A Study of Various Types of Composites and Properties of Aluminum

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Abstract

Composite are the substances which might be composed of two or greater different phases (at least one of them is solid) such that the aggregate of those phases offers us with the properties that are advanced to any of the individual phases. The properties of the so obtained composite are the end result of the cooperation of the individual phases at the interface. The formation of the composite is due to mutual cooperation of the two phases at the interface, and this is called Synergy effect. Another critical aspect to bear in mind is the matrix-reinforcement interplay i.e., wettability of the surface of the reinforcement particles with the matrix phase. There has to be no chemical reaction between the reinforcement and the matrix at the interface, as this could lead to the formation of a few brittle inter-segments, deteriorating the quality of the composite.

Keywords: Composite, Aluminum, Alumina, Reinforcement & Matrix etc.

Introduction:

Generally, a composite is composed of two components i.e. primary phase which is continuous- **the matrix** and a secondary phase which is mostly discontinuous- **the reinforcement.**

1. The Matrix

The matrix is the bulk part of the composite which holds the reinforcement phase and protects the reinforcement particles from the effects of external influences. The matrix phase is ought to transmit the forces to the reinforcement. Different types of matrices are used for the creation of different types of composites with defined and desired properties such as metals, polymers, ceramics, etc.

2. The reinforcement

The reinforcement phase is the discontinuous phase to which the external load is transferred by the matrix. The properties of the composites depend upon the size, distribution, orientation, shape, etc. of the reinforcement phase

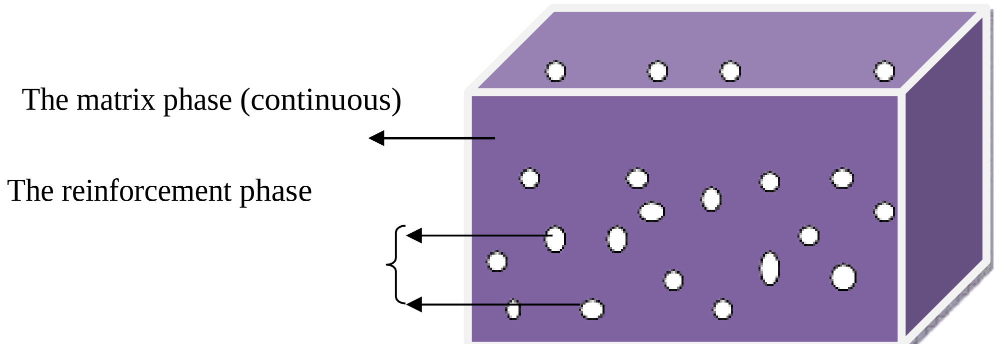


Fig.: Components of a Composite

Advantages of Composites

- Composite substances in contrast to the conventional monolithic materials have advanced properties that may host the needs of the current era.
- It is possible to get the desired combination of properties of the parent materials which are otherwise unattainable.
- Composites can have a very high strength-to-weight ratio, high stiffness, hardness, etc. with being very light in weight.
- It can be engineered according to the needs -such as alternative composites to steel can be formed that do not corrode.
- Better fatigue properties.
- Obtaining high strength at extended temperatures.

Disadvantages of Composites

- Many important composites have anisotropic properties.
- Attacks by chemical compounds or solvents could be very common to polymer-based composites.
- Composites are ordinarily high priced.
- Fabrication strategies for composites are often steeply-priced, complex and slow.
- Reuse and disposal are not smooth.
- Weak transverse properties.

Applications of Composites

Composites are of great importance in various fields due to their superior properties and enhanced performance such as-

1) Automobile parts
2) Aircrafts
3) Bulletproof vests

4) Construction materials
5) Sports
6) Sanitary – sinks, bathtubs, drains, etc.
7) Energy – fuel cells, solar panels, etc.
8) Household appliances – dishwasher, cooking, refrigerators, etc.

In a nutshell, composites are replacing the already existing materials in various fields because of the advantages composites have over these materials. Therefore, research on composites is expanding through leaps and bounds.

Classification of Composites

1. Classification on the basis of reinforcement

On the basis of the type of reinforcement used, composites are classified as follows:

a) Particle –reinforced composites
b) Fiber –reinforced composites
c) Structural composites- laminates and sandwich panels

a) Particle reinforced composites

In particle reinforced composites the reinforcement is in the form of particles distributed in the matrix phase. Depending upon whether the particles are small or large, the interaction between the reinforcement particles and the matrix is different and so is the strengthening mechanism. Thus there are two sub-classifications of particle reinforced composites i.e. large particle and dispersion strengthened particle reinforced composites. In the large particle reinforcement, the particle and matrix interaction is not at the atomic level and the reinforcement particles restrain the movement of the matrix. The strengthening and the properties of the composite depend upon the particle-matrix interaction. In dispersion strengthened composites the size of the particles is very small and thus the interaction of particles and the matrix cause the strengthening at the atomic level. The strengthening in dispersion strengthened particle reinforced composites is much more similar to the precipitation hardening. In large particle reinforcements, the matrix transfers the load to the particles and bears a fraction of load while in dispersion strengthened reinforcement, the matrix bears the major portion of the load.

b) Fiber reinforced composites

These are the most widely used composites in which the reinforcement is in the fiber phase distributed in the matrix. The properties of the composite depend upon factors like fiber size, distribution, orientation, concentration, etc. On the basis of the size and character, fibers are classified as:

1. Whiskers – these are single crystals that have very high length-to-diameter ratio and thus are extremely thin. Whiskers are extremely strong owing to their crystal perfection and are flawless. Whiskers include- graphite, silicon carbide, aluminium oxide, silicon nitride, etc.
2. Fibers – these are either polycrystalline or amorphous materials with very small diameters which are either polymers or ceramics (e.g. Glass fibers, aramids, carbon fibers, etc.)
3. Wires – these generally have larger diameters and include materials like steel, molybdenum, tungsten, etc.

For the efficacious strengthening of the composite, some critical fiber length (l_c) is necessary which depends upon the diameter of the fiber, its ultimate (tensile) strength, and the fiber-matrix bond strength. If the fiber length is greater than this critical fiber length ($l >> l_c$), then it is called as continuous fibers.

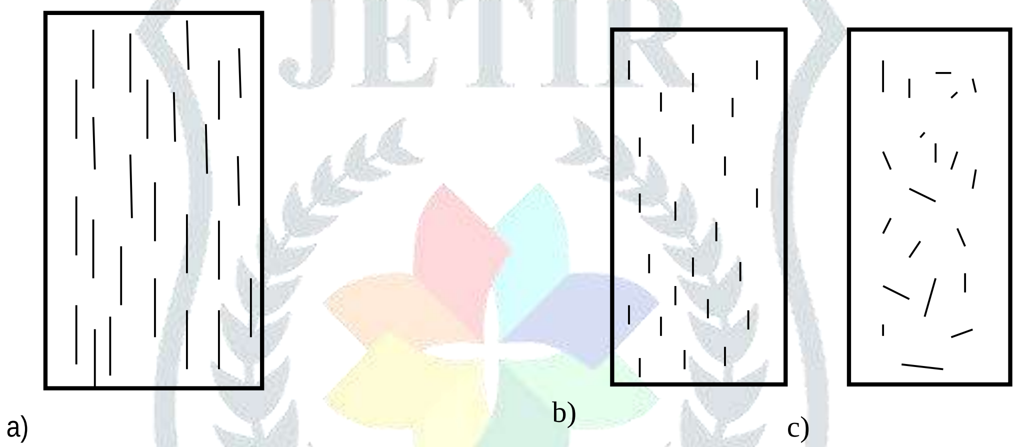


Fig. Schematic representation of fiber reinforced composites (a). Continuous fibers unidirectional aligned b). Discontinuous fibers unidirectionally aligned c). Discontinuous fibers randomly oriented [1]

c) Structural composites

Structural composites are compositions of different materials whose properties depend upon the design and properties of the component materials. Two general types of structural composites are- Laminates and Sandwich panels.

Laminar composites are made by stacking sheets of materials having the orientation of the grains in each layer is different (generally at right angles) from the successive layer. These composites have high directional strength; plywood is an example of laminar composites.

2. Classification on the basis of the matrix

On the basis of the type of matrix used, composites are classified as follows:

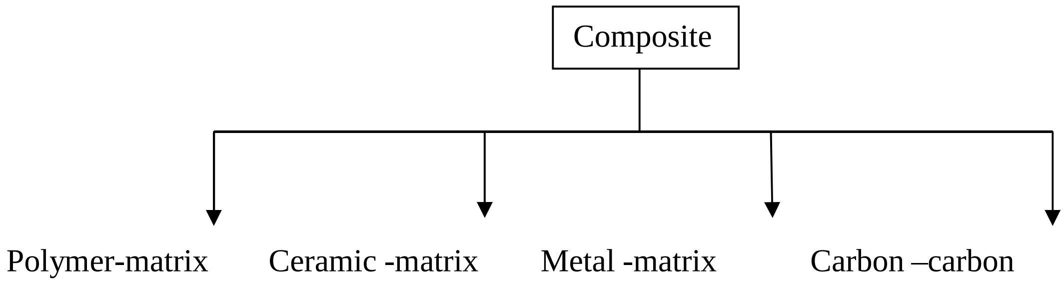


Fig.1.8: Classification of composites on the basis of matrix [1, 5]

a) Polymer-matrix composites

The matrix in the polymer matrix composites is polymer resin in which the reinforcement is dispersed. These composites are used in a wide diversity of application because of their ease of fabrication, cost, and room-temperature properties, etc. The most commonly used reinforcements in polymer matrix composites are glass fibers, carbon fibers, aramids (e.g. Kevlar, Nomex, etc.). Other reinforcements include silicon carbide, boron, aluminium oxide, etc. The most common polymers used as a matrix are-

- Polyesters and vinyl esters- most widely used and cheaper.
- Epoxies – better mechanical properties and resistance to moisture, extensively used for aerospace industry applications.
- Polyimide-for high-temperature applications
- Thermoplastic resins like poly (phenylene sulfide) (PPS), polyetherimide (PEI), etc.

i. Glass-fiber-reinforced polymer composites (GRFP)

These are the largest produced polymer matrix composites with glass fibers as the reinforcement in the polymer matrix. GRFP composites have the following characteristics-

- Strength to weight ratio is high
- Modulus of elasticity is high
- High corrosion resistance
- Efficient insulating properties
- Chemical inertness, etc.

The limitations to these polymers include low stiffness and rigidity making them unsuitable for many applications. The service temperature for these composites is not very high as at high temperatures most of the polymers begin deteriorating. Most common applications of GRFP composites include marine bodies, plastic pipes, containers and in the transportation industry to reduce vehicle weight.

ii. Carbon fiber –reinforced polymer composites (CFRP)

These composites consist of high-performance carbon fibers reinforced in the polymer matrix. Characteristics of carbon fibers which make it a better choice as reinforcement are-

- Highest specific modulus and specific strength
- At elevated temperatures, they retain their high tensile modulus and strength.
- Not affected by moisture or any solvents, acids, bases, etc. at room temperature. CFRPs are being used in recreation and sports (like in golf clubs, fishing rods, etc.), pressure vessels, extensively used in military and commercial aircrafts structural components, etc.

b) Ceramic – Matrix Composites

Ceramic matrix composites are the composites with reinforcements in the form of particulates or fibers that are dispersed in a ceramic matrix. Ceramics are materials (mostly oxides, carbides, nitrides, etc.) that have appealing properties like high hardness, high-temperature stability, corrosion resistance, chemical inertness, etc. making it suitable for the applications in fields like aerospace, automobile industries. But the major drawback of the ceramics is the brittle fracture. Therefore, ceramics are being reinforced with other materials to minimize or reduce the limitations of the ceramic materials making them suitable for use in these fields for various purposes. Different materials either in particulate form, whiskers or fiber form are reinforced in the ceramic matrix to form ceramic-ceramic, ceramic – metal, etc. composites. Ceramic matrix composites are being used in cutting tools due to their properties like high hardness, wear resistance, etc.

c) Carbon-Carbon Composites

Carbon fiber reinforced in carbon matrix commonly termed as carbon-carbon composites is very appealing engineering materials with high-temperature tensile strength, creep resistance, high fracture toughness values. Carbon-Carbon composites are very less susceptible to thermal shocks due to their low coefficient of thermal expansion and high thermal conductivity. These composites have complex processing techniques and are quite expensive making it difficult to use it in large scales. The considerable limitation of carbon-carbon composites is the readiness to oxidation at high temperature. These are very advanced composites materials used in rocket materials, high-performance machine components, components of the turbine, etc.

d) Metal-matrix Composites

Metal–matrix composites, as the name suggests, are composites with a ductile metal as a matrix. Most commonly used metals as matrix are alloys of aluminium, nickel, titanium, copper, etc. Metals are being reinforced with materials like ceramics to reduce the limitations of metals for use at higher temperatures, improve properties like specific strength, toughness, hardness, etc. Metals have a high coefficient of thermal expansion making it unsuited for many applications; adding reinforcements improve the directional stability of these materials. Metal matrix composites are being used as structural components, aircraft materials, in the automobile industry, etc. for their superior properties than the metals.

Advantages of Metal-matrix composites

- High service temperature
- High hardness and toughness
- Non-flammability
- High resistance to wear/surface damages
- High specific strength and creep resistance
- Greater dimensional stability and more.

Disadvantages of Metal-matrix composites

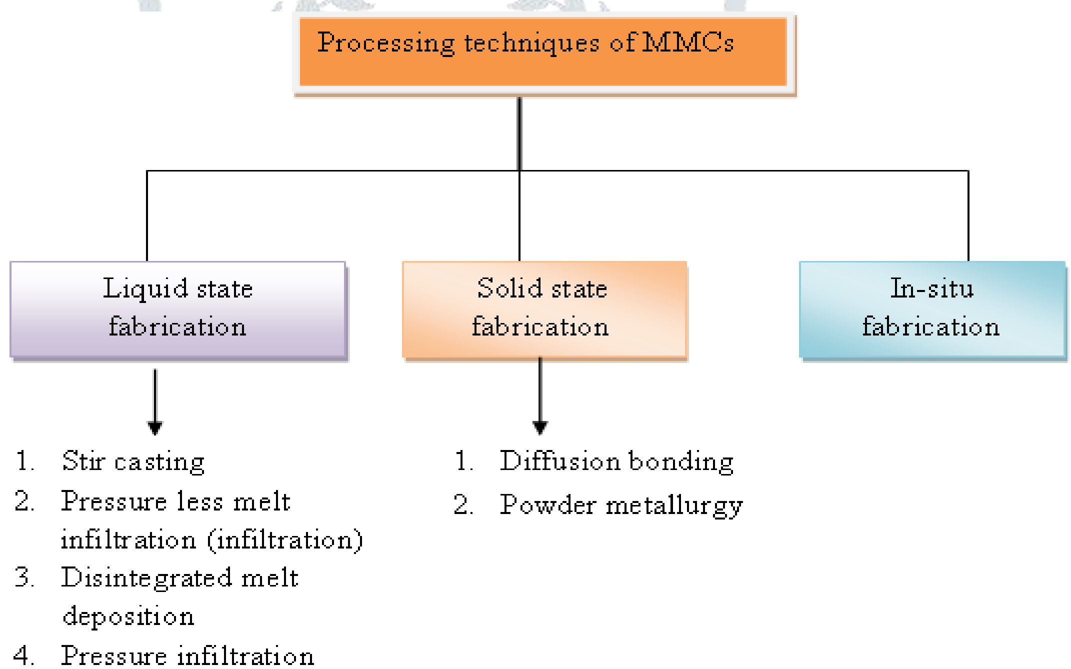
- Production is complex and relatively underdeveloped technology
- Formability is poor
- Higher cost

Processing techniques of Metal-matrix Composites

The large-scale production of metal-matrix nanocomposites is strenuous to achieve due to the problems like poor wettability of the reinforcement particles and the clustering of the nanoparticles. Due to the advantages of MMCs over conventional monolithic materials and over polymer-based materials as they have high specific modulus, high strength, stiffness and higher service temperature (compared to plastics or polymer matrix composites); MMCs offer a wide range of applications. Several processing methods have been studied and employed by the researchers to overcome the problems associated with the metal matrix nanocomposites which are the poor wettability and the agglomeration of nanoparticles in the composite giving rise to unwanted effects on the properties of the composite. Processing techniques for the particle reinforced metal matrix composites is less complex making them cheaper and of greater interest than the fiber reinforced composites, but the fiber reinforced metal matrix composites provide more efficacious strengthening [3]. Different processing techniques for the fabrication of metal matrix composites are [2]:

Fig.: Processing techniques of MMCs [2]

Aluminum and its properties



Aluminum is used as the matrix because of the versatility of the metal in terms of its applications and properties. Aluminum is the most abundant metal and is the most widely used material after steel. Pure aluminum is mostly used for foils and conducting cables due to its softness, high electrical conductivity, corrosion resistance, etc. Aluminum and its alloys are being used in abundance due to their lightweight, high strength to weight ratio, rust proof, formability, cheap and environmentally friendly recycling, etc. Alloying of aluminum with copper, zinc, magnesium, silicon, titanium, chromium, etc. is done to increase its strength and other properties making it suitable for many other applications in various fields like the automobile industry, aerospace, marine, defense, sports, construction material, etc.

Table: Properties of aluminum

Crystal structure	FCC structure
Density	2.70 g/cm^3
Melting point	660.32°C
Boiling point	2470°C
Thermal conductivity	237 W/ (m.K)
Young's modulus	70 GPa
Shear modulus	26 GPa
Bulk modulus	76 GPa
Vickers hardness	160-350 MPa
Brinell hardness	160-550 MPa

Alumina (Al_2O_3)

It is a colorless or pale white substance and is the most commonly found oxide of aluminum occurring naturally in its crystalline phase corundum. Alumina is one of the most widely used ceramic reinforcement due to its properties like-

- High hardness,
- High-temperature stability making it a better choice as refracting material,
- Very good wear resistance,
- High coefficient of thermal expansion,
- Low thermal conductivity (which is usually not so for ceramic materials), etc.

Table: Thermal properties of alumina

Thermal conductivity	12-38.5 W/m.K
Coefficient of thermal expansion	4.5-10.9* 10^{-6} /K
Specific heat	451-955 J/Kg.K
Maximum service temperature	1350-2114 K
Melting point	2072 °C
Boiling point	2977 °C

Table: Mechanical properties of alumina

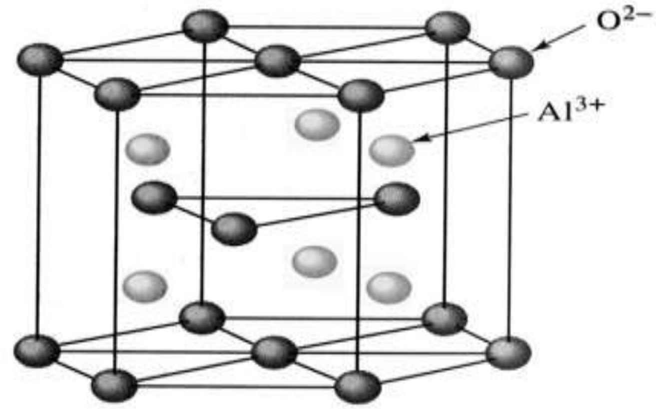
Tensile strength	69.665 MPa
Compressive strength	690-5500 MPa
Fracture toughness	3.3-5 $MPa.m^{1/2}$
Hardness	5500-22050 MPa
Mohs hardness	9
Endurance limit	59-488 MPa

Table: Physical properties of alumina

Appearance	White solid
Crystal structure	Trigonal
Density	3.987-4.1 g/cm^3
Molar mass	101.96 $g.mol^{-1}$
Solubility	Insoluble in water, ethanol, etc.

Polymorphs of Alumina

The most thermodynamically stable form of alumina is α –Al_2O_3 (corundum) but it also exists in various other polymorphic meta-stable forms having a different arrangement of the captions and anions. The two arrangements of oxygen anions are face-centered cubic and hexagonal close-packed whereas the arrangement of the aluminum caption makes these polymorphic forms of alumina. In the FCC arrangement of the oxygen anions, the polymorphic forms of alumina are – γ, η (cubic), θ (monoclinic) and δ (tetragonal / orthorhombic) while HCP arrangement includes – α (trigonal), κ (orthorhombic) and χ (hexagonal) forms [12, 59]. The alpha phase is the most stable form at high temperatures and all the other polymorphs also get transformed to alpha form at high temperatures.



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