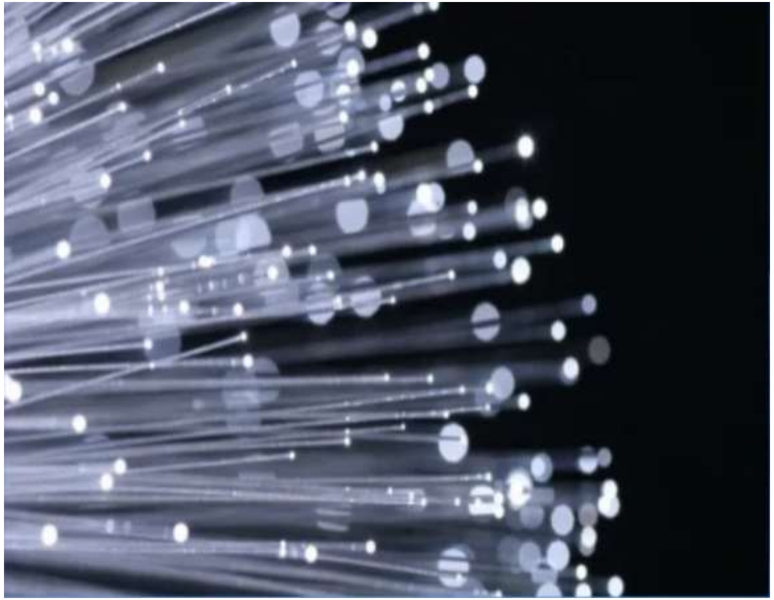
Thermoresponsive Materials

Thermoresponsive is the ability of a material to change properties in response to changes in temperature. They are useful in thermostat control and in parts of automotive and air vehicles.



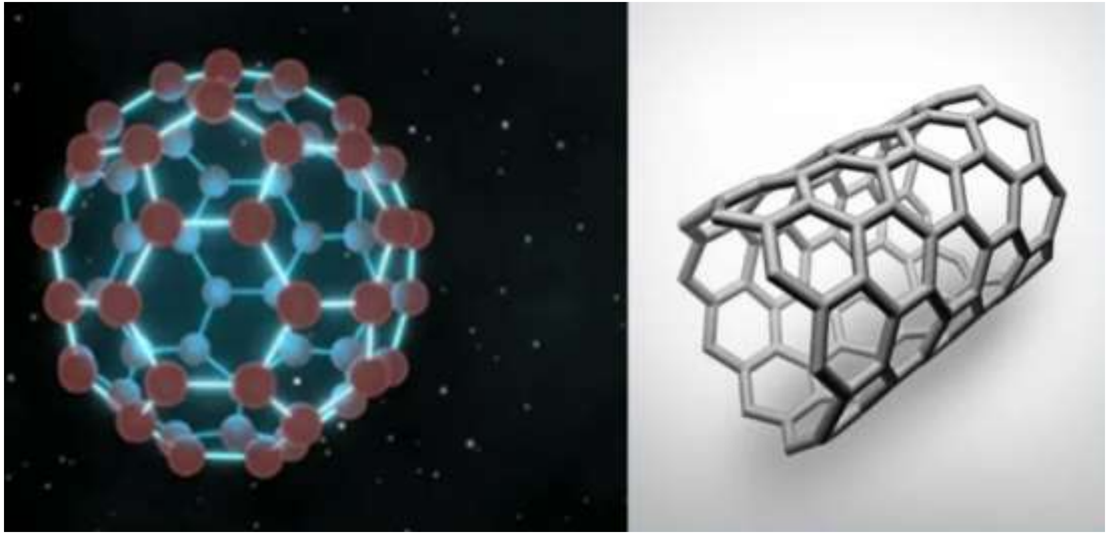
Electrochromic materials

Electrochromic is the ability of a material to change its optical properties(e.g.color) when a voltage is applied across it. They are used in LCDs and cathodes in lithium batteries.



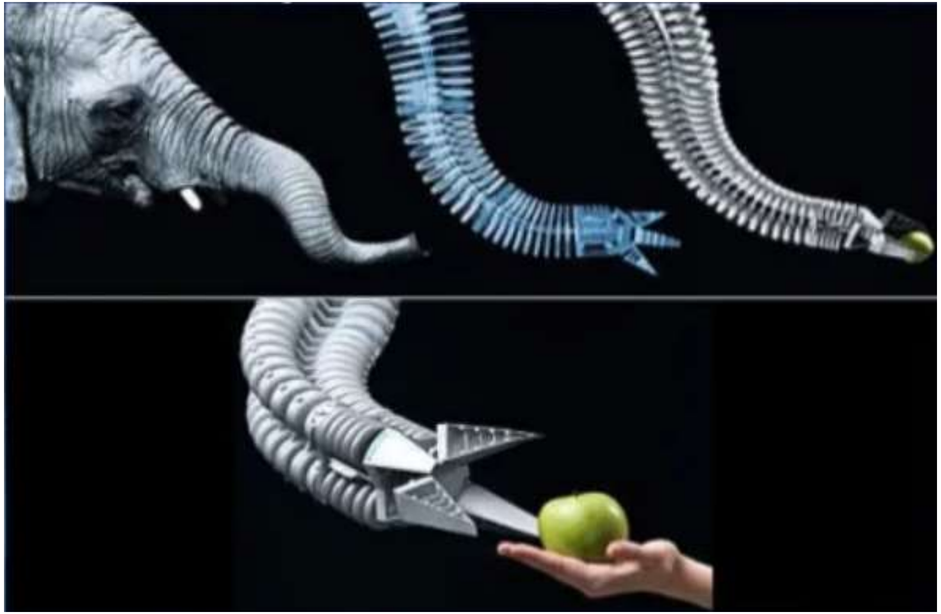
Fullerences

- These are spherically caged molecules with carbon atoms at the corner of a polyhedral structure consisting of pentagons and hexagons. These are usually used in polymeric matrices for use in smart systems. They are used in electronic and microelectronic devices, superconductors, optical systems.



Biomimetic Materials

- The materials and structures involved in natural systems have the capability to sense their environment, process the data and respond instantly. For Example to allow leaf surfaces to follow the direction of sunlight and essentially a real-time change in the load path through the structure to avoid overload of a damaged region.



Smart Gels

- These are gels that can shrink or sell by several orders of magnitude. Some of these can also be programmed to absorb or release fluids in response to a chemical or physical stimulus. These ges are used in areas such as food, drug delivery, organ replacement and chemical processing.

Shape Memory Alloys (SMA)

- In 1930s, Arne Olander was first observed the shape memory effect while working with an ally of gold and cadmium.

- This Au-Cd alloys was plastically deformed when cold but returns to its original configuration when heated.

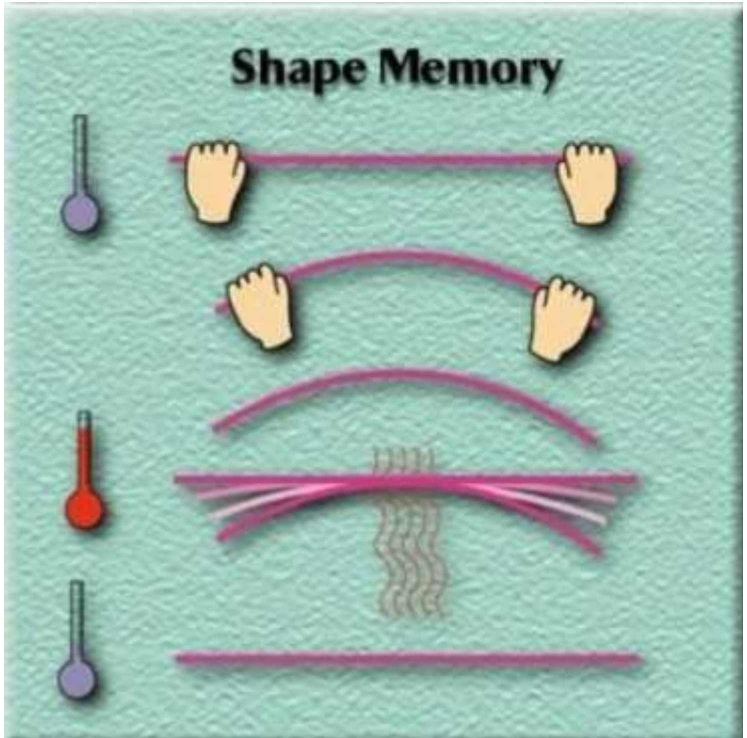
- The shape memory properties of nickel-titanium alloys were discovered in the 1960s. Although pure nickel-titanium alloys has very low ductility in the martensitic phase, the properties can be modified by the addition of a small amount of a third element.

- These groups of alloys is known as Nitinol (Nickel-Titanium-Naval-Ordance-Laboratires)

How SMA works?

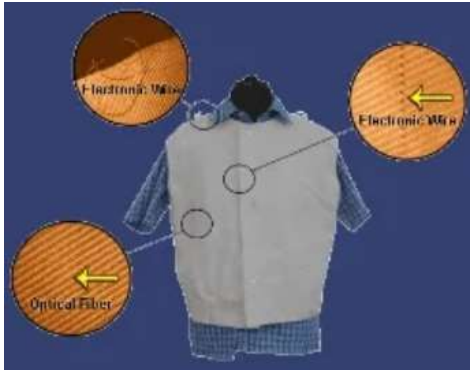
- SMA occurs due to the change in the crystalline structure of materials

- Two phases are:
  - Martensite
    - Low temperature phase
    - Relatively weak
  - Austenite
    - High temperature phase
    - Relatively strong



Applications

- Aircrafts
- Orthopedic surgery
- Dental braces
- Robotics
- Reducing vibration of helicopter blades
- Smart fabrics
- Sporting goods
- Smart glass



Merits and Demerits of Smart materials

Merits

- Bio-compatibility
- Simplicity
- Compactness
- Safety mechanism
- Good mechanical properties

Demerits

- More expensive
- Law energy efficiency
- Complex control
- Limited bandwidth

What is Nanomaterial?

- Nanomaterials are commonly defined as materials with an average grain size **less than 100 nanometers**.

- Nanomaterials have extremely small size which having at least **one dimension 100 nm**.

- **One billion** nanometers equals to **One meter.**

Properties of nanomaterials

- Physical Properties
- Chemical Properties

Physical properties of nanomaterials

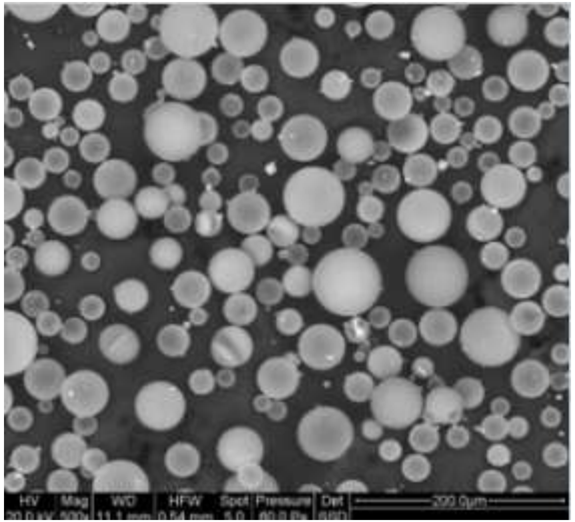
- Size, shape, specific surface area, aspect ratio
- agglomeration/aggregation state
- Size distribution
- Surface morphology/topography
- Structure, including crystallinity and defect structure
- solubility

Chemical properties of nanomaterials

- Structure formula/molecular structure
- Composition of nanomaterial (including degree of purity, known impurities or additives)
- Phase identity
- Surface chemistry (composition, charge, tension, reactive sites, physical structure, photocatalytic properties, zeta potential)
- hydrophilicity/lipophilicity

Nanomaterial shapes

- Nanomaterials can be nanoscale in **one dimension** (surface films)
- **Two dimensions** (strands or fiber)
- **Three dimensions** (particles)



They can exist in single or fused forms with spherical, tubular, and irregular shapes.

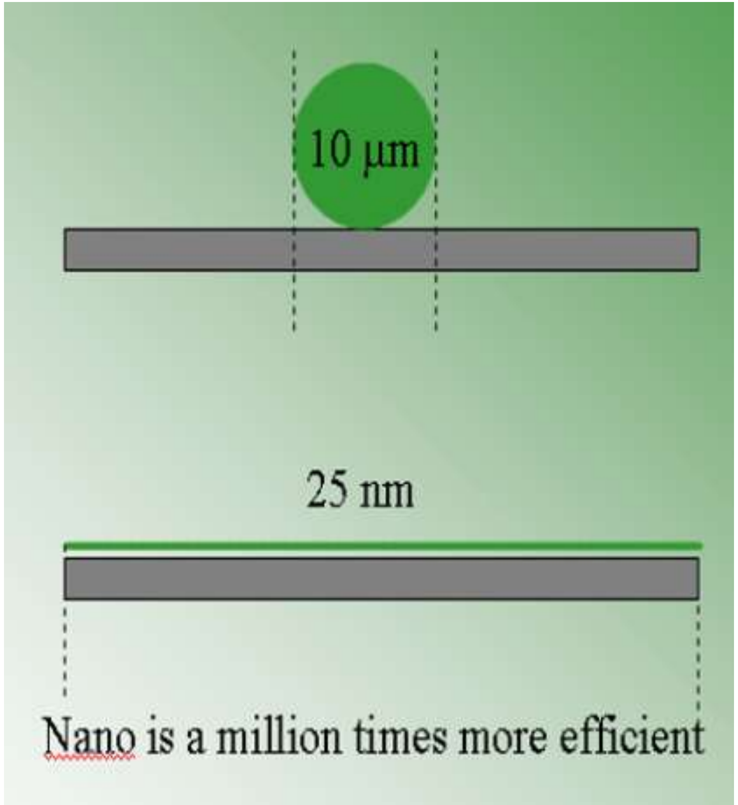
Why Nanomaterials?

- Nanotechnology exploits benefits of ultra small size, enabling the use of particle of deliver a range of important benefits.
  - Small particle are **‘invisible’**
    - **Transparent Coatings**/Films are attainable
  - Small particles are **very weight efficient**
    - Surfaces can be modified with minimal material
  - The behaviour of nanomaterials may depend more on the **surface area** than particle composition itself.

These materials have created a high interest in recent years by their **mechanical, electrical, optical and magnetic properties**

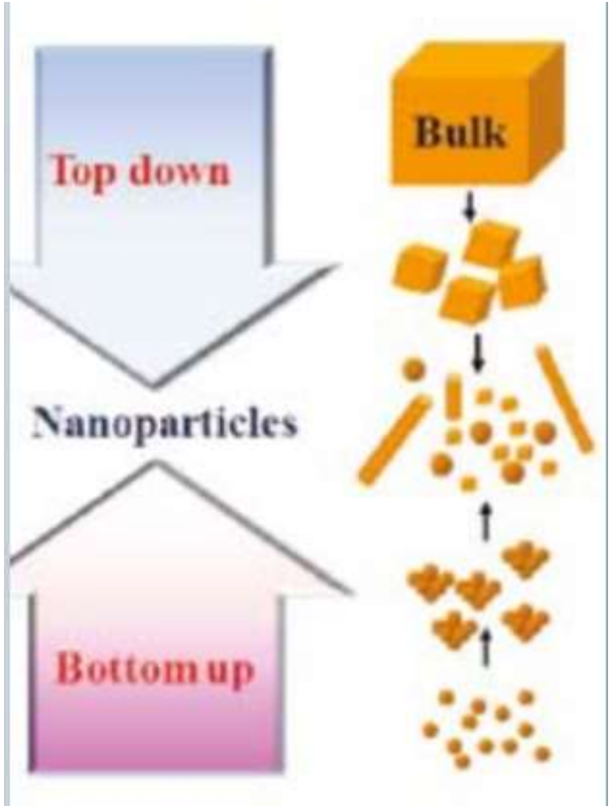
Weight efficient and uniform coverage

- Large spherical particles do not cover much surface area
- Nano particles equal mass of small platelet particles provides through coverage (1 x 106 times more)
- By patterning matter on **the nanoscale,** it is possible to vary fundamental properties of materials **without changing the chemical composition.**



Approaches

- **Top-down -** Breaking down matter into more basic building blocks. Frequently uses chemical or thermal methods.
- **Bottoms-up -** building complex systems by combining simple atomic level components.



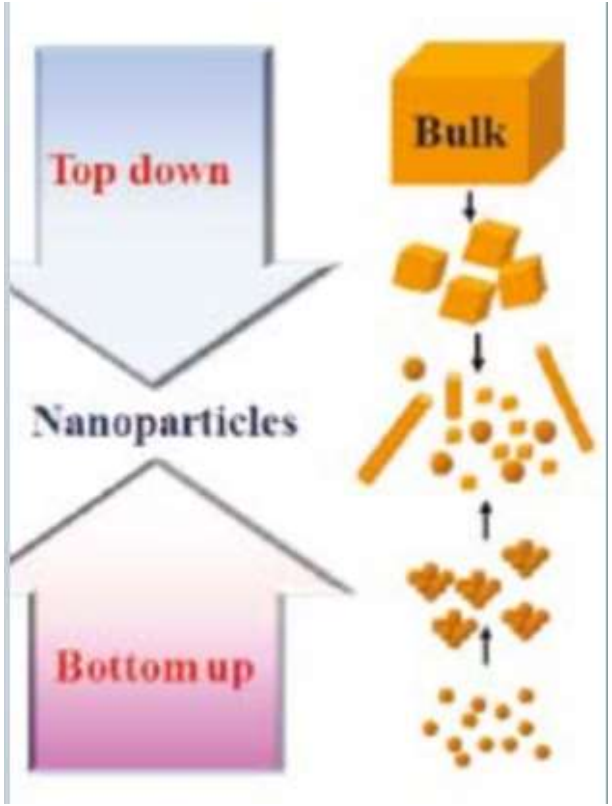
Methods of creating nanostructures

- **Mechanical grinding**

  Example of top-down method

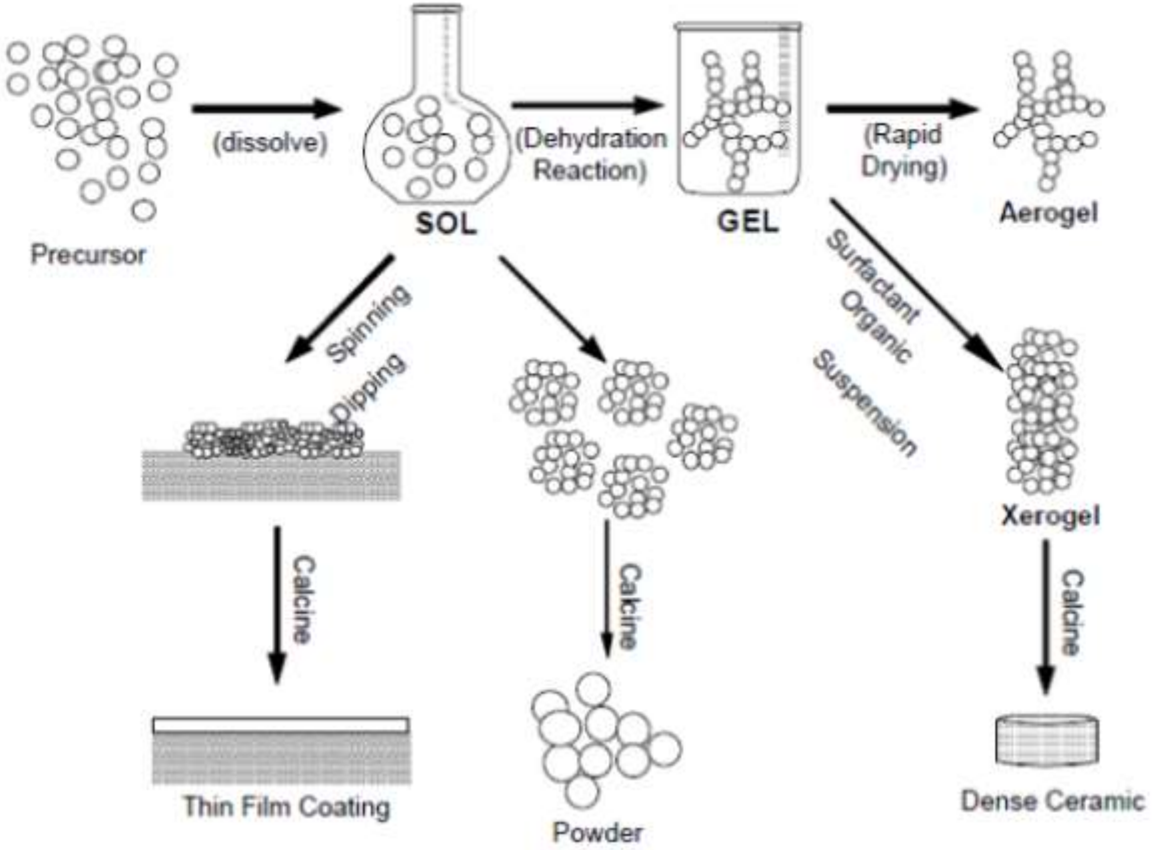
- **Wet chemical**

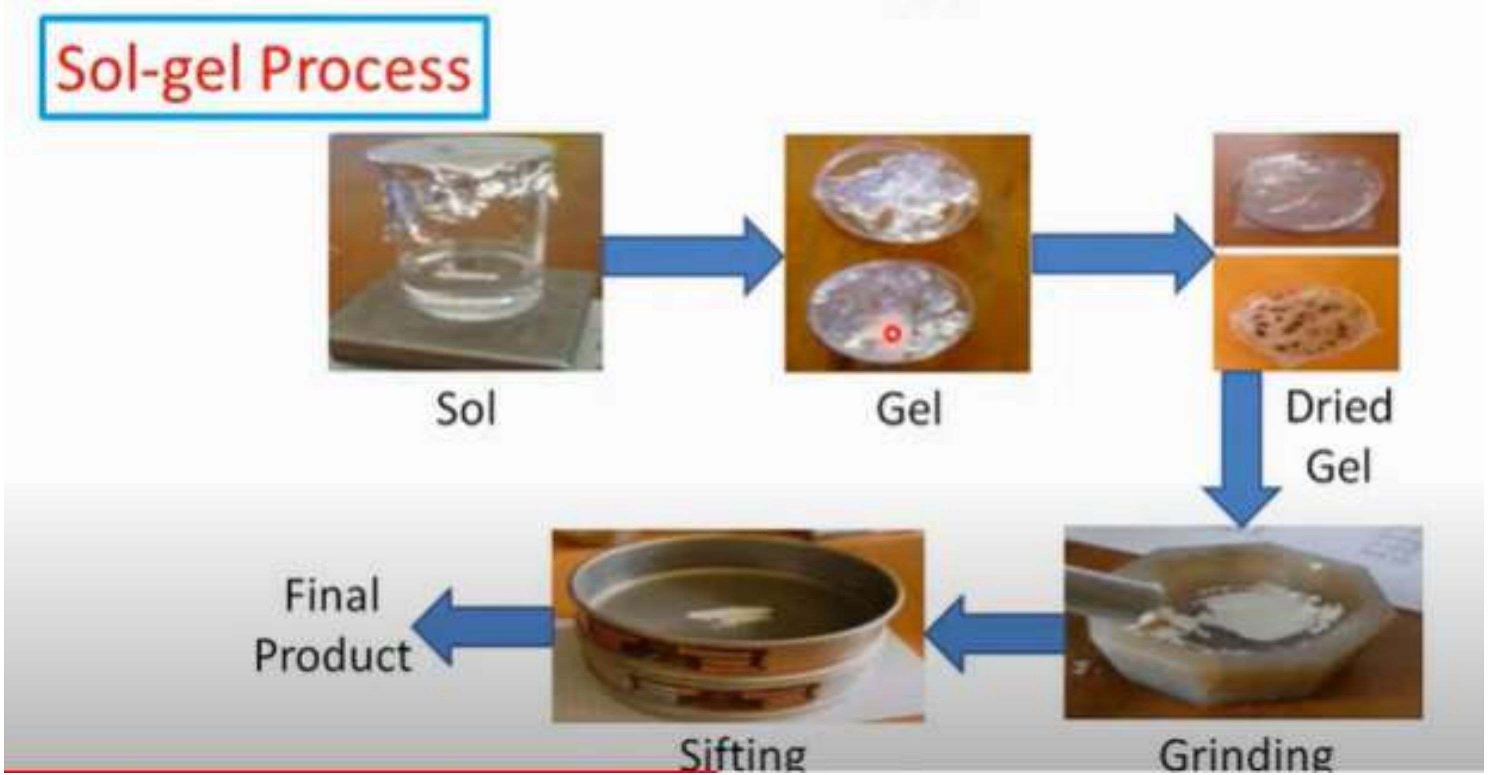
  Example of both (top-down) & (bottom up)



Methods of creating nanostructures

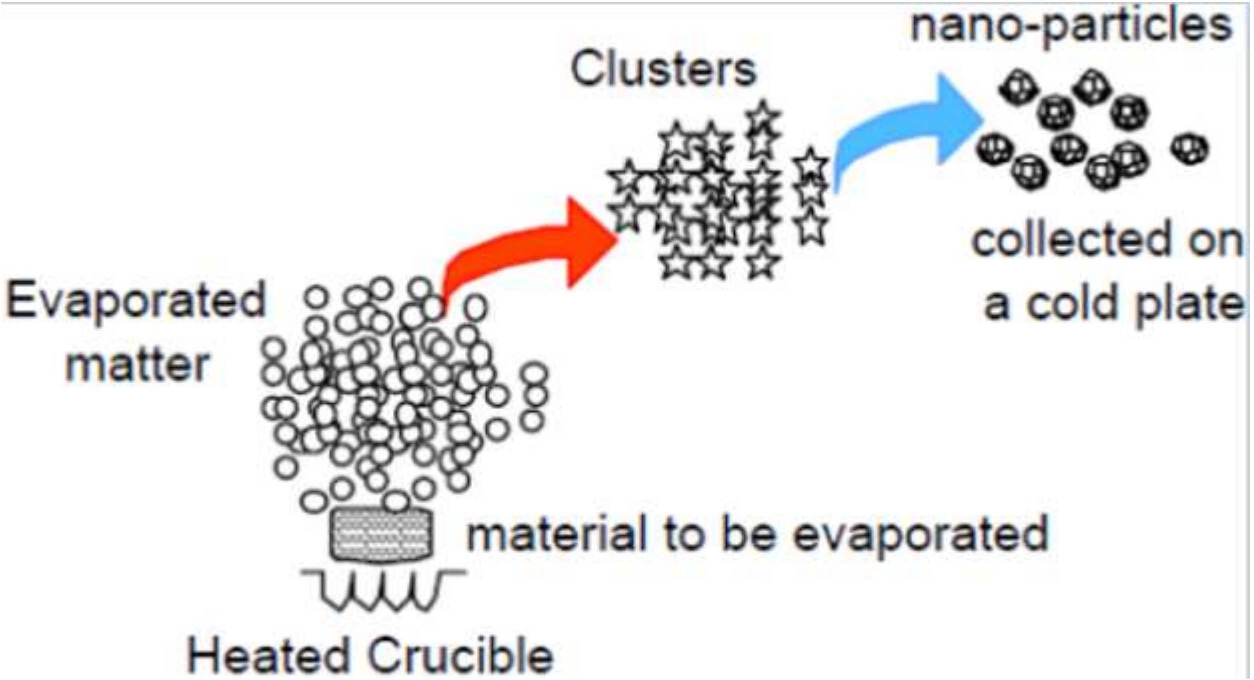
- Sol-gel process




Sol-gel Process
Sol
Gel
Dried
Gel
Grinding
Sifting
Final
Product

Methods of creating nanostructures

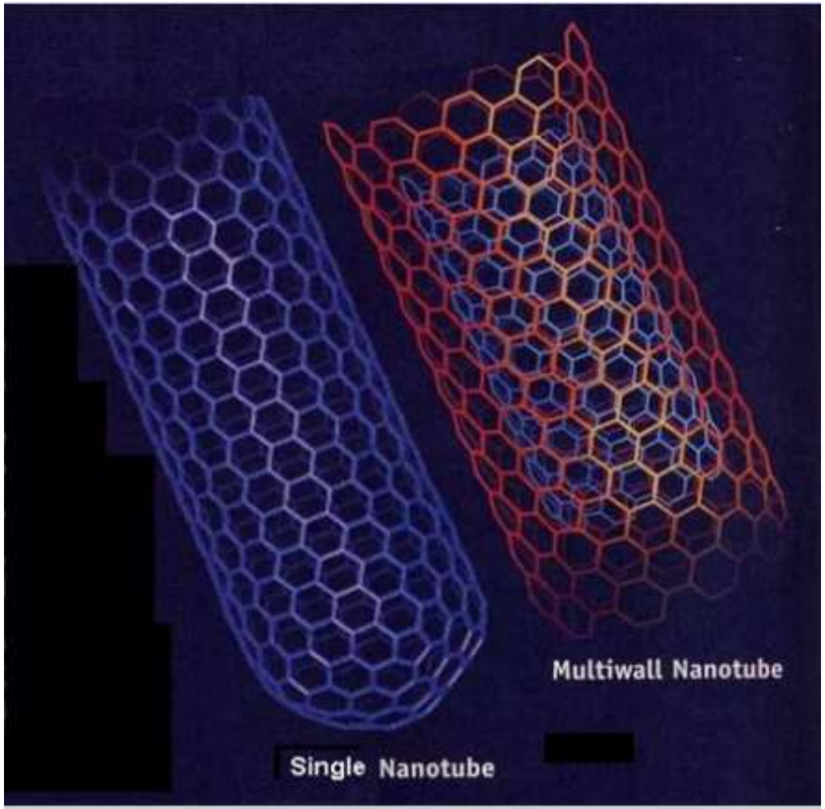
- Gas-phase (furnace)



Different types of nanomaterials

- **Nanopowder**
- **Nanotube**

  Tiny strips of graphite sheet rolled into tubes



Applications of nanomaterials

- Light source - QD lasers, QC (Quantum cascade) lasers
- Light detector - QDIP (Quantum Dot Infrared Photodetector)
- Electromagnetic induced transparency (EIT) - to obtaining transparent highly dispersive materials
- Ballistic electron devices
- Single electron devices

Advantages of nanomaterials

- Ability to tailor for specific requirements accentuates their usefulness
- Due to their high porosity, which again increases the demand for their use in various industries.
- In energy sector, the use of nanomaterials is advantageous in that they can make the existing methods of **generating electricity/energy efficient** such as solar panel - **more efficient and cost effective,** as well as opening up new ways in which to both harness and store energy.
- In the electronics and computing industry, their usage will permit an **increase in the accuracy of the construction of electronics circuits on an atomic level,** assisting in the development of numerous electronic products.

Disadvantages of nanomaterials

- There is no much information is available on the **health and safety aspects of exposure to the materials**.
- Danger of **inhalation exposure**. Nanomaterials such as CNT and Nanofibers may cause detrimental pulmonary effects such as pulmonary fibrosis.
- The **manufacturing process can often be complex and difficult**. The overall process is expensive.

THANK YOU