MODULE 1

INTRODUCTION TO COMPOSITE

Composites are engineered or naturally occurring materials made from the physical amalgamation of two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct within the finished structure. A composite material is a material that consists of one or more discontinuous components (particles/fibers/reinforcement) that are placed in a continuous medium (matrix). Composite materials, or shortened to composites, are microscopic or macroscopic combinations of two or more distinct engineered materials (those with different physical and/or chemical properties) with a recognizable interface between them in the finished product. One of the materials is present in the matrix phase, and another one could be in particle or fiber form. Composites are broadly categorized into two types: structural composites with outstanding mechanical properties and functional composites with various outstanding physical, chemical or electrochemical properties. For structural applications, the definition can be restricted to include those materials that consist of a reinforcing phase such as fibers or particles supported by a binder or matrix phase. Some features of composites include:

- The distribution of materials in the composite is controlled by mechanical means.
- 2) The term composite is usually reserved for materials in which distinct phases are separated on a scale larger than atomic, and in which the composite's mechanical properties are significantly altered from those of the constituent components.
- 3) The composite can be regarded as a combination of two or more materials that are used in combination to rectify a weakness in one material by a strength in another.
- 4) A recently developed concept of composites is that the composite should not only be a combination of two materials, but the combination should have its own distinctive properties. In terms of strength, heat resistance, or some other desired characteristic, the composite must be better than either component alone.

Composites were developed because no single, homogeneous structural material could be found that had all of the desired characteristics for a given application. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness. The continuous phase is the matrix, which is a polymer, metal, or ceramic. Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility, and ceramics have high strength and stiffness but are brittle. The matrix (continuous phase) performs several critical functions, including maintaining the fibers in the proper orientation and spacing and protecting them from abrasion and the environment. In polymer and metal matrix composites that form a strong bond between the fiber and the matrix, the matrix transmits loads from the matrix to the fibers through shear loading at the interface. In ceramic matrix composites, the objective is often to increase the toughness rather than the strength and stiffness; therefore, a low interfacial strength bond is desirable. The type and quantity of the reinforcement determine the final properties. There is a practical limit of about 70 volume percent reinforcement that can be added to form a composite. At higher percentages, there is too little matrix to support the fibers effectively. Fiber-reinforced composites were first developed to replace aluminum alloys, which provide high strength and fairly high stiffness at low weight but are subject to corrosion and fatigue. The discontinuous filler phase in a composite is usually stiffer or stronger than the binder phase. There must be a substantial volume fraction of the reinforcing phase (about10%) present to provide reinforcement. Natural composites include wood and bone. Wood is a composite of cellulose and lignin. Cellulose fibers are strong in tension and are flexible. Lignin cements these fibers together to make them stiff. Bone is a composite of strong but soft collagen (a protein) and hard but brittle apatite (a mineral).

Advantages and Disadvantages of Composite Materials

The advantages of composites are many, including lighter weight, the ability to tailor the layup for optimum strength and stiffness, improved fatigue life, corrosion resistance, and, with good design practice, reduced assembly costs due to fewer detail parts and fasteners. The specific strength (strength/density) and specific modulus (modulus/density) of high strength fibers (especially carbon) are higher than those of other comparable aerospace metallic alloys. This translates into greater weight savings resulting in improved performance, greater payloads, longer range, and fuel savings. Corrosion of aluminum alloys is a major cost and a constant maintenance problem for both commercial and military aircraft. The corrosion resistance of composites can result in major savings in supportability costs. Carbon fiber composites cause galvanic corrosion of aluminum if the fibers are placed in direct contact with the metal surface, but bonding a glass fabric electrical insulation layer on all interfaces that contact aluminum eliminates this problem. As long as reasonable strain levels are used during design, fatigue of carbon fiber composites should not be a problem. Assembly costs can account for as much as 50 percent of the cost of an airframe. Composites offer the opportunity to significantly reduce the amount of assembly labor and the number of required fasteners. Detail parts can be combined into a single cured assembly either during initial cure or by secondary adhesive bonding.

Disadvantages of composites includes: high raw material costs, usually high fabrication and assembly costs, adverse effects of both temperature and moisture, poor strength in the out-of plane direction where the matrix carries the primary load (they should not be used where load paths are complex, such as with lugs and fittings), susceptibility to impact damage and delaminations or ply separations, and greater difficulty in repairing them compared to metallic structures. The major cost driver in fabrication for a composite part using conventional hand lay-up is the cost of laying up or collating the plies. This cost is generally 40 to 60 percent of the fabrication cost, depending on part complexity. Assembly cost is another major cost driver, accounting for about 50 percent of the total part cost. As previously stated, one of the potential advantages of composites is the ability to cure or bond a number of detail parts together to reduce assembly costs and the number of required fasteners. Temperature has an effect on composite mechanical properties. Typically, matrix-dominated mechanical properties decrease with increasing temperature. Fiber-dominated properties are somewhat affected by cold temperatures, but the effects are not as severe as those of elevated temperature on the matrix-dominated properties. Design parameters for carbon/epoxy are cold dry tension and hot-wet compression. An important design factor in the selection of a matrix resin for elevated-temperature applications is the cured glass transition temperature. The cured glass transition temperature (Tg) of a polymeric material is the temperature at which it changes from a rigid, glassy solid into a softer, semi-flexible material. At this point, the polymer structure is still intact but the crosslinks are no longer locked in position. Therefore, the Tg determines the upper use temperature for a composite or an adhesive and is the temperature above which the material will exhibit significantly reduced mechanical properties. The amount of absorbed moisture depends on the matrix material and the relative humidity. Elevated temperatures increase the rate of moisture absorption. Absorbed moisture reduces the matrix-dominated mechanical properties and causes the matrix to swell, which relieves locked-in thermal strains from elevated-temperature curing. These strains can be large, and large panels fixed at their edges can buckle due to strains caused by swelling. During freeze-thaw cycles, absorbed moisture expands during freezing, which can crack the matrix, and it can turn into steam during thermal spikes. When the internal steam pressure exceeds the flatwise-tensile (through-the-thickness) strength of the composite, the laminate will delaminate. Composites are susceptible to de-laminations (ply separations) during fabrication, during assembly, and in service. During fabrication, foreign materials such as pre-preg backing paper can be inadvertently left in the lay-up. During assembly, improper part handling or incorrectly installed fasteners can cause de-laminations. In service, low-velocity impact damage from dropped tools or forklifts running into aircraft can cause damage. The damage may appear as only a small indentation on the surface but it can propagate through the laminates, forming a complex network of de-laminations and matrix cracks. Depending on the size of the de-lamination, it can reduce the static and fatigue strength and the compression buckling strength. If it is large enough, it can grow under fatigue loading. Typically, damage tolerance is a resin-dominated property.

APPLICATIONS OF COMPOSITE MATERIALS

Applications include aerospace (advanced spacecraft and aircraft components), transportation (automobiles components), construction (structural applications), marine goods, sporting goods, biomedical materials and more recently infrastructure, with construction and transportation being the largest. In general, high-performance but more costly continuous-carbon-fiber composites are used where high strength and stiffness along with lightweight are required, and much lower-cost fiberglass composites are used in less demanding applications where weight is not as critical. In military aircraft, low weight is “king” for performance and payload reasons, and composites often approach 20 to 40 percent of the airframe weight. For decades, helicopters have incorporated glass fiber-reinforced rotor blades for improved fatigue resistance, and in recent years helicopter airframes have been built largely of carbon-fiber composites. Military aircraft applications, the first to use high performance continuous-carbon-fiber composites, drove the development of much of the technology now being used by other industries. Both small and large commercial aircraft rely on composites to decrease weight and increase fuel performance, the most striking example being the 50 percent composite airframe for the new Boeing 787. All future Airbus and Boeing aircraft will use large amounts of high-performance composites. Composites are also used extensively in both weight-critical reusable and expendable launch vehicles and satellite structures. Weight savings due to the use of composite materials in aerospace applications generally range from 15 to 25 percent. The major automakers are increasingly turning to composites to help them meet performance and weight requirements, thus improving fuel efficiency. Cost is a major driver for commercial transportation, and composites offer lower weight and lower maintenance costs. Typical materials are fiberglass/polyurethane made by liquid or compression molding and fiberglass/ polyester made by compression molding. Recreational vehicles have long used glass fibers, mostly for their durability and weight savings over metal. The product form is typically fiberglass sheet molding compound made by compression molding. For high-performance Formula 1 racing cars, where cost is not an impediment, most of the chassis, including the monocoque (a structure design in which the frame and body are built as a single integrated structure), suspension, wings, and engine cover, is made from carbon fiber composites. Corrosion is a major headache and expense for the marine industry. Composites help minimize these problems, primarily because they do not corrode like metals or rot like wood. Hulls of boats ranging from small fishing boats to large racing yachts are routinely made of glass fibers and polyester or vinyl ester resins. Masts are frequently fabricated from carbon fiber composites. Fiberglass filament-wound SCUBA tanks are another example of composites improving the marine industry. Lighter tanks can hold more air yet require less maintenance than their metallic counterparts require. Jet skis and boat trailers often contain glass composites to help minimize weight and reduce corrosion. More recently, the topside structures of many naval ships have been fabricated from composites. Using composites to improve the infrastructure of our roads and bridges is a relatively new, exciting application. Many of the world’s roads and bridges are badly corroded and in need of continual maintenance or replacement. In the United States alone, it is estimated that more than 250,000 structures, such as bridges and parking garages, need repair, retrofit, or replacement. Composites offer much longer life with less maintenance due to their corrosion resistance. Typical processes/materials include wet lay-up repairs and corrosion-resistant fiberglass pultruded products. In construction, pultruded fiberglass rebar is used to strengthen concrete, and glass fibers are used in some shingling materials. With the number of mature tall trees dwindling, the use of composites for electrical towers and light poles is greatly increasing. Typically, these are pultruded or filament-wound glass. Wind power is the world's fastest-growing energy source. The blades for large wind turbines are normally made of composites to improve electrical energy generation efficiency. These blades can be as long as 37 m and weigh up to 5200 kg. In 2007, nearly 50,000 blades for 17,000 turbines were delivered, representing roughly 180 million kg of composites. The predominant material is continuous glass fibers manufactured by either lay-up or resin infusion. Tennis racquets have been made of glass for years, and many golf club shafts are made of carbon. Processes include compression molding for tennis racquets and tape wrapping or filament winding for golf shafts. Lighter, stronger skis and surfboards also are possible using composites. Another example of a composite application that takes a beating yet keeps on performing is a snowboard, which typically involves the use of a sandwich construction (composite skins with a honeycomb core) for maximum specific stiffness. Although metal and ceramic matrix composites are normally very expensive, they have found uses in specialized applications. Frequently, they are used high temperature applications. However, the much higher temperatures and pressures required for the fabrication of metal and ceramic matrix composites lead to very high costs, which severely limits their application. In conclusion, advanced composites are a diversified and growing industry due to their distinct advantages over competing metallics including lighter weight, higher performance, and corrosion resistance. They are used in aerospace, automotive, marine, sporting goods, and, more recently, infrastructure applications. The major disadvantage of composites is their high cost. However, the proper selection of materials (fiber and matrix), product forms, and processes can have a major impact on the cost of the finished part.

Figure 2.1: applications of composite materials

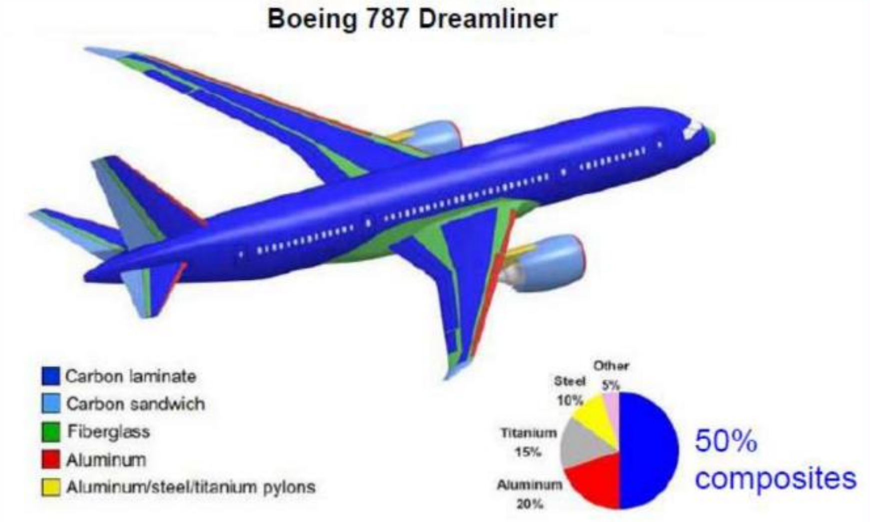


Figure 2.2 Applications of composite materials in aircraft components

CLASSIFICATION OF COMPOSITE MATERIALS

Apart from being broadly categorized into structural and functional, composites are also classified according to their content, i.e., base material and filler: (1) the matrix and (2) the type of reinforcement form. The base material, which binds or holds the filler material in structures, is termed as a matrix or a binder material, while filler material is present in the form of sheets, fragments, particles, fibers, or whiskers of natural or synthetic material.

Classification based on type of matrix.

This classification gives three main categories, which include:

- Organic Matrix Composites (OMC)
  i. Polymer Matrix Composites (PMC)
  ii. Carbon Matrix Composites (CMC) (these are carbon-carbon composites i.e. carbon fiber in a graphite matrix)
- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)

Polymer matrix composites: Based on type of polymer resin used, composite materials can be classified into thermoplastic and thermoset composites.

Thermoplastic composites- this is a type of composite with a thermoplastic resin like polyester, HDPE etc. They are lesser used as high-tech materials due to their high viscosity which cause problems during their penetration into the reinforcement.

Thermoset composites- in these composites thermoset polymers like epoxy, unsaturated polyester and vinyl-ester are used as resin. They are the most used composite materials in automotive, naval, aeronautical, and aerospace applications.

Classification based on type of reinforcement form

This classification gives three main categories, which include:

- Fiber Reinforced Composites (FRC), continuous or discontinuous.
  i. Considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length.
  ii. On the other hand, when the length of the fiber is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fiber reinforced.
  iii. Fiber are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibers must be supported to keep individual fiber from bending and buckling.
- Laminar Composites (LC); layers of materials held together by matrix (Sandwich structures).
- Particulate Composites (PC); particles distributed or embedded in a matrix body. The particles may be flakes or in powder form (e.g. Concrete and wood particle).

ORGANIC METAL COMPOSITES:

Polymer Matrix Composites (PMC) Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. Two main kinds of polymers are thermosets and thermoplastics.

Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing.

- They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics.

- They can be retained in a partially cured condition too over prolonged periods, rendering thermosets very flexible. Thus, they are most suited as matrix bases for advanced fiber reinforced composites.
- Thermosets find wide ranging applications in the chopped fiber composites form, particularly, when a premixed compound with fibers happens to be the starting material as in epoxy, polymer and phenolic polyamide resins.
- Thermoset resins are – epoxy, polyester, phenolic polyamide resins.

Epoxy Resins

- Widely used in filament-wound composites and electrical circuit boards.
- Reasonably stable to chemical attacks and are excellent adherents having slow shrinkage during curing and no emission of volatile gases.
- These advantages make epoxies expensive.
- Cannot be used above 140^{o}C (limiting their applications).

Polyester Resins

- Easily accessible, cheap and used widely.
- Stored at room temperature for long periods and the mere addition of a catalyst can cure the matrix material within a short time.
- Cured polyester is usually rigid or flexible and transparent.
- Used in automobile and structural applications.

Aromatic Polyamides

Most sought after as the matrices of advanced fiber composites for structural applications demanding long duration exposure for continuous service at around 200- 250oC.

Thermoplastics- include: polyethylene, polystyrene, polyamides, nylons, and polypropylene.

- Have one- or two-dimensional molecular structure and they tend to show an exaggerated melting point at an elevated temperature.
- Soften at elevated temperatures can be reversed to regain its properties during cooling, facilitating applications of conventional techniques to mold the compounds.

- Resins comprise an emerging group of composites and the main goal is to improve the base properties of the resins, which would extract the greatest functional advantages from them.
- Whether crystalline or amorphous, these resins possess the facility to alter their creep over an extensive range of temperature.
- Reinforcement in such systems can increase the failure load as well as creep resistance. Moreover, addition of filler raises the heat resistance.

Advantages of thermoplastics include:

- There are no chemical reactions involved, which often result in the release of gases or heat.
- Manufacturing is limited by the time required for heating, shaping and cooling the structures.

Thermoplastics resins are sold as molding compounds. Fiber reinforcement is apt for these resins. Since the fibers are randomly dispersed, the reinforcement will be almost isotropic. However, when subjected to moulding processes, they can be aligned directionally. They tend to lose their strength at elevated temperatures. However, their redeeming qualities like rigidity, toughness and ability to avoid creep, place thermoplastics in the important composite materials bracket. They are used in automotive control panels, electronic products encasement etc

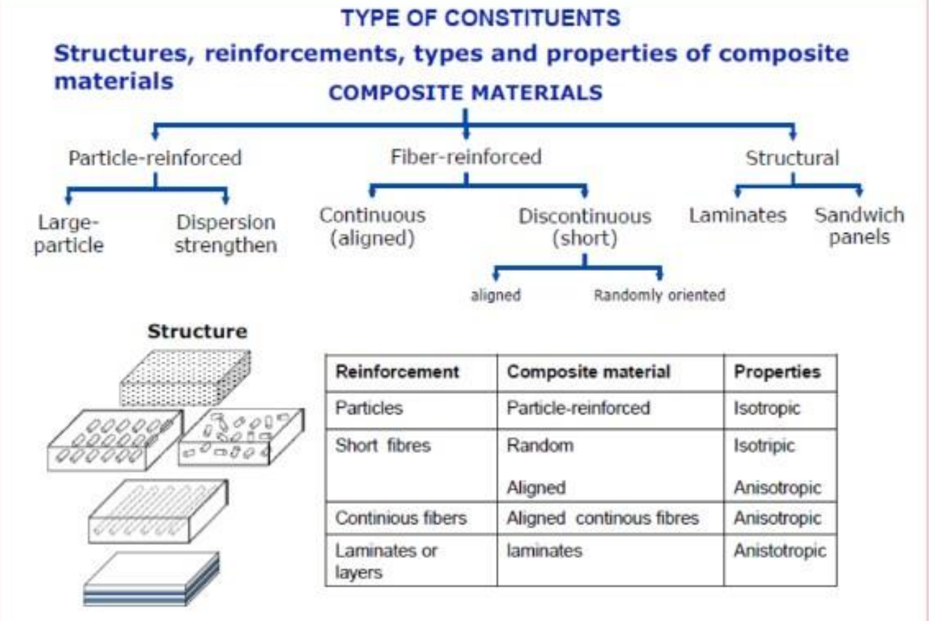
Metal Matrix Composites (MMC)

- Though generating a wide interest in research, are not as widely in use as plastic.
- High strength, fracture toughness and stiffness are offered by metal matrices when compared to their polymer counterparts.
- Withstand elevated temperature in corrosive environment than polymer composites.
- Most metals and alloys - used as matrices. Hence, require reinforcement materials – stable over a range of temperatures and non-reactive too.
- Guiding aspect for the choice depends on matrix material.
- Light metals (low strength) form the matrix while the reinforcements have high moduli.
- If metal matrix has high strength, they require even higher modulus reinforcements.
- Hence, light metals (Al, Ti, and Mg) are the popular matrix metals with their low density. e.g. carbide in a metal matrix.

- The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites.
- Most metals, ceramics and compounds can be used with matrices of low melting point alloys. As the melting points of matrix materials become high, the choice of reinforcements becomes small.

Ceramic Matrix Composites (CMC)

- Ceramics- solid materials which exhibit strong ionic bonding (in some cases covalent bonding)
- High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength - ceramic matrix materials used above 1500ºC (high temperature applications). e.g. cermet, concrete.
- Most ceramic possess high modulus of elasticity and low tensile strain and hence addition of reinforcements to improve their strength have proved futile. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix, which keeps composite from transferring an effective quantum of load to the reinforcement, and the composite may fail unless the percentage of fiber volume is high enough. However, addition of any high-strength fiber (as reinforcing material) to a weaker ceramic has not always been successful and often the resultant composite has proved to be weaker
- When ceramics have a higher thermal expansion coefficient than reinforcement materials, the resultant composite is unlikely to have a superior level of strength. In that case, the composite will develop stress within ceramic at the time of cooling resulting in microcracks extending from fiber to fiber within the matrix. Microcracking can result in a composite with lower tensile strength than that of the matrix.
- Motivation to develop CMCs - to overcome the problems associated with the conventional technical ceramics like alumina, silicon carbide, aluminium nitride, silicon nitride or zirconia –they fracture easily under mechanical or thermo-mechanical loads because of cracks initiated by small defects or scratches. The crack resistance is – like in glass – very low



TYPE OF CONSTITUENTS

Structures, reinforcements, types and properties of composite materials

COMPOSITE MATERIALS

- Particle-reinforced
  - Large-particle
  - Dispersion strengthen
- Fiber-reinforced
  - Continuous (aligned)
  - Discontinuous (short)
    - aligned
    - Randomly oriented
- Structural
  - Laminates
  - Sandwich panels

Structure

Reinforcement	Composite material	Properties
Particles	Particle-reinforced	Isotropic
Short fibres	Random	Isotripic
	Aligned	Anisotropic
Continious fibers	Aligned continous fibres	Anisotropic
Laminates or layers	laminates	Anistotropic

Figure 4.1: classification of reinforcements

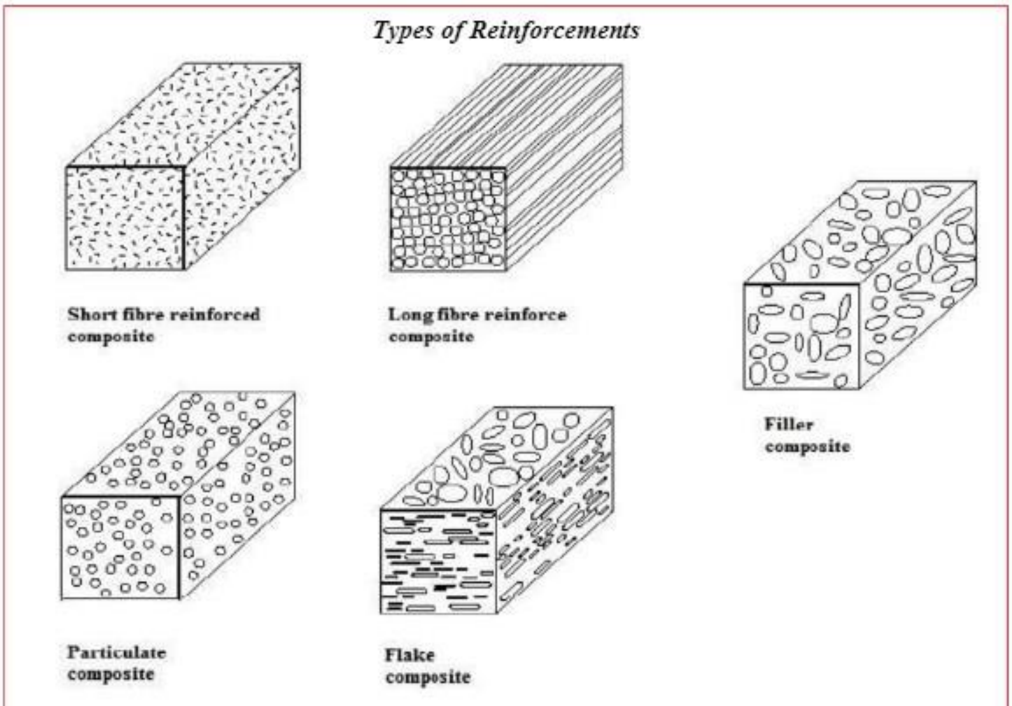


Figure 4.3: illustrations of reinforcement arrangement

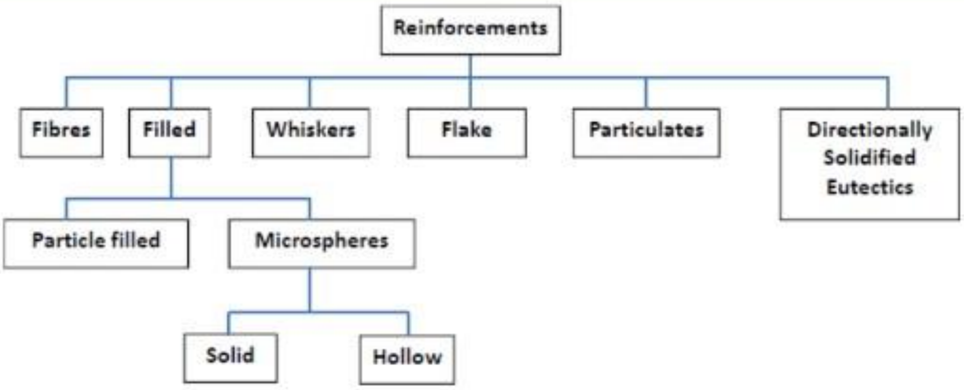
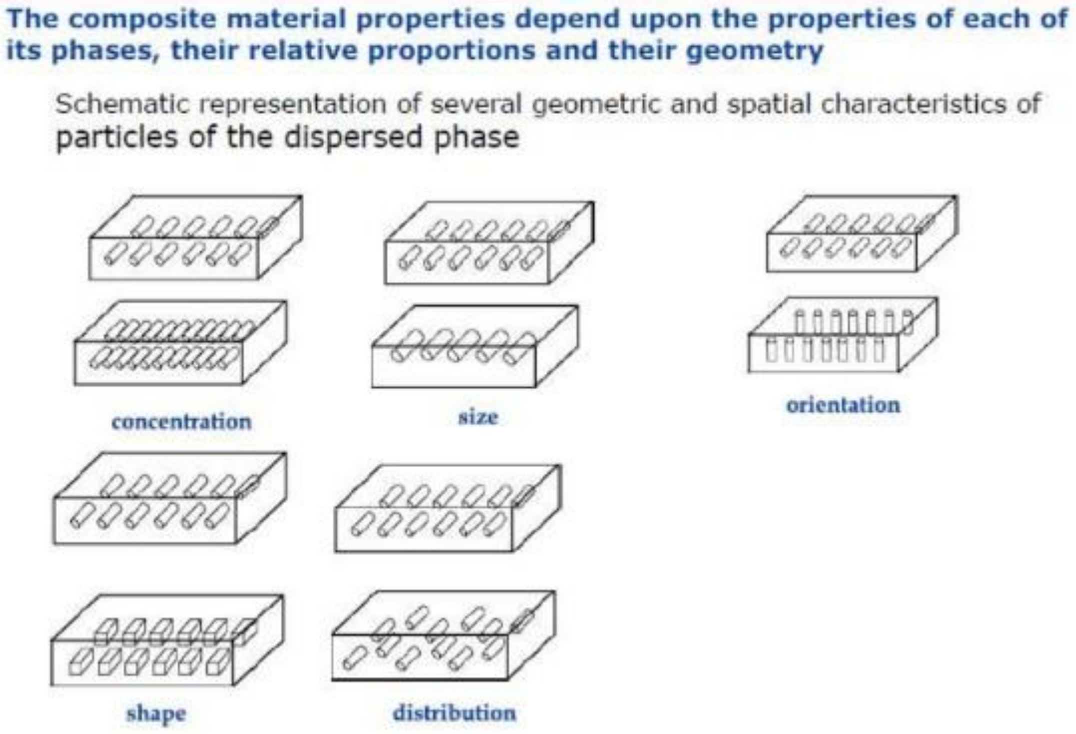


Figure 4.2: classification of reinforcements



The composite material properties depend upon the properties of each of its phases, their relative proportions and their geometry

Schematic representation of several geometric and spatial characteristics of particles of the dispersed phase

Figure 4.4: orientation of reinforcements

Reinforcements Definition

- A strong, inert, woven and nonwoven fibrous material incorporated into the matrix to improve its mechanical and physical properties e.g. asbestos, boron, carbon, metal or glass or ceramic fibers, graphite, jute, sisal, whiskers, macerated fabrics, and synthetic fibers.

- Reinforcement and filler difference: reinforcement markedly improves tensile and flexural strength, whereas filler usually does not to be effective, reinforcement must form a strong adhesive bond with resin.
- Role of the reinforcement: increase the mechanical properties of the neat resin system. Different fibers have different properties - affect the properties of the composite in different ways. However, individual fibers or fiber bundles can only be used on their own in a few processes such as filament winding. For most other applications, the fibers need to be arranged into some form of sheet, known as a fabric, to make handling possible.
- Different ways for assembling fibers into sheets and the variety of fiber orientations - Lead to different types of fabrics, each of which has its own lead characteristics.
- Reinforcements for the composites can be fibers, fabrics particles or whiskers.
- Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular.
- Particles have no preferred orientation and so does their shape.
- Whiskers have a preferred shape but are small in both diameter and length as compared to fibers. 4.2 Particle Reinforced Composites
- Microstructures of metal and ceramics composites, which show particles of one phase scattered in the matrix, are known as particle-reinforced composites.
- Square, triangular, irregular and round shapes of reinforcement are known, but the particle dimensions are observed to be more or less equal.
- The size and volume concentration of the dispersant distinguishes particle-reinforced composites from dispersion-strengthened composites.
- The dispersed size in particulate composites is of the order of a few microns and volume concentration is greater than 28%.

Cermets/ Ceramal (Cermet – ‘ceramic’ and ‘metal’ composite)

Designed to have the optimal properties of both ceramic (high temperature resistance and hardness) and metal (the ability to undergo plastic deformation). The metal (Ni, Mo, Co etc.) is used as a binder for an oxide, boride, carbide, or alumina. Cermets are usually less than 20% metal by volume – used in:

- Manufacture of resistors (potentiometers), capacitors etc. - experience high temperatures.
- Spacecraft shielding (as they resist the high velocity impacts of micrometeoroids and orbital debris better than Al and other metals.
- Vacuum tube coatings of solar hot water systems.
- Material for fillings and prostheses.
- Machining of cutting tools. Titanium nitride (TiN), titanium carbonitride (TiCN), titanium carbide (TiC)

Cermet are usually produced by:

- Using power metallurgy techniques (ceramic and metal powder mixed and sintered).
- Impregnation of a porous ceramic structure with a metallic matrix binder.
- Coating in powder form, which is sprayed through a gas flame and fused to a base material.

FIBER-REINFORCED POLYMER (FRP) COMPOSITES

Fibers - important class of reinforcements, as they effectively transfer strength to the matrix influencing and enhancing composite properties as desired. Glass fibers (earliest known reinforcing fibers). Ceramic and metal fibers used subsequently to make composites stiffer and more heat resistant. The performance of a fiber composite is judged by:

- The length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix.
- Orientation of the fiber in the matrix (strength greatest along the longitudinal directional & slightest shift in the angle of loading drastically reduce the strength)

Since unidirectional loading is found in very few structures, a mix of fiber orientations is given to withstand load from different angles (particularly more fibers in the direction where load is expected to be the heaviest). Monolayer tapes consisting of continuous or discontinuous fibers can be oriented unidirectional stacked into plies containing layers of filaments also oriented in the same direction. Properties of angle-plied composites, which are not quasi-isotropic, may vary with the number of plies and their orientations.

Orientation of short fibers - random orientations by sprinkling on to given plane, addition of matrix in liquid or solid state before or after the fiber deposition. Experience has shown that continuous fibers (or filaments) exhibit better orientation, although it does not reflect in their performance. These are found in mass production of filaments in different ways like winding, twisting, weaving and knitting, which exhibit the characteristics of a fabric. **Organic and inorganic fibers** are used to reinforce composites. Almost all organic fibers have low density, flexibility, and elasticity. Inorganic fibers (glass fibers, silicon carbide fibers, high silica and quartz fibers, aluminina fibers, metal fibers and wires, graphite fibers, boron fibers, aramid fibers and multiphase fibers) are of high modulus, high thermal stability and possess greater rigidity than organic fibers.

5.1 Whisker Reinforced Composites

Whiskers are Single crystals grown with nearly zero defects (usually discontinuous and short fibers of different cross-sections made from materials like graphite, silicon carbide, copper, iron etc.). Typical lengths are range from 3 - 55 nm. Whiskers differ from particles in that, whiskers have a definite length to width ratio (> 1) with extraordinary strengths up to 7000 MPa. Whiskers (laboratory produced) Metal-whisker combination, strengthening the system at high temperatures, has been demonstrated at the laboratory level. Since whiskers are fine, small sized materials and not easy to handle, it becomes a hindrance in composite fabrication. Early research has shown that whisker strength varies inversely with effective diameter. When whiskers were embedded in matrices, whiskers of diameter up to 2 - 10μm yielded fairly good composites. Ceramic whiskers have high moduli, useful strengths and low densities. Specific strength and specific modulus are very high and this makes them suitable for low weight structure composites. They also resist temperature, mechanical damage and oxidation more than metallic whiskers (which are denser than ceramic whiskers). However, they are not commercially viable because they are damaged while handling.

5.2 Flakes Reinforced Composites

Flakes are often used in place of fibers as they can be densely packed. Metal flakes that are in close contact with each other in polymer matrices can conduct electricity or heat, while mica flakes and glass can resist both. Flakes are not expensive to produce and usually cost less than fibers. However, limitations include control of size, shape of flakes and defects in the end product. Glass flakes tend to have notches or cracks around the edges, which weaken the final product. (also resistant to be lined up parallel to each other in a matrix, causing uneven strength). They are usually set in matrices, or held together by a matrix with a glue-type binder.

Advantages of flakes over fibers –

- Parallel flakes filled composites provide uniform mechanical properties in the same plane as the flakes.
- While angle plying is difficult in continuous fibers which need to approach isotropic properties, it is not so in flakes.
- Flake composites have a higher theoretical modulus of elasticity than fiber reinforced composites.
- They are relatively cheaper to produce and be handled in small quantities.

Filled Composites

Addition of filler materials to plastic matrices to replace a portion of the matrix, which would enhance or change the properties of the composites. The fillers also enhance strength and reduce weight in some cases. Fillers may be the main ingredient or an additional one in a composite. The filler particles may be irregular structures, or have precise geometrical shapes like polyhedrons, short fibers or spheres. They also occasionally impart colour or opacity to the composite, which they fill. As inert additives, fillers can change almost any basic resin characteristic in all directions required, to surpass many limitations of basic resins. The final composite properties can be affected by the shape, surface treatment, blend of particle types, size of the particle in the filler material and the size distribution. Filled plastics tend to behave like two different constituents. They do not alloy and accept the bonding (they desist from interacting chemically with each other). Although the matrix forms the bulk of the composite, the filler material is also used in such great quantities relatively that it becomes the rudimentary constituent. The benefits of fillers - increase stiffness, thermal resistance, stability, strength and abrasion resistance, porosity and a favorable coefficient of thermal expansion.

Disadvantages of fillers are that methods of fabrication are very limited and the curing of some resins is greatly inhibited, shorten the life span of some resins, and weaken a few composites. Fillers produced from powders are also considered as particulate composite. In a porous or spongy composite, metal impregnates are used to improve strength or tolerance of the matrix. Metal casting, graphite, powder metallurgy parts and ceramics belong to this class of filled composites. In the honeycomb structure, sheet materials in the hexagonal shapes are impregnated with resin or foam and are used as a core material in sandwich composites.

Microspheres Composites

Microspheres - useful fillers due to specific gravity, stable particle size, strength and controlled density modify products without compromising profits or physical properties. Solid glass microspheres are most suitable for plastics. Microspheres coated with a binding agent - bonds between sphere's surface and resin. This increases the bonding strength and basically removes absorption of contaminants/ moisture (reduce attraction between particles).

Role and Selection of Reinforcements

- Compatibility with matrix material, thermal stability, density, melting temperature etc.
- Efficiency of discontinuously reinforced composites - dependent on tensile strength and density of reinforcing phases.
- Difference between the coefficients of thermal expansion of the matrix and reinforcement -composites used in thermal cycling application.
- The manufacturing process selected and the reinforcement affects the crystal structure.
- In particulate/whisker reinforced composites, the matrix (major load bearing constituent). Role of the reinforcement - strengthen and stiffen the composite through prevention of matrix deformation by mechanical restraint. This restraint is generally a function of the ratio of interparticle spacing to particle diameter.
- In continuous fiber reinforced composites, the reinforcement (principal load-bearing constituent). The matrix serves to hold the reinforcing fibers together and transfer as well as distribute the load.
- Discontinuous fiber reinforced composites - properties between continuous fiber and particulate reinforced composites. Addition of reinforcement increases the strength, stiffness and temperature capability.
- Reduce density of composite if the matrix material has high density.

Role and Selection of Matrix

- The matrix provides support for the fibers and assists them in carrying the loads. It also provides stability to the composite material. Resin matrix system acts as a binding agent in a structural component in which the fibers are embedded.
- When too much resin is used, the part is classified as resin rich. On the other hand, if there is too little resin, the part is called resin starved.
- A resin rich part is more susceptible to cracking due to lack of fibre support, whereas a resin starved part is weaker because of void areas and the fact that fibres are not held together and they are not well supported.
- In case of MMCs, thermodynamically stable dispersoids (particles) are essential for high temperature applications.
- Done using an alloy-matrix (alloy particles in a metal matrix) system in which solid state diffusivity, interfacial energies and elemental solubility are minimized, in turn reducing interfacial reactions.
- Al and Mg alloys matrices widely used due to low density and high thermal conductivity.
- Additionally, composites with low alloying additions to the matrix result in attractive combinations of ductility, toughness and strength.
- Alloying elements (usually used as grain refiners) may form coarse inter-metallic compounds during consolidation, thus, reducing the tensile properties of the composite.
- The choice of a matrix is dictated by - continuously or discontinuously reinforced fibers.
- Continuous fibers - transfer of load to the reinforcing fibers (hence composite strength will be governed by the fiber strength.

Functions of the Matrix

- Holds the fibers together.
- Protects the fibers from environment.
- Distributes the loads evenly between fibers so that all fibers are subjected to the same amount of strain.
- Enhances transverse properties of a laminate.

- Improves impact and fracture resistance of a component. Avoid propagation of crack growth through the fibers by providing alternate failure path along the interface between the fibers and the matrix.
- Carry inter-laminar shear (design consideration for structures under bending loads); in-plane shear strength (under torsion loads)
- Minor role - in the tensile load-carrying capacity of a composite structure.
- Provide lateral support against the possibility of fiber buckling under compression loading.
- Finally, the processing ability and defects in a composite material depend strongly on the physical and thermal characteristics, such as viscosity, melting point, and curing temperature of the matrix

Desired Functions of Matrix

- Reduced moisture absorption.
- Low shrinkage.
- Low coefficient of thermal expansion.
- Good flow characteristics so that it penetrates the fiber bundles completely and eliminates voids during the compacting/curing process.
- Reasonable strength, modulus and elongation (elongation should be greater than fiber).
- Must be elastic to transfer load to fibers.
- Strength at elevated temperature (depending on application).
- Low temperature capability (depending on application).
- Excellent chemical resistance (depending on application).
- Should be easily fabricated into the final composite shape.
- Dimensional stability (maintains its shape).

STRUCTURAL COMPOSITES

Composite materials and homogeneous materials form structural composites. Properties depends on the geometry of the structural elements. There are two types: laminated composites and sandwich structures.

Laminated composites: involves piling of layers or laminar of unidirectional composite material. Laminar composite examples include: continuous and aligned fiber reinforced plastics with matrices such as epoxy, polyester, PE, PA, PET, etc. In order to get different mechanical properties, layers of materials with different properties are piled, or a different way of piling layers on top of each other.