Alloys

> *"Polished brass will pass upon more people than rough gold"*

1 INTRODUCTION

High malleability, ductility, lusture and good electrical conductivity are the few useful properties possessed by metal. But for most of the applications their tensile strength, corrosion resistance and hardness are not sufficient. These properties can be improved by mixing (alloying) metal with some other metal/non-metal.

An Alloy is thus solid mixture of two or more different elements having the following characteristics :

(*a*) Atleast one element must be a metal ;

(*b*) The two components are intimately mixed ; and

(*c*) Metallic characteristics are retained or improved after alloying.

2 NECESSITY OF MAKING ALLOYS

Alloys are basically made for getting the desired performance in given service conditions at economical rates. The following properties are generally modified after alloying :

(*a*) ***Hardness.*** Pure metals, which are generally soft, can be made harder by alloying them with other metal/non-metal. For example, hardness of lead can be improved to such an extent, by alloying it with arsenic (0.5%), that it can be used for making bullets. Similarly Cu is mixed with gold and carbon is alloyed with iron to impart hardness.

In general, we can say that, alloys are made to enhance to hardness of the metal.

(*b*) ***Melting point.*** Alloying lowers down the melting point of pure metal which thus becomes more fusible. For example, an alloy of bismuth, lead, tin and cadmium possess melting point (= 71°C) which is much less than its constituent components. This alloy is popularly known as wood's metal used for soldering.

In general, we can say that alloys are made to lower the melting point of its constituent elements.

(*c*) ***Tensile strength.*** Tensile strength of pure iron can be increased up to ten times by alloying it with one percent carbon.

In general, alloy formation enhances the tensile strength of the parent/base metal.

(*d*) ***Corrosion-resistance.*** Pure metals have poor corrosion-resistance. For example, pure iron is corroded even in moist air. But an alloy of iron with Cr, Ni and

Mo is even acid proof. It is popularly known as *stainless steel*. The protection against corrosion is due to the formation of dense, tough film of chromium oxide at the surface of iron, especially when the content of Cr ≥ 16%. If this film is broken in service, it gets healed-up automatically.

Similarly, an alloy of Cu with tin (bronze) is more corrosion resistant than Cu.

In general, we can say that, alloys are made to enhance the corrosion resistance.

(e) ***Castability.*** For getting good castings the material used should show the following characteristics : easy fusibility, strength and expansion on solidification. Pure metals cannot be used for *casting printing type* since they undergo contraction on solidification. But when 5% tin and 3% antimony are incorporated in lead it shows exceptionally good casting properties and is used for casting printing type.

In general, we can say that, alloying is done to provide better castability.

(f) ***Colour.*** The colour of copper is red and zinc is silver-white in colour. An alloy of these (Cu + Zn) is brass which is yellow in colour.

Thus, by alloying a metal with another suitable element, we can modify its colour.

Example 1. *Express the composition of the compound alloy Cu_3Au in Karats.*

Solution. Cu_3Au percent composition :

$$(3 \text{ mol Cu}) (63.5 \text{ g/mol}) = 190.5 \text{ g}$$
$$(1 \text{ mol Au}) (197 \text{ g/mol}) = 197.0 \text{ g}$$

Formula weight $Cu_3Au = 190.5 + 197.0 = 387.5$ g/mol

$$\% \text{ Cu} = (190.5/387.5)(100\%) = 49.0\%$$
$$\% \text{ Au} = (197/387.5)(100\%) = 51.0\%$$

The number of Karats in an alloy is the number of parts of gold per 24 parts of the alloy. The alloy is 51.0 parts gold per 100 parts alloy, or

$$\frac{51.0 \text{ parts}}{100 \text{ parts}} = \frac{x}{24.0 \text{ parts}}$$

$$\Rightarrow \quad x = 12.2 \text{ Karats.}$$

3 CLASSIFICATION OF ALLOYS

Alloys can be classified based on following criterions :

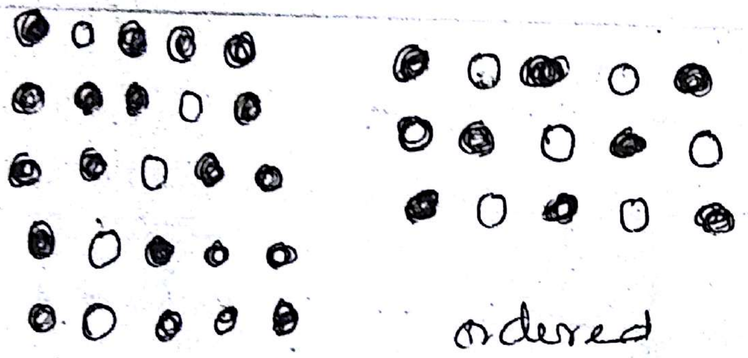
(a) ***Based on microstructure.*** For example, substitutional and interstitial alloys.

(b) ***Based on presence and absence of iron.*** For example, we have ferrous and non-ferrous alloys. Ferrous alloys like stainless steel (Fe + Cr) contain Fe as constituent while non-ferrous alloys like bronze (Cu + Sn) does not contain iron.

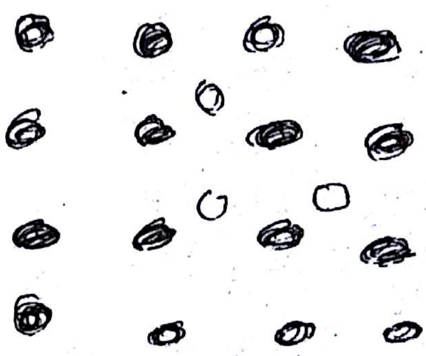
(c) ***Based on the principal metal in the alloy.*** For example, A copper alloy has copper as the major constituent, lead alloy has Pb as major component and ferrous alloys contain iron as the major component.

There are two types of Solid Solutions

*1 **Substitutional** → Solid atoms occupy the regular lattice site of the parent metal (Solvent). Substitutional solid solution can random (Li–Ni) or ordered (Lu–Au)



random ordered



Interstitial

● → Solvent
O – solute

Interstitial → Solute atoms occupy the interstitial positions (steel – C solute atom in Fe).

4 BRASS

It is an alloy of copper with zinc. These two metals form three types of intermetallic compounds which have fixed compositions. The crystal structures of these compounds are different from the parent metals. If we divide the number of valence electrons in an intermetallic compound (better intermetallic phase, the term *intermetallic phase* is more appropriate than the term intermetallic compound since their compositions may vary within certain limits although they are denoted by definite formulae.) by the number of atoms in it, a definite ratio (known as the *Hume-Rothery Ratio*) is obtained for each type of phase. These ratios are summarized in Table 1 for different intermetallic compounds of brass.

Table 1. *Intermetallic phases of brass*

Stoichiometry of brass intermetallic compounds	*The Hume-Rothery Ratio (Electron : Atom ratio)*	*Crystal structure*	*Type of Intermetallic phase*
$CuZn$	3 : 2	body-centred cubic	β
Cu_5Zn_8	21 : 13	complex cubic	γ
$CuZn_3$	7 : 4	close-packed hexagonal	ϵ

Out of these three only the β - *Type brasses are industrially important*. This is because they are strong, ductile, good conductor of heat and electricity and have metallic bonding. In contrast, the γ *type* and ϵ *type* intermetallic phases are hard, brittle and poor conductor of heat and electricity. The poor conduction indicates that the bond among the atoms in the γ and ϵ - type phases is not truly metallic, some covalent character is also there.

There are two more phases in the composition ranges 0–35% Zn and 97 to 100% Zn and are respectively known as a α phase and η phase. These are in fact *random substitutional solid solutions* of Zn in Cu and Cu in Zn respectively.

5 BRONZE

It is an alloy of copper with tin. These two metals also form three types of intermetallic phases respectively known as β, γ and ϵ phase. The stoichiometry and the Hume-Rothery ratios of these phases are summarized in Table 2.

Table 2. *Intermetallic phases of bronze*

Stoichiometry of bronze intermetallic phase	*The Hume-Rothery ratio (Electron : atom ratio)*	*Type of intermetallic phase*
Cu_5Sn	3 : 2	β
$Cu_{31}Sn_8$	21 : 13	γ
Cu_3Sn	7 : 4	ϵ

These two alloys of Cu viz. brass and bronze rank next to steel as engineering materials. The composition, properties and applications of commercially important copper alloys are summarized is Table 3.

Composite Materials

> *"We never reach our ideals, whether of mental or moral improvement, but the thought of them shows us our deficiencies and spurs us on to higher and better things"*

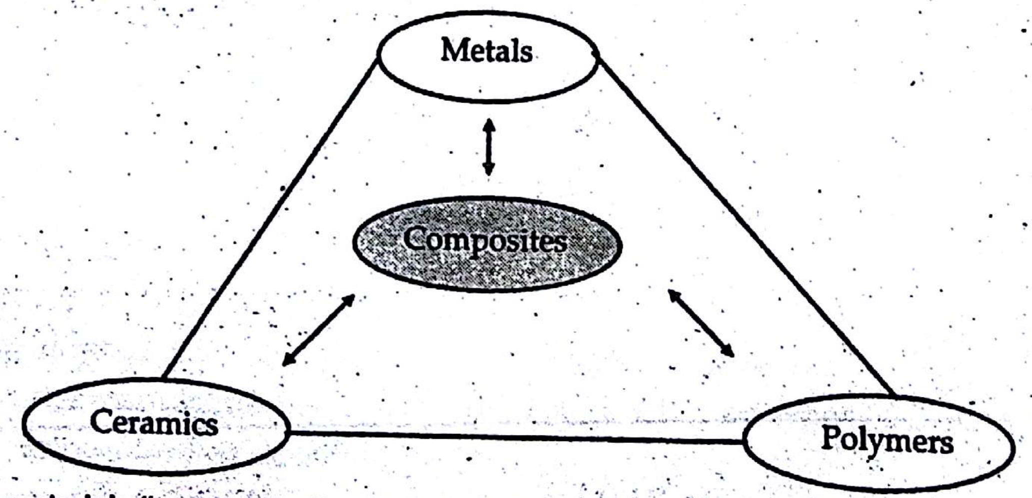
1 INTRODUCTION

For better overall performance we require unusual combinations of properties that cannot be provided by conventional materials like metals, ceramics or polymers. For example, structural materials required for aircraft must have high specific strength, stiffness and excellent resistance to corrosion, abrasion, impact and heat. This is rather unusual combination of properties since strong materials are generally dense and also increase in strength and stiffness usually results in decrease in impact strength.

The great and diverse demands made on materials for better overall performance led to the concept of composite materials.

A ***composite*** may be defined *as any multiphase material which consists of two or more physically and/or chemically distinct phases with an interface separating them.*

(As per this definition most of the metallic alloys, ceramic materials etc., are not considered as composite materials.)



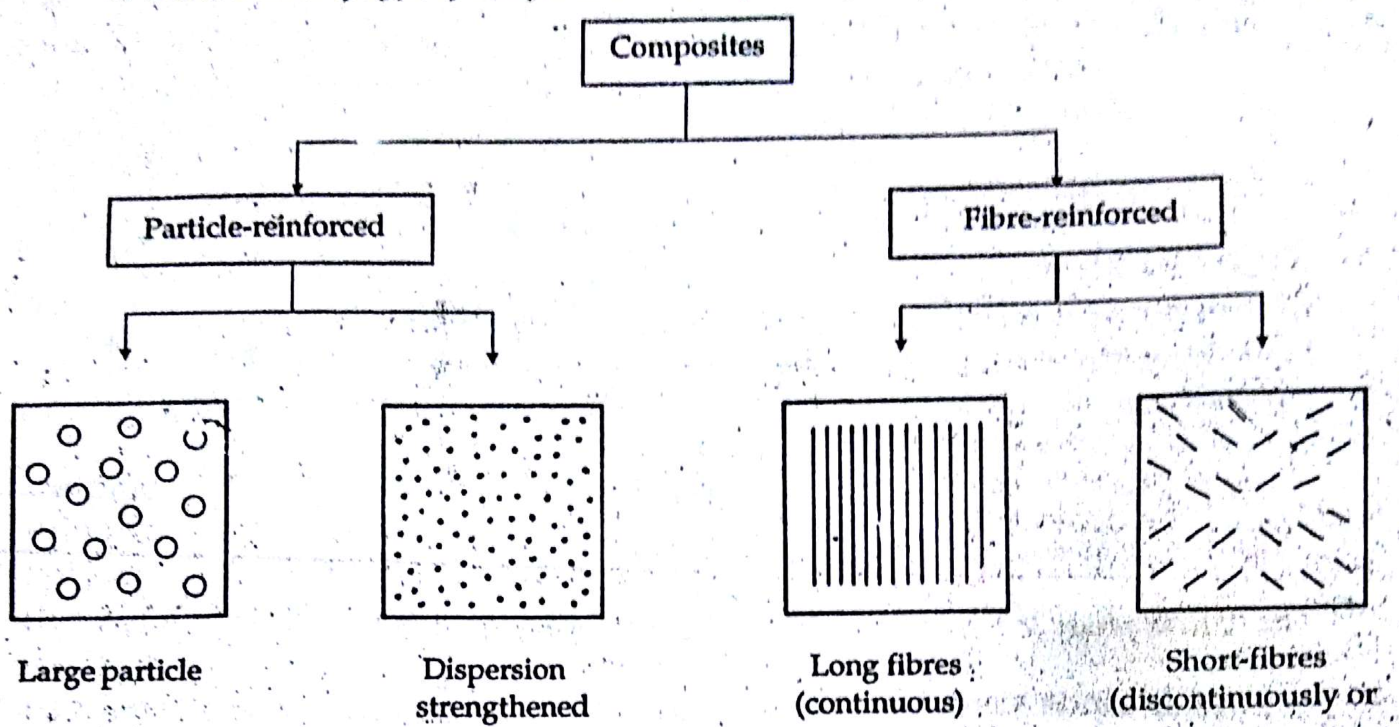
Newer materials "composites" are obtained from conventional materials like Metals, Ceramics & Polymers by adding fibers, particles etc. to them.

The composite materials shows properties distinctively different from those of the individual materials of the composite. In fact, composites show extraordinary combination of properties like toughness and strength with low weights and high temperature resistance. For instance, compared to steel and aluminium, composites are lighter, have low coefficient of thermal expansion and have superior strength, stiffness and fatigue resistance.

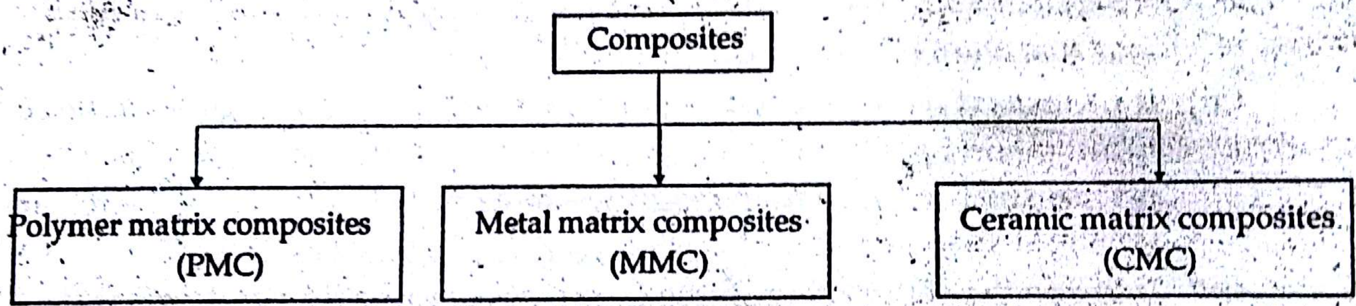
2 CLASSIFICATION OF COMPOSITE MATERIALS

Composite materials can be broadly classified into following types :

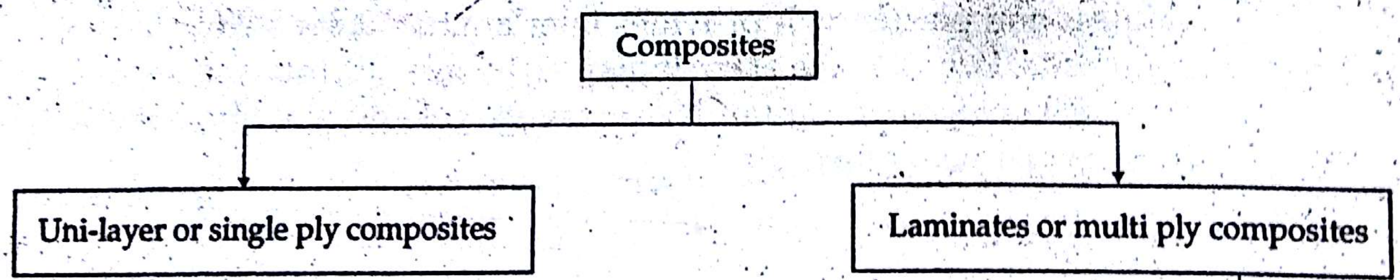
1. *On the basis of type of reinforcement used in the matrix*



2. *On the basis of type of matrix*



3. *On the basis of number of ply or lamina's or layers*



3 CONSTITUENTS OF COMPOSITES

Composites, in general, consist of body constituents and structural constituents. The *body constituent* enclose the composite and give it its bulk form. The continuous *matrix phase* is the body constituent. The *structural constituents* determine the internal structure of the composite. This is also known as *dispersed phase.*

The surface forming the common boundary between the matrix and dispersed phase is known as *interphase.*

Properties of the composites depends upon :

(*i*) The properties of the constituent materials ;

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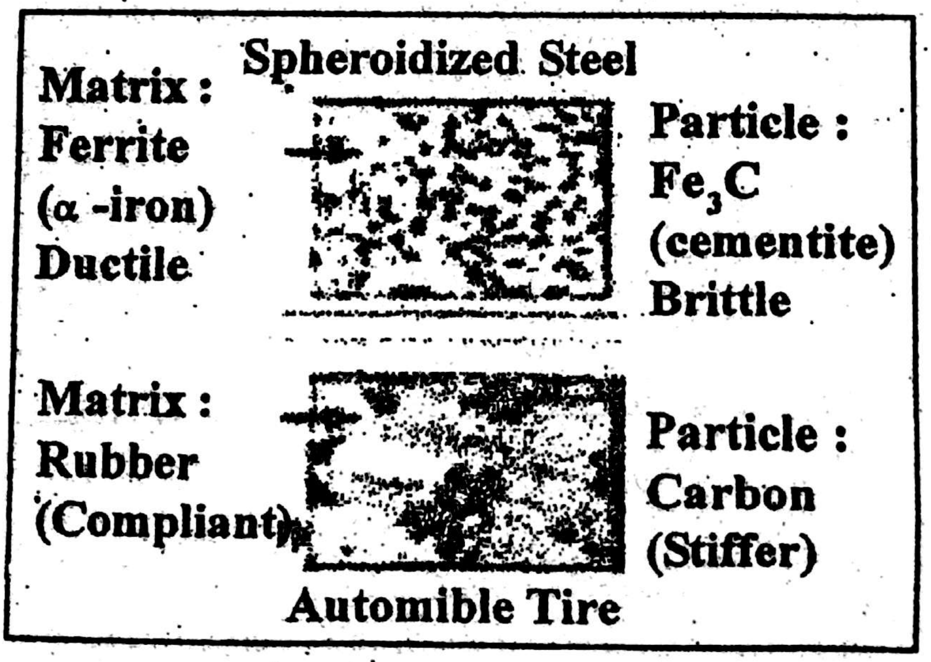
10.4 Classification on the basis of the type of reinforceme used in the matrix

1. Particle Reinforced Composites:

Particles used for reinforcing include ceramics and glasses such as small min particles, metal particles such as aluminum, and amorphous materials, includ polymers and carbon black. Particles are used to increase the modulus of the mat to decrease the permeability of the matrix, to decrease the ductility of the mat Particles are also used to produce inexpensive composites.

They are again two kinds: dispersion-strengthened and particulate- reinfor composites.

In dispersion-strengthened composites, particles are comparatively smal and are of 0.01-0.1 μm in size. Here the strengthening occurs at atomic/molec level i.e. mechanism of strengthening is similar to that for precipitation hardenin metals where matrix bears the major portion of an applied load, while disperse hinder/impede the motion of dislocations. Examples: Thoria (ThO_2) dispersed alloys (TD Ni-alloys) with high-temperature strength; SAP (sintered alumini powder) – where aluminium matrix is dispersed with extremely small flakes of alum (Al_2O_3). Metallic alloys which have multiphase structure are examples of su category. For example, Spheroidized steel an alloy of carbon steel is made of altern layer of soft ductile phase of pure iron and hard brittle compound of Fe_3C (Fig.10.



Practicle Reinforced Composites

Fig.10.6

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(*b*) *Carbide based cerments*

Carbide	*Matrix*	*Applications*
WC	Co	Wire-drawing die, valves and other machine parts requiring very high hardness
CrC	Co	Valves, pump-parts & spray nozzle as it has very high resistance to corrosion and abrasion.

(*ii*) ***Metallic in non-metallic composites.*** Examples of metallic in non-metallic are :

Aluminium paint in which aluminium flakes suspended in paint.

(*iii*) ***Metallic in metallic-composites.*** Examples of metallic in metallic-composites are :

(*a*) Lead particles in copper alloys & steel, improves the machineability of the latter.

(*b*) Bearings made from Cu alloys utilize lead as a natural lubricant.

(*iv*) ***Non-metallic in non-metallic composites.*** Examples of non-metallic in non-metallic composites are ;

(*a*) Flakes of mica or glass in glass or plastic matrix respectively.

(*b*) Concrete is another example of this class in which particles of sand and rock are dispersed in cement which then chemically react with water for hardening.

11 STRUCTURAL COMPOSITES

The composite materials which are used as structural components in demanding applications for better overall performance are known as "structural composites".

In general properties of structural composite depends on

(*i*) The properties of the constituent materials, and

(*ii*) Their geometrical design

Structural composites are broadly classified as :

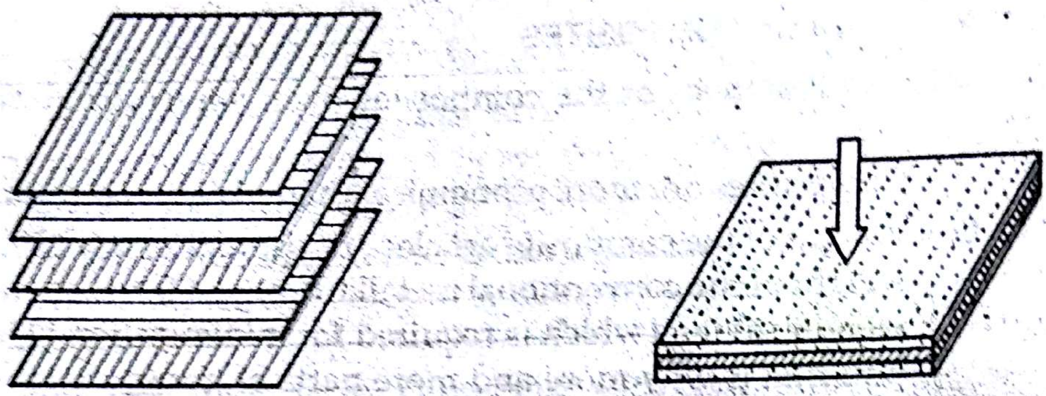
(*a*) Laminar and

(*b*) Sandwich composites.

These are briefly discussed below :

(*a*) *Laminar Composites* : They consists of number of two-dimensional sheets or layers that are stacked and subsequently cemented together (such that the orientation of reinforcement varies with each successive layer). This is shown in Fig. 5.

These layers possess relatively high strength in the direction of reinforcement and hence the resulting laminar composite has high strength in number of directions.



(*a*) Stacking of sucessive oriented fiber-reinforced layers (*b*) Fabricated laminar composite

Fig. 5. Successive stacking of oriented fiber reinforced layers for producing a laminar composite.

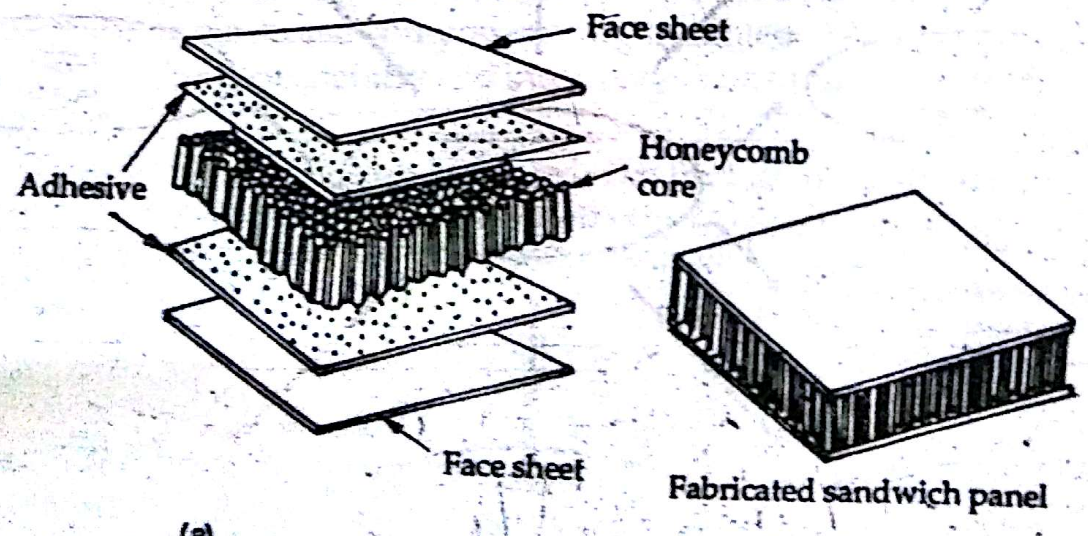
(*b*) **Sandwich Panels :** They consist of two stronger outer sheets (called "faces") separated by a layer of less-dense "core" material.

Core material should be light weight, able to transfer load from one facing to the other and should have high corrosion resistance.

The structural functions of the "core" is to resist any deformation perpendicular to the face plane by providing certain degree of shear rigidity. The "faces" bear most of the in-plane loading, as well as any transverse bending stresses.

The stiffness of the sandwich panels increases as the core thickness increases. For instance, if we increase the thickness of the core four times, relative stiffness increases by 39 times. As the core is generally of lighter materials so corresponding increase in weight is just 6%.

"Honeycomb" structure (made up of thin foils that have formed interlocked hexagonal cells with their axes oriented in a perpendicular direction to the "face" planes) is very popular type of "core material". It is shown below in Fig. 6.



(*a*) (*b*)

Fig. 6

Applications of Sandwich structures :

(*i*) For fabrication of wings of aircrafts,

(*ii*) For fabrication of roofs, floors and walls of building and

(*iii*) Design of ships, boat hulls etc.

12 ADVANTAGES OF COMPOSITES

The major advantages of the composites over conventional material are as follows :

(*i*) Composites are more economical than metals and ceramics.

(*ii*) Weight of the composite articles are approximately 25% to 50% of the weight of the conventional metallic design. Hence, there is significant weight savings which is required for minimization of fuel consumption that is why more and more parts of transportation industry are now-a-days made from composites.

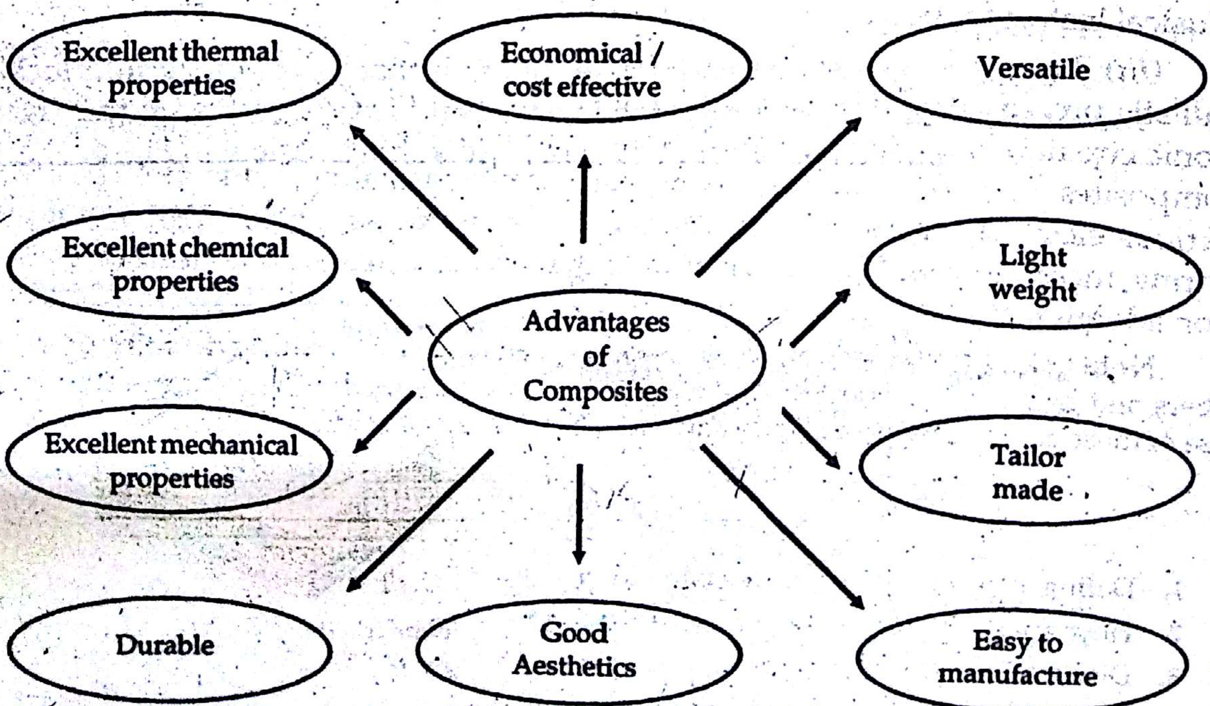
(*iii*) Composites show excellent mechanical properties *e.g.*

(*a*) Fibre-reinforced polymer composites show high strength and stiffness. They store more energy per unit weight and hence rotational components made out of them function significantly faster than those made of steel alloys.

(*b*) High modulus fiber reinforced composites show excellent torsional stiffness. This property is required by various high speed vehicles and aircrafts.

(*c*) Composites also show excellent impact and damage tolerance characteristics.

(*d*) Carbon fiber reinforced polymers shows outstanding friction and wear properties. For instance, the coefficient of friction of a carbon composite on steel is approximately 40% of that of lubricated steel on steel.



Advantages of composites