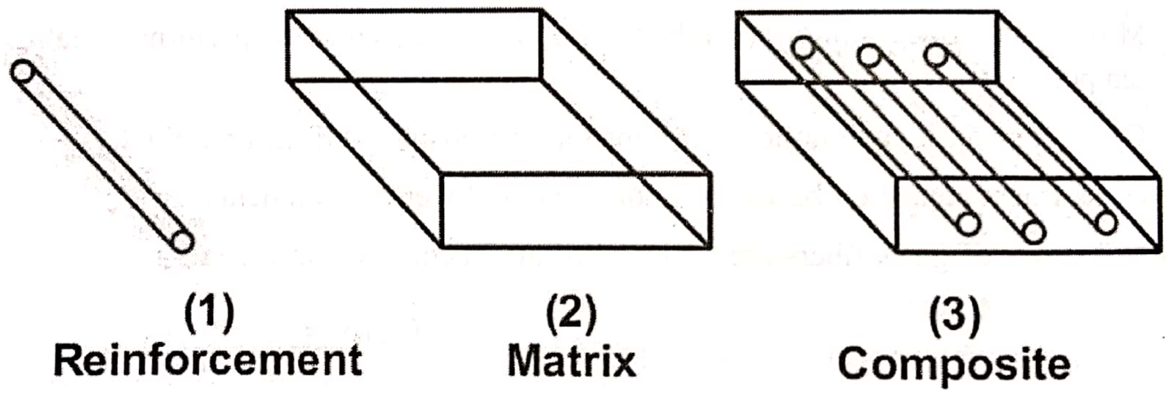
## 4.5 Introduction to Composites

**Definition of Composite:** A *Composite* is defined as a material which is a combination of two or more dissimilar materials which have different interfaces between them and the resulting material properties are enhanced compared to the individual constituent materials.

Composite has existed from the times of Egyptians who used straw bricks (1400 BC), a composite material and Mongols invented the composite bow. Today we find the use of composites in automobile parts, aircraft parts, in sports equipment, office furniture, in laptops, loudspeakers, in healthcare etc.

### 4.5.1 Constituents of a Composite

The main constituents of composites (as in *Fig 4.2(a)*) are the reinforcements and the matrix. In a composite material one material forms a matrix to bond together the other material called *reinforcement material.* The matrix and reinforcement are chosen in such a way that their mechanical properties complement each other, at the same time their deficiencies are neutralised. Example: in Glass Reinforced Plastic moulding, the matric is the polyester resin and this binds together the glass fiber reinforcement.




**Components of a Composite**
**Fig. 4.2(a)**

The reinforcement material in a composite is in the form of rods, strands, fibers or particles which is bonded together with the other matrix materials.

The functions of a Reinforcement includes

1. Contributing the desired properties,
2. Carrying the load and
3. Transferring the strength to the matrix.

The functions of the matrix includes

1. Holding the fibres together
2. Protecting the fibres from abrasion amongst themselves
3. Protecting the fibres from environment
4. Distributing fibres properly
5. Distributing the loads evenly between fibres
6. Apart from the fibre, the matrix also enhances few properties of the resulting material and structural component. These properties are the transverse strength of the lamina and the impact resistance.
7. Providing good finish to the product

### 4.5.2 Classification of Composites

**Classification method I**

Based on the type of matrix material, Composites are classified as below:

**a. Metal Matrix Composites (MMC)**

Metal Matrix Composites are composites that contain at least two component parts one of which is metal. The other material may be a metal or ceramic or an organic compound. MMC is made by dispersing a ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase into a metal matrix (aluminium, magnesium, iron, cobalt, copper).

***Properties of Metal Matrix Composites***

MMCs offer properties such as higher specific strength, stiffness, higher operating temperature, low co-efficient of thermal expansion and greater wear resistance, and also the opportunity to tailor these properties for a specific application. However, MMCs have lower ductility and the cost of fabricating is high.

***Applications of Metal Matrix Composites***

1. Used in making piston for diesel engine. The MMC piston offers good wear resistance and strength at high temperatures than compared to the traditional cast iron piston.
2. Metal matrix composites possessing high strength and specific stiffness can be used in applications where weight saving is a vital factor. Examples are robots, high-speed machinery, and high-speed rotating shafts for ships or land vehicles.
3. MMCs are used in automotive engine and brake parts due to its good wear resistance and high specific strength.
4. They are also used in lasers, precision machinery, and electronic packaging due to the tailorable coefficient of thermal expansion and thermal conductivity of the MMC.
5. They also find applications in spacecraft structures, missile structures, fighter aircraft engines and structures.

**b. Ceramic Matrix Composites (CMC)**

Ceramic Matrix Composites consists of ceramic fibres embedded in a matrix made from ceramic materials such as carbon (C), silicon carbide (SiC), alumina ($Al_2O_3$), mullite ($Al_2O_3$-$SiO_2$) or zirconia ($ZrO_2$). The fibres can also be of the same materials as mentioned for matrix. CMC is usually represented as "Fibre type/Matrix type". Example: C/SiC (Carbon fiber/Silicon Carbide Matrix), etc.

***Properties of Ceramic Matrix Composites***

The CMCs offer useful properties such as good corrosion resistance, high compressive strength, high thermal shock resistance, high mechanical strength at high temperatures, high thermal stability, etc. The downside of Ceramic Matrix Composites is its low crack resistance resembling glass. This is now overcome to a large extent by integration of long strand fibres.

***Applications of Ceramic Matrix Composites***

1. *Automotive applications*: C/C type CMCs are used in Disc Brakes of airplanes and racing cars due to lesser wearing, no effect of humidity, corrosion resistance and lesser disk mass.
2. *Space Applications*: Since CMCs can withstand very high temperatures, they are used in space applications such as nose, leading edges, lower surface of the wing and steering flaps.
3. *Gas Turbine applications*: Gas turbine engine components such as combustor liners, vanes, shrouds, blades, flaps, seals, etc made from CMCs are being researched and tested by GE Aircraft engines (*Courtesy: GE*)
4. *Pump applications*: SiC/SiC Ceramic Matrix Composite is used in shaft sleeve of Slide bearings of pumps (particularly boiler feedwater pumps of power stations)
5. *Cutting tool applications*: CMCs such as SiC whisker reinforced aluminium oxide are used in Cutting tools for machining of materials that are generally hard to machine.
6. Other applications include heat exchanger and radiant burner tubes, flame tubes, and high temperature furnace parts.

**c. Polymer Matrix Composites (PMC)**

Polymer Matrix Composites are composites that comprises of a variety of short or continuous fibres that are bound together in an organic polymer matrix. They contain a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polysterene) and embedded fibres are of glass, carbon, steel or Kevlar (dispersed phase). The reinforcement supports the mechanical loads to which the structure is subjected to. The function of the matrix is to bond the fibres together as well as to transfer loads between them.

***Properties of Polymer Matrix Composites***

1. The reinforcement in a Polymer Matrix Composite provides high strength and stiffness along the direction of reinforcement.

2. PMCs weigh less and hence are ideally suited in aerospace and automotive industry.
3. Superior corrosion and fatigue resistance when compared to metals.

***Applications of Polymer Matrix Composites***

1. ***Aerospace Applications***: Due to the low weight of PMCs, it is used in the Aerospace in parts such as rotor blades & hubs, fuselage, thrust reversers, satellite structure, bulkhead & floor, cargo liner, wings, landing gear and doors.
2. ***Marine Applications***: Due to anti-rusting properties, PMCs are used in boat parts such as propeller shafts, floorboards, rudders, boat hulls, masts, booms, submersibles pressure hull, and bulkheads.
3. ***Automotive Applications***: PMCs are of low weight and its usage in automotive parts can reduce overall vehicle weight and hence can contribute to more fuel efficiency. PMCs are therefore used in automotive parts like car exterior body panel, battery trays, engine components, bumper fascia, protective shields, grills of the radiator, instrument panels and fuel lines.
4. ***Construction Applications***: Due to Corrosion resistance and the speed & ease of erection, PMCs are used in construction applications such as Bridge decks, bridges, column wraps, cladding, etc.
5. ***General engineering Applications***: PMCs find its use in storage tanks, pressure vessels, pipe systems, air ductwork, power transmission drive shafts, etc.
6. ***Electrical & Electronics Applications***: PMCs are used in equipment housings, cable trays, transformer spacers, etc.
7. ***Sports Industry Applications***: PMCs are used in bike frames, canoes, fishing rods, racquets, archery bows, golf clubs, ski poles & skis, surf boards, etc.
8. ***Domestic consumer Applications***: PMCs are used in sanitary ware, bath unit, shower enclosures, sinks and furniture.

**Classification method II**

Composites can also be classified based on reinforcing material structure as

A. Particulate Composites

B. Fibre reinforced Composites

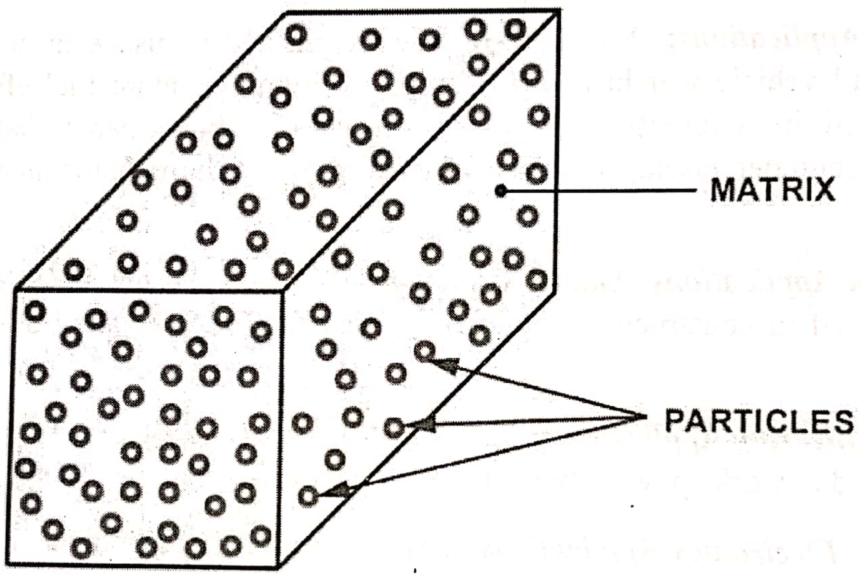
C. Laminate Composites

**A. Particulate Composites**

Particulate Composites consists of particles embedded in a body of matrix. The particles can be in the form of flakes, powders, chopped fibres, platelets, hollow spheres, buckyballs or carbon nanotubes form. These embedded particles are very fine particles, sometimes even less than 0.25 microns. The embedded particles provides reinforcement to the matrix material, strengths it, and provides specific properties for various applications.

Example of particulate composite is binging course rock and gravel in a matrix of cement for providing strength and stiffness. The advantages of using particulate composites include high tensile (or pulling) strength at high temperatures, high toughness and oxidation resistance. They also possess a high strength to weight ratio, hence are less dense, and lighter, than other materials which can withstand the same amount of force.

A typical Particulate composite is shown in the *Fig.4.3* below:




**Particulate Composite**
**Fig. 4.3**

### *Applications of Particulate Composites*

1. Because of its inherent strength and cheap construction, particulate composites find applications in small appliances such as cell phone casings and even in helmets.
2. Aluminium alloy-corundum particulate composite is used in automobile piston and cylinder sleeve applications. The reinforcement used is corundum ($Al_2O_3$) due to its properties such as high wear resistance and less thermal conductivity.
3. Ceramic-metal particulate composites or cermets are used as a tool material for high speed cutting of materials such as hardened steels which are difficult to machine. Cermets also finds its applications in wheels of the turbine, mechanical seals, valve and valve seats, etc.
4. Carbon black particles with reinforced rubber is a particulate composite used in automobile tyres. Carbon black particles are of nanometer sizes and provides resistance to wear & tear and increase the stiffness and tensile strength of the tyres.

## B. Fibre reinforced Composites (FRC)

Fibre Reinforced Composites or FRC are composed of axial particles in the form of fibres embedded in a matrix material. The aim of developing a fibre-reinforced composite material is to obtain a material which has high strength and high elastic modulus for its weight. Reinforcing fibres are usually of metals, ceramics, glasses, or polymers that are turned into graphite (and called carbon fibres). Fibres help by increasing the modulus of the matrix material. The strong covalent bonds that exist along the length of the fibres provides them with a very high modulus in the particular direction since to break or extend the fibre, the bonds should also be broken or moved. When Carbon fibres are embedded in the matrix, they are called Carbon Fibre Reinforced Composite (CFRC). The FRC is relatively costly since the fibres are not easy to process into composites.

One classic example of Fibre reinforced Composite is the fibreglass in a thermoset plastic.

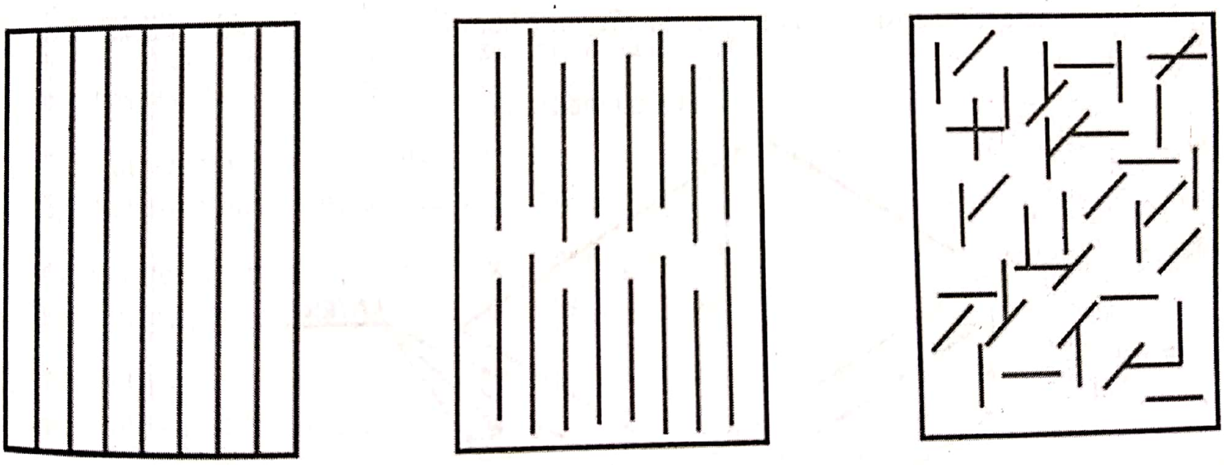
Fibre reinforced composites are classified into

a) ***Continuous fibre reinforced composite***: If the length of the fibre is such that any further increase in length does not increase the elastic modulus of the composite, then composite is called as a continuous fibre reinforced.

b) ***Discontinuous fibre reinforced composite***: In this type, the properties of the composite vary with fibre length. These have two sub types:

   i. Discontinuous and aligned fibres
   
   ii. Discontinuous and randomly oriented fibres

*Fig. 4.4* shows the various types of Fibre reinforced Composites based on the fibre orientations.



(a) Continuous and aligned fibres

(b) Discontinuous and aligned fibres

(c) Discontinuous and randomly oriented fibres

Various types of Fibre Reinforced Composites
Fig. 4.4

*Applications of Fibre Reinforced Composites:*

1. Fibre-reinforced composites are used in advanced sports equipment like a time-trial racing bicycle frame that consists of carbon fibres in a thermoset polymer matrix.
2. The body parts of racing cars and few other automobiles are of composite material that is made of fiberglass in a thermoset matrix.
3. A hybrid mixture of Carbon fibres and Kevlar 49 fibres are used as primary materials to make wings, fuselage and tail assembly components of an aircraft.

## C. Laminate Composites

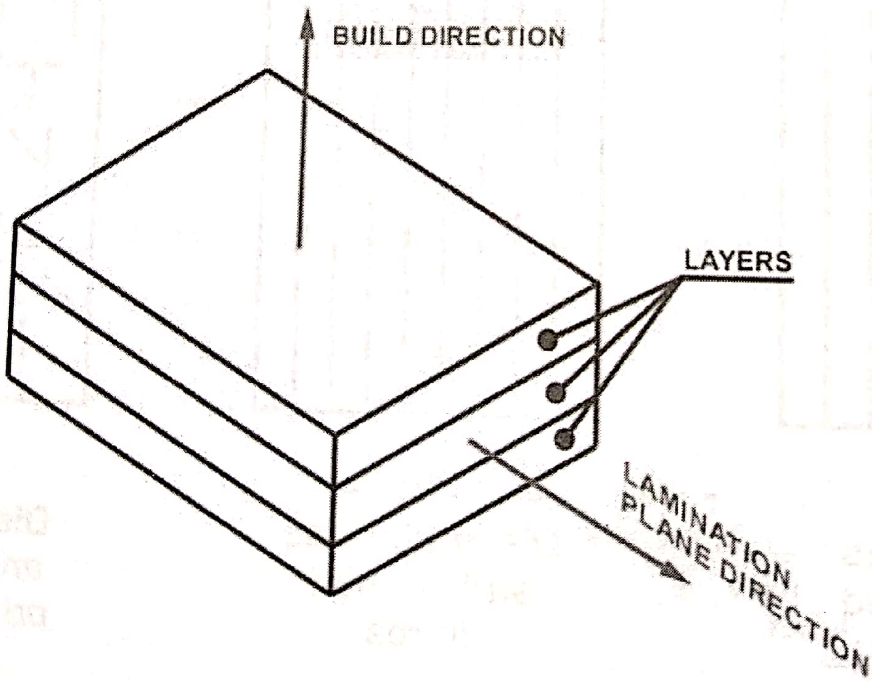
This type of composite consists of various layers of materials held together to give stiffness, strength and co-efficient of thermal expansion and the layers are held together in a polymeric, metallic or ceramic material. The fibres used in laminate composites can be glass, graphite, silicon carbide and boron. The matrix materials can be epoxies, alumina, titanium, aluminium, polyimides etc. Laminate composites involve two or more layers of the same or different materials. The layers can be arranged in different directions to provide the strength where required. Example: carbon sandwich composite.

Examples of laminate materials include Formica and plywood.

*Applications of laminate composites:*

1. Aramid aluminium laminate (Arall) and Glass Aluminium laminate is finding its application as possible skin materials for aircraft.
2. Plywood is used in making furniture

A typical Laminate Composite is as shown in *Fig. 4.5* below:




**Laminate Composite**
**Fig. 4.5**

### 4.5.3 Properties of Composites

Composite materials have the following useful properties:

1. Light in weight.
2. Excellent specific strength and stiffness. High strength to weight ratio.
3. Excellent spring-back property with resilience.
4. Non-corrosive and resistant to chemicals. Good weathering properties.
5. Fire retardant and fire-resistant.
6. Low thermal conductivity.

### 4.5.4 Advantages of Composite Materials

When compared to metal parts, composite materials have the following advantages:

1. Composite materials are non-corrosive and resistant to chemical agents that includes acid rain and salt spray, whereas metal parts would suffer under action of these agents. Thus the maintenance and repair costs are reduced.

2. Composite materials have lower weight than their metal counterparts. Usage of Composites can lead to substantial savings in weight compared to similar metal parts (25% the weight of steel, 30% lighter than aluminium). This reduction of weight amounts to significant cost savings especially in fuel consumption.

3. Outstanding strength-to-weight and stiffness-to-weight ratios can be achieved by using Composite Materials.

4. Composite materials exhibit good Resilience. That is, the ability to deform and spring back to its original shape without resulting in any major damage. In the transport industry, composites show good Shape memory and impact tolerance.

5. Both the composite materials and adhesives/coatings share a comparable polymeric make-up, Adhesive and coatings are very much compatible with each other.

6. Composite structures have good thermal properties and are very good insulators. They retain their shape and do not become brittle at cold temperatures.

7. Particularly in military applications, using high strength composites can give good protection from blast and ballistic threats.

8. Fibre-reinforced composites are low in electrical conductivity and are very good fire retardants, thereby making it fire safe. This is why composites are selected to make covering for electrical parts.

9. Innovative designs that were previously difficult to achieve can now be achieved with use of composites with no loss in performance or strength. Example: complex aerodynamic profiles.

10. Expensive finishing on the surface is not required in composites as it gives post-mould paint-finish type surface.
11. The part and fastener count is reduced in composites.
12. Almost any colour shade of the composite part is possible through pigmentation of the gelcoat.

### 4.5.5 Disadvantages of Composite Materials

Although composites have distinct merits over metals, they do have few disadvantages as mentioned below:

1. The cost involved in the fabrication of composites is high. For example, a part made of graphite/epoxy composite may cost up to 10 to 15 times the material costs. However, improvements in processing and manufacturing techniques may lower these costs in the future.
2. Composites are more brittle than the wrought metals. Therefore composites are more easily damaged than the wrought metals.
3. The repair of composites is not a simple process unlike that in metals.
   a. Repair at the original cure temperature requires the right pressure and tooling.
   b. In few cases, the critical flaws and cracks in composite structures may go undetected which may lead to structure breakdown.
   c. Hot curing is required in many cases and this require special tooling
4. Composite materials must be cleaned thoroughly before repair. This consumes time.
5. The Cost of raw materials used for manufacturing composites are high.
6. Composite materials are not isotropic (exhibiting same properties in all directions). Thus the mechanical characterization of composites is much complex than compared to the metals.
7. The Matrix in the composites is subject to environmental degradation.

### 4.5.6 Applications of Composite Materials

Following are the various applications of Composite Materials:

1. **Aircraft Industry**: From the 1960s, Aircraft parts such as fairings, spoilers, and flight controls are made from composite materials since use of composites saves weight over aluminium parts. In the present generation large aircraft composite usage is found in fuselage and wing structures.

2. **Automobile Industry**: Modern automobile industry uses composites to make the vehicle lighter, safer and more fuel-efficient. Car parts such as front ends, tail doors, cross-car beam, side doors, seating, hoods, bonnets, fuse boxes, moulded headlamps, engine valve cover, car leaf springs, etc are made of composites by many Car manufacturers today.
3. **Sports equipment**: Composites finds its application in sports equipment such as Badminton racket, tennis racket, golf stick, hockey stick, softball bat, table tennis bat, light boat structure, helmets, climbing ropes, high jump pole, skis, snowboards, inline skates, ski boots, etc.
4. **Construction industry**: Polymer composite materials have been used by the construction industry in non-load bearing applications like trimmings, kitchenware, vanities and cladding.
5. **Biomedical industry**: Composite materials are widely used in orthopaedic applications such as bone fixation plates, hip joint replacement, bone cement, and bone grafts. Composites finds in dental applications such as in the preparation of crowns, repair of cavities, or entire tooth replacement.
6. **Wind Energy Applications**: Composites are used in the manufacture of blades of a Wind turbine.
7. **Marine Applications**: Composite materials are used nowadays extensively in the construction of ships and marine structures since composites have a higher stiffness and strength by weight than compared to most other materials like steel and aluminium. Composites are used in marine applications in Boat Hulls, Minesweepers, Ship Superstructures, etc
8. **Military applications**: Composites are used in submarines, armoured vehicles, bullet-proof vests and military aircraft.

### 4.5.7 Advanced Composites

Advanced Composite Materials or ACMs as they are called are composite materials that consists of high strength fibres with high stiffness or modulus of elasticity while bound together in a weaker matrix. The high strength fibres provide higher strength along the direction of the reinforcing fibre. Apart from high stiffness or elasticity, the high strength fibres also exhibit properties such as chemical resistance, temperature resistance, dimensional stability, flexibility and ease of processing. The aircraft / aerospace industry is today slowly replacing metal parts with advanced composite parts.

### 4.5.8 Applications of Composites in Aerospace / Aircraft

Composite materials are widely used in the Aircraft Industry. The use of light weight, structurally strong and temperature resistant composite materials have reduced fuel consumption, improve efficiency, improve performance and reduce direct operating costs of aircrafts.

The usage of Composite materials date back to 1950s when Boeing used Fibreglass in their 707 passenger jet. Fibreglass is a common composite material that consists of glass fibres embedded in