Chapter - 2

Survey of Literature
2.1 Engineering Materials

There are more than 50,000 materials available to engineers for the design and manufacturing products for various applications. These materials range from copper, cast iron, brass, which have been available for so many years, to the more recently developed advanced materials such as composites, ceramics and high-performance steels. Due to wide choice of materials, today’s engineers are posed with a big challenge for the right selection of material and manufacturing processes for an application.

These materials depending on their major characteristics like stiffness, strength, density and melting temperature, can be classified into four categories. They are (1) Metals (2) Plastics (3) Ceramics and (4) Composites.

2.1.1 Metals

Metals have been the dominating materials in the past for structural applications. They provide the largest design and processing history to the engineers. The common metals are iron, aluminium, copper, zinc, magnesium, lead, nickel and titanium. In structural applications, alloys are more frequently used than pure metals. Alloys are manufactured by mixing different elements in right proportions. Alloys offer better mechanical properties when compared with pure metals. Through the principle of alloying, thousands of new alloying composites are developed for various high technical applications.

Metals have high stiffness, strength, thermal stability and good electrical conductivity. Due to their higher temperature resistance than plastics, they can be used for applications with service temperature applications.

2.1.2 Plastics

Due to their light weight, easy processability and corrosion resistance, plastics are widely used for automobile, aerospace and consumer goods. Plastics can be formed into near-net-shaped parts with ease. They provide high surface finish coupled with low production cost.

2.1.3 Ceramics

These are more rigid of all the engineering materials. The major distinguishing characteristic of ceramics compared to metals is that they possess almost no ductility.
They fail in a brittle manner. They have the highest melting points. They are generally used for high-temperature and high-wear applications and are resistant to most forms of chemical attack.

2.1.4 Composites

These materials have been utilized to solve the technological problems for a long time but only in the 1960s did these materials start capturing the attention of industries with the introduction of polymeric-based composites. Since then, composite materials have become common engineering materials and are designed and manufactured for various applications including automotive composites, sporting goods, aerospace parts, consumer goods, and in the marine and oil industries. The growth in composite usage also came about because of increased awareness regarding product performance and increased competition in the global market for light weight components.

Among all the existing materials, composites have the potential to replace the widely used steel and aluminium with better performance. Replacing steel components with composite components can save 60 to 80% in component weight and 20 to 50% weight by replacing aluminium parts. Today, it appears that composites are the materials of choice for many engineering applications.[25]

2.2 Aluminium and Its Alloy:

2.2.1 Introduction.

Aluminum, the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently at the end of the 19th century. The emergence of three important industrial developments would, by demanding material characteristics consistent with the unique qualities of aluminium and its alloys, greatly benefit growth in the production and use of the new metal. When the electrolytic reduction of alumina (Al₂O₃) dissolved in molten cryolite was independently developed by Charles Hall in Ohio and Paul Heroult in France in 1886, the first internal-combustion-engine-powered vehicles were appearing, and aluminium would play a role as an automotive material of increasing engineering value. Electrification would require immense quantities of light-weight conductive metal for long-distance transmission and for construction of the towers needed to support the overhead network of cables which deliver electrical energy from sites of power generation. Within a few decades of development of aluminium alloy, Wright brothers gave birth to an entirely new industry which grew in partnership with the aluminium industry development of structurally
reliable, strong and fracture-resistant parts for airframes, engines and ultimately for missile bodies, fuel cells, and satellite components [26].

Aluminium is the most abundant metal and the third most abundant chemical element in the earth's crust comprising over 8% of its weight. Only oxygen and silicon are more prevalent. Yet until about 150 years ago aluminium in its metallic form was unknown to man, the reason for this is that aluminium, unlike iron or copper, does not exist as a metal in nature. Because of its affinity for oxygen, aluminium is always found combined with other elements mainly as aluminium oxide. As such it is found in nearly all clays and many minerals.

It was not until 1886 that scientists learnt how to economically extract aluminium from aluminium oxide via electrolytic reduction. Yet in the more than 100 years since that time, aluminium has become the second most widely used of the approximately 60 naturally occurring metals [26].

2.2.2 Properties of aluminum

Among the most striking characteristics of aluminium is its versatility. The range of physical and mechanical properties that can be developed from refined high-purity aluminium to the most complex alloys is quite remarkable. More than three hundred alloy compositions are commonly recognized and many additional variations have been developed internationally and in supplier/consumer relationships. The properties of aluminium that make this metal and its alloys the most economical and attractive for a wide variety of uses are appearance, light weight, excellent fabricability, good physical properties, better mechanical properties, and good corrosion resistance.

Aluminium typically displays excellent electrical and thermal conductivity, but specific alloys have been developed with high degrees of electrical resistivity. These alloys are useful, for example, in high-torque electric motors. Aluminium is often selected for its electrical conductivity, which is nearly twice that of copper on an equivalent weight basis. The requirements of high conductivity and mechanical strength can be met by use of long-line, high-voltage, and aluminium steel-cored reinforced transmission cable. The thermal conductivity of aluminium alloys, about 50 to 60% that of copper, is advantageous in heat exchangers, evaporators, electrically heated appliances and utensils, and automotive cylinder heads and radiators.

Aluminium is non-ferromagnetic, a property of importance in the electrical and electronics industries. It is non-pyrophoric, which is important in applications involving inflammable or explosive-materials handling or exposure. Aluminium is also non-toxic
and is routinely used in containers for foods and beverages. It has an attractive appearance in its natural finish, which can be soft and lustrous or bright and shiny. It can be virtually any colour or texture. Some aluminium alloys exceed structural steel in strength. However, pure aluminium and certain aluminium alloys are noted for extremely low strength and hardness.

Aluminium has a density of only 2.7g/cm³, approximately one-third as much as steel (7.83g/cm³), copper (8.93g/cm³), or brass (8.53g/cm³). It exhibits excellent corrosion resistance in most environments including atmosphere, water (including salt water), petrochemicals and many other chemical systems. Aluminium surfaces can be highly reflective. Radiant energy, visible light, radiant heat, and electromagnetic waves are efficiently reflected, while anodized and dark anodized surfaces can be reflective or absorbent. The reflectance of polished aluminium, over a broad range of wave lengths, leads to its selection for a variety of decorative and functional uses.

One important property of aluminium is that everyone is familiar is its light weight or technically its low specific gravity which is only 2.7 times that of water and roughly one third that of steel or copper. The following are some of the other properties of aluminium and its alloys.

- **Formability**: Aluminium can be formed by every process in use today and in more ways than any other metal. Its relatively low melting point, does make it easy to cast.

- **Mechanical properties**: Through alloying, naturally soft aluminium can attain strength twice that of mild steel.

- **Strength-to-weight ratio**: Some aluminium alloys possess the highest strength-to-weight ratio. This facts leads to ideal choice as structural metal for commercial and military aircraft.

- **Cryogenic properties**: Unlike most steels, which tend to become brittle at cryogenic temperatures, aluminium alloys actually get tougher at low temperature and hence enjoy many cryogenic applications.

- **Corrosion resistance**: Aluminium possesses excellent resistance to corrosion by natural atmospheres and by many foods and chemicals.

- **High electrical and thermal conductivity**: On a volume basis the electrical conductivity of pure aluminium is roughly 60% of the international annealed copper standard, but aluminium is a better conductor of heat and electricity than copper and is surpassed only by sodium, which is a difficult metal to use in everyday situations.
• Reflectivity: Aluminium can accept surface treatment to become an excellent reflector and it does not dull from normal oxidation.

• Finishability: Aluminium can be finished in more ways than any other metal used today [27].

2.2.3 Aluminium alloys:

While commercially pure aluminium (defined as at least 90% aluminium) does find applications in electrical conductors, chemical equipment and sheet metal work, it is a relatively weak material, and its use is restricted to applications where strength is not an important factor. Some strengthening of the pure metal can be achieved through cold working, called strain hardening. However, much greater strengthening is obtained through alloying with other metals, and the alloys themselves can be further strengthened through strain hardening or heat treating. Other properties, such as castability and machinability, are also improved by alloying. Thus aluminium alloys are much more widely used than the pure metal and in many cases, when aluminium is mentioned, the reference is actually to one of the many commercial alloys of aluminium.

The principal alloying additions to aluminium are copper, manganese, magnesium and zinc. Other elements are also added in smaller amounts for metallurgical purposes. Since there have been literally hundreds of aluminium alloys developed for commercial use, the aluminium association formulated and administers special alloy designation systems to distinguish and classify the alloys in a meaningful manner. Some of the important aluminium alloys are discussed below.

2.2.3.1 Aluminum-magnesium alloys casting alloys are essentially single-phase binary alloys with moderate-to-high strength and toughness properties. High corrosion resistance, especially to marine atmospheres is the primary advantage of castings made of Al-Mg alloys. Best corrosion resistance requires low impurity content (both solid and gaseous), and thus alloys must be prepared from high-quality metals and handled with great care in the foundry. These alloys are suitable for welded assemblies and are often used in architectural and other decorative or building needs. Aluminum-magnesium alloys also have good machinability and an attractive appearance when anodized. In comparison to the aluminum-silicon alloys, all the aluminum-magnesium alloys require more care in gating and greater temperature gradients to produce sound castings. This often means more chilling and larger risers. Also, careful melting and pouring practices are needed to compensate for the greater oxidizing tendency of these alloys when molten. This care is also needed because many of the applications of these alloys require
polishing and/or fine surface finishing, where defects caused by oxide inclusions are particularly undesirable. The relatively poor castability of Al-Mg alloys and the tendency of the magnesium to oxidized increase handling difficulties and therefore the cost.

### 2.2.3.2 Aluminum-silicon alloys

Alloys that do not contain copper additions are used when good castability and good corrosion resistance are needed. If high strength and hardness are needed, magnesium additions make these alloys heat treatable. Alloys with silicon contents as low as 2% have been used for casting, but silicon content usually is between 5 and 13%. Strength and ductility of these alloys, especially those with higher silicon, can be substantially improved by modification of the Al-Si eutectic. Modification of hypoeutectic alloys (<12% Si) is particularly advantageous in sand castings and can be effectively achieved through the addition of a controlled amount of sodium or strontium, which refines the eutectic phase. Calcium and antimony additions are also used. Pseudo modification, in which the fineness of the eutectic but not the structure is affected, may be achieved by control of solidification rates.

In hypereutectic Al-Si alloys, refinement of the proeutectic silicon phase by phosphorus additions is essential for casting and product performance.

### 2.2.3.3 Al-Si-Mg alloys

The main components of the alloys are silicon and magnesium to form Mg$_2$Si. The compound Mg$_2$Si is in equilibrium and there is a quasibinary line Al-Mg$_2$Si at the Mg:Si ratio 1.73. When in solution in aluminium, magnesium and silicon tend to cluster together to form molecules of Mg$_2$Si. The solid solubility of Mg$_2$Si in aluminium is reduced slightly by the presence of silicon in excess over the Mg:Si = 1.73 ratio, but an excess of magnesium greatly reduces the solubility. Magnesium excess leads to better corrosion resistance but lower strength and formability. Silicon excess produces higher strength without loss of formability and weldability, but some tendency to intergranular corrosion.

The main constituent is Mg$_2$Si, which in the heat treated condition, is in solution and which is due the age hardening after artificial ageing. In age hardening precipitation starts with the formation of spherical GP zones. These zones elongate in the matrix direction and assume a needle shape. The needles grow to become rods and eventually platelets of Mg$_2$Si. Peak hardness reached just before the platelets form. A delay between quenching and artificial ageing affects the properties appreciably.

### 2.2.3.4 Al-Cu Alloy

Al-Cu alloys with somewhat higher copper contents (7 to 8%), formerly the most commonly used aluminum casting alloys, have steadily been replaced by Al-Cu-Si alloys and today are used to a very limited extent. The best attribute of higher-copper Al-Cu alloys is their insensitivity to impurities. However, these alloys
display very low strength and only fair castability. Also in limited use are Al-Cu alloys that contain 9 to 11% Cu, whose high-temperature strength and wear resistance are attractive for use in aircraft cylinder heads and in automotive (diesel) pistons and cylinder blocks.

2.3 Alloy Designation Systems:

It is convenient to divide aluminium alloys into two major categories: cast compositions and wrought compositions. A further differentiation for each category is based on its primary mechanism as property development. Many alloys respond to thermal treatments which include solution heat treatment, quenching and precipitation or age hardening. For either casting or wrought alloys some alloys are described as heat treatable. A large number of other wrought compositions rely instead on work hardening through mechanical reduction, usually in combination with various annealing procedures for property development. These alloys are referred to as work hardening. Some casting alloys are essentially not heat treatable and are used only in as-cast or in thermally modified conditions.

Cast and wrought alloy nomenclatures have been developed. The aluminium association system is most widely recognized in United States. Their alloy identification system employs different nomenclatures for wrought and cast alloys, but divides alloys into families for simplification.

The wrought category is a broad one, since aluminium alloys may be shaped by virtually every known process, including rolling, extruding, drawing, forging and a number of other, more specialized processes. Cast alloys are those that are poured molten into sand (sand casting) or high-strength steel (permanent mould or die casting) moulds and are allowed to solidify to produce the desired shape. The wrought and cast alloys are quite different in composition: wrought alloys must be ductile for fabrication, while cast alloys must be fluid for castability.

2.3.1 System for designating Al and Al alloys (wrought):

Table 2.1 reports the designation of wrought aluminium alloy

A four-digit numerical designation system is used to identify wrought aluminium alloys. The first digit of the four digit designation indicates the group to which it belongs like Cu, Mn, Mg, Si, tin or mg-si.
In aluminium alloys from 2xxx to 8xxx alloy groups, the second digit in the designation indicates alloy modification. If second digit is zero, it indicates the original alloy; integers through 1 through 9 assigned consequently, indicates modifications of the original alloy. Explicit rule have been established for determining whether a proposed composition is merely a modification of a previously registered alloy or it is an entirely new alloy. The last two digit of the four digits in the 2xxx through 8xxx groups have no special significance, but serve only to identify the different aluminium alloys in to group. [26].

Table 2.2 reports the physical properties of 6061 alloy which is one of the most popular 6xxx series aluminium alloy. Table 2.3 reports the mechanical properties of Al6061 alloy.

**Table 2.1: The designation of wrought Al alloys**

<table>
<thead>
<tr>
<th>Series</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>Controlled unalloyed (pure) composition.</td>
</tr>
<tr>
<td>2xxx</td>
<td>Alloys in which copper is the principal alloying element, through other elements, notably magnesium, may be specified.</td>
</tr>
<tr>
<td>3xxx</td>
<td>Alloys in which manganese is the principal alloying element.</td>
</tr>
<tr>
<td>4xxx</td>
<td>Alloys in which silicon is the principal alloying element.</td>
</tr>
<tr>
<td>5xxx</td>
<td>Alloys in which magnesium is the principal element.</td>
</tr>
<tr>
<td>6xxx</td>
<td>Alloys in which magnesium and silicon are principal alloying element.</td>
</tr>
<tr>
<td>7xxx</td>
<td>Alloys in which zinc is the principal alloying element, but other elements such as copper, magnesium, chromium and zirconium may be specified.</td>
</tr>
<tr>
<td>8xxx</td>
<td>Alloys including tin and some lithium compositions characterizing miscellaneous compositions.</td>
</tr>
<tr>
<td>9xxx</td>
<td>Reserved for future use.</td>
</tr>
</tbody>
</table>
Table 2.2: The Physical property of 6061 aluminium alloy

<table>
<thead>
<tr>
<th>Property</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average coefficient of thermal expansion</td>
<td>23.6μm/m°C</td>
</tr>
<tr>
<td>Approximate melting point</td>
<td>580-650°C</td>
</tr>
<tr>
<td>Temper</td>
<td>0</td>
</tr>
<tr>
<td>Thermal conductivity at 25°C</td>
<td>180 W/m°C</td>
</tr>
<tr>
<td>Electrical conductivity at 20°C</td>
<td>47 (Equal volume)</td>
</tr>
<tr>
<td>Electrical resistivity at 20°C</td>
<td>0.0365Ωmm²/m</td>
</tr>
<tr>
<td>Density</td>
<td>2.7gm/cm³</td>
</tr>
</tbody>
</table>

Table 2.3 The Mechanical property of 6061 aluminium alloy

<table>
<thead>
<tr>
<th>Alloy</th>
<th>6061-0</th>
<th>6061-T4,51</th>
<th>6061-T6, T651</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile strength in Mpa</td>
<td>125</td>
<td>240</td>
<td>310</td>
</tr>
<tr>
<td>Tensile Yield Strength in Mpa</td>
<td>55</td>
<td>145</td>
<td>275</td>
</tr>
<tr>
<td>Elongation in 50mm</td>
<td>25</td>
<td>22</td>
<td>12</td>
</tr>
<tr>
<td>Hardness</td>
<td>30</td>
<td>65</td>
<td>95</td>
</tr>
<tr>
<td>Ultimate shear strength in Mpa</td>
<td>85</td>
<td>165</td>
<td>205</td>
</tr>
<tr>
<td>Youngs Modulus (E) in Gpa</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
</tbody>
</table>

2.3.2 Temper designation system for aluminum alloys.
The following lists the temper designations for aluminum alloys:

F. As fabricated. Applies to products shaped by cold working, hot working, or casting processes in which no special control over thermal conditions or strain hardening is employed.

O. Annealed. Applies to wrought products that are annealed to obtain lowest-strength temper, and to cast products that are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero. Such a digit indicates special characteristics. For example, for heat-treatable alloys, O1 indicates a product that has
been heat treated at approximately the same time and temperature required for solution heat treatment and then air cooled to room temperature.

**H.** Strain hardened (wrought products only). Applies to products that have been strengthened by strain hardening, with or without supplementary heat treatment to produce some reduction in strength. The H is always followed by two or more digits. The digit following the designation H1, H2, and H3, which indicates the degree of strain hardening, is a numeral from 1 through 8. An 8 indicates tempers with ultimate tensile strength equivalent to that achieved by about 75 percent cold reduction (temperature during reduction not to exceed 50°C) following full annealing.

**H1.** Strain hardened only. Applies to products that are strain hardened to obtain the desired strength without supplementary thermal treatment. The digit following the H1 indicates the degree of strain hardening.

**H2.** Strain hardened and partially annealed. Applies to products that are strain hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. The digit following the H2 indicates the degree of strain hardening remaining after the product has been partially annealed.

**H3.** Strain hardened and stabilized. Applies to products that are strain hardened and whose mechanical properties are stabilized by a low-temperature thermal treatment that slightly decreases tensile strength and improves ductility. This designation is applicable only to those alloys that, unless stabilized, gradually age soften at room temperature. The digit following the H3 indicates the degree of strain hardening after stabilization.

**W.** Solution heat treated. An unstable temper applicable only to alloys that naturally age after solution heat treatment. This designation is specific only when the period of natural ageing is indicated.

**T.** Heat treated to produce stable tempers other than F, O, or H. Applies to products that are thermally treated, with or without supplementary strain hardening, to produce stable tempers. The T is always followed by one or more digits:

**T1.** Cooled from an elevated temperature-shaping process and naturally aged to a substantially stable condition. Applies to products that are not cold worked after an elevated temperature-shaping process such as casting or extrusion and for which mechanical properties have been stabilized by room-temperature ageing.

**T2.** Cooled from an elevated temperature-shaping process, cold worked, and naturally aged to a substantially stable condition. Applies to products that are cold worked specifically to improve strength after cooling from a hot working process such as rolling.
or extrusion and for which mechanical properties have been stabilized by room-
temperature ageing.

T3. Solution heat treated, cold worked, and naturally aged to a substantially stable condition. Applies to products that are cold worked specifically to improve strength after solution heat treatment and for which mechanical properties have been stabilized by room-temperature ageing.

T4. Solution heat treated and naturally aged to a substantially stable condition. Applies to products that are not cold worked after solution heat treatment and for which mechanical properties have been stabilized by room-temperature ageing.

T5. Cooled from an elevated temperature-shaping process and artificially aged. Applies to products that are not cold worked after an elevated temperature-shaping process such as casting or extrusion and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment.

T6. Solution heat treated and artificially aged. Applies to products that are not cold worked after solution heat treatment and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment.

T7. Solution heat treated and stabilized. Applies to products that have been precipitation heat treated to the extent that they are overaged. Stabilization heat treatment carries the mechanical properties beyond the point of maximum strength to provide some special characteristic, such as enhanced resistance to stress corrosion cracking.

T8. Solution heat treated, cold worked, and artificially aged. Applies to products that are cold worked specifically to improve strength after solution heat treatment and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment.

T9. Solution heat treated, artificially aged, and cold worked. Applies to products that are cold worked specifically to improve strength after they have been precipitation heat treated.

T10. Cooled from an elevated temperature-shaping process, cold worked, and artificially aged. Applies to products that are cold worked specifically to improve strength after cooling from a hot working process such as rolling or extrusion and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment. [26].
2.4 Definition of Composite.

A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale.

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.[28]

As defined by Jartiz, [29] Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form.

Kelly [30] very clearly stresses that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength or resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them.

Berghezan [31] defines as “The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their shortcomings”, in order to obtain an improved material.

Van Suchetclan [32] explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can also be considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

2.5 Characteristics of the Composites

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the ‘reinforcement’ or ‘reinforcing material’, whereas the continuous phase is termed as the ‘matrix’.

Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the summation of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from
the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties.

The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross-sectioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix.

Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites, but also an easily controllable manufacturing variable used to alter its properties. [28].

2.6 Classification of Composites

Composite materials can be classified in different ways [33]. Classification based on the geometry of a representative unit of reinforcement is convenient since it is the geometry of the reinforcement which is responsible for the mechanical properties and high performance of the composites. The two broad classes of composites are (1) Particulate composites and (2) fibrous composites.

2.6.1 Particulate Composites

As the name itself indicates, the reinforcement is of particle nature (platelets are also included in this class). It may be spherical, cubic, tetragonal, a platelet, or of other regular or irregular shape, but it is approximately equiaxed. In general, particles are not very effective in improving fracture resistance but they enhance the stiffness of the composite to a limited extent. Particle fillers are widely used to improve the properties of matrix materials such as to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, increase wear and abrasion resistance, improve machinability, increase surface hardness and reduce shrinkage.[28].

2.6.2 Fibrous composites

A fiber is characterized by its length being much greater when compared to its cross-sectional dimensions. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly with brittle matrices.
Man-made filaments or fibers of non polymeric materials exhibit much higher strength along their length since large flaws, which may be present in the bulk material, are minimized because of the small cross-sectional dimensions of the fiber. In the case of polymeric materials, orientation of the molecular structure is responsible for high strength and stiffness.

Fibers, because of their small cross-sectional dimensions, are not directly usable in engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites. The matrix serves to bind the fibers together, transfer loads to the fibers, and protect them against environmental attack and damage due to handling. In discontinuous fiber reinforced composites, the load transfer function of the matrix is more critical than in continuous fiber composites.

2.7 Components of a Composite Material

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix.

2.8 Role of matrix in a composite

Many materials when they are in fibrous form exhibit very good strength property but to achieve these properties the fibers should be bonded by a suitable matrix. The matrix isolates the fibers from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibers in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distribute the stresses.

A study of the nature of bonding forces in laminates [34] indicates that upon initial loading there is a tendency for the adhesive bond between the reinforcement and the matrix to be broken. The frictional forces between them account for the high strength properties of the laminates.

2.9 Reinforcements

Reinforcement material is the one, which gives strength to the two phase material. It improves and imparts stiffness. It prolongs the life of a composite by improvement of
mechanical and physical properties such as thermal and electrical conductivity.

Based on aspect ratio (length to thickness) reinforcements are classified as

- Fibers
- Whiskers
- Platelets and flakes
- Particulate

2.9.1 Fiber:

Fibers are the materials that have very long axis having more strength in their longitudinal direction. These are available in several diameters and lengths including continuous, which can be used as it is, or chopped to the desired length. These can be polycrystalline or amorphous and forms the principal constituents in a fiber-reinforced composite with polymer or ceramic or metal matrices. They occupy the largest volume fraction in a composite and share the major portion of the load acting. Because of their extremely large aspect ratio they are effective and influences the following properties of a composite.

- Specific gravity.
- Tensile strength and modulus.
- Compressive strength and modulus.
- Fatigue strength and fatigue failure mechanism.
- Electrical & thermal conductivity
- Cost

Some of the important fibers are glass, carbon, kevlar, boron, silicon carbide and alumina.

2.9.2 Whiskers:

Whiskers are very thin acicular (needle) single crystals with a diameter in the range of 0.01 - 10 µm and an aspect ratio of usually over 10. They have a very large surface to volume ratio and a noncircular cross-section (like triangular, hexagonal, rhombohedral). Their diameter is defined as the square root of the cross-sectional surface area. Because of their large aspect ratio they are efficient. The shape of the whisker affects the total whisker/matrix interfacial area. The interface in turn has a strong
influence on physical and mechanical properties of the composites. The low density of defects in whiskers is due to the single crystalline form and low dimensions which imparts them the strength.

- Whiskers are incorporated in metals primarily for stiffness, creep and wear resistance.
- Whiskers enhances the fracture toughness to a greater extent when it is reinforced with ceramic matrix
- Whiskers are used in polymer composites to improve thermal and electrical properties. [35]

Some important whiskers are asbestos, carbon, silicon carbide, silicon nitride, alumina, mullite, titania, titanium carbide, titanium nitride aluminium borate, calcium carbonate, silica, niobium carbide, aluminium nitride, tin oxide, cadmium oxide. [36]

2.9.3 Flakes and Platelets:

Platelets and flakes have an aspect ratio in the range of 30-120. Width usually ranges from 20 to 500 µm. These reinforcements are attractive with ceramic matrix materials because of its smooth surfaces, flake and platelet filled composites exhibits less anisotropic microstructure and lower tendency of wrapping. Mica, silicon carbide, boron carbide, aluminum, copper are some of the important platelets. [36]

2.9.4 Particulates:

Particulate can be considered as small microscopic material in the form of a powder. They have low aspect ratio. The dimensions of a particulate reinforcement are approximately equal in all directions. The shape of the particle may be spherical, cubic, plate like or irregular or regular geometry. The efficiency of the particulate reinforcement depends on the factors like size, geometry, distribution, and volume fraction. The particulate are selected according to the type of adhesion with the matrix phase and they are of two forms. i) Non-Metallic  ii) Metallic.

2.9.4.1 Metallic: Metallic particles are generally used to improve the conducting property of a polymer. Metallic particles cannot be dissolved in another metallic matrix. Some of the examples are rocket propellant, which consist of aluminum powder in polyurathene [37].

2.9.4.2 Non – Metallic: Non-metallic particulates that are mostly used are ceramics, conductive materials such as graphite, conductive carbon black etc. Ceramics are the most
popular materials which are dispersed in the matrix and resulting composite are termed as cermet. Some of the important non metallic particulates are \text{Al}_2\text{O}_3, \text{AlN}, \text{BN}, \text{SiC}, \text{Si}_3\text{N}_4, \text{Graphite}, \text{TiC}, \text{TiN}, \text{W}, \text{WC}, \text{B}, \text{TiB}_2, \text{Glass}, \text{ZrO}_2, \text{CaF}_2 \ [38]

2.10 Advantages of Composites:

Composites have been routinely designed and manufactured for applications in which high performance and light weight are needed. They offer several advantages over traditional engineering materials as discussed below \[39\].

1. Composite materials provide capabilities for part integration. Several metallic components can be replaced by a single composite component.

2. Composite structures provide in-service monitoring or online process monitoring with the help of embedded sensors. This feature is used to monitor fatigue damage in aircraft structures or can be utilized to monitor the resin flow in an RTM (resin transfer molding) process. Materials with embedded sensors are known as “smart” materials.

3. Composite materials have a high specific stiffness (stiffness-to-density ratio). Composites offer the stiffness of steel at one fifth the weight and equal the stiffness of aluminum at one half the weights.

4. The specific strength (strength-to-density ratio) of a composite material is very high. Due to this, airplanes and automobiles move faster and with better fuel efficiency. The specific strength is typically in the range of 3 to 5 times that of steel and aluminum alloys.

5. The fatigue strength (endurance limit) is much higher for composite materials. Steel and aluminum alloys exhibit good fatigue strength up to about 50\% of their static strength. Unidirectional carbon/epoxy composites have good fatigue strength up to almost 90\% of their static strength.

6. Composite materials offer increased amounts of design flexibility. For example, the coefficient of thermal expansion (CTE) of composite structures can be made zero by selecting suitable materials and lay-up sequence. Because the CTE for composites is much lower than for metals, composite structures provide good dimensional stability.

7. Complex parts, appearance, and special contours, which are sometimes not possible with metals, can be fabricated using composite materials without welding or riveting the separate pieces. This increases reliability and reduces production times. It offers greater manufacturing feasibility.
8. Composite materials offer greater feasibility for employing design for manufacturing (DFM) and design for assembly (DFA) technique [28].

2.11 Metal Matrix Composites:

Metal matrix composites (MMCs) offer designers many added benefits, as they are particularly suited for applications requiring good strength at high temperatures, good structural rigidity, dimensional stability, and lightweight. They are well known for their superior mechanical and tribological properties.

Metal matrix composites are increasingly being used in the aerospace and automobile industries because of their improved strength, stiffness and increased wear resistance other unreinforced alloys [40]. The commonly used metallic matrixes include light metals such as aluminum, magnesium, titanium, and their alloys. The reinforcement can be in the form of fibers, whiskers and particulates. Widely used reinforcements are silicon carbide, aluminum oxide and graphite. [41,42] Reinforcements of aluminium alloys with Al₂O₃ or SiC have generally been observed to improve wear and abrasion resistance [43, 44, 12, 45,46].

Metal matrix composites have emerged as a class of materials suitable for advanced structural, thermal management, and wear applications. MMCs exhibit significant improvement in physical and mechanical properties compared with unreinforced alluminium alloys, such as in strength, elastic modulus, fatigue resistance and tribological properties [47].

MMCs exhibit the ability to withstand high tensile and compressive stresses by the transfer and distribution of the applied load from the ductile matrix to the reinforcement phase. This load transfer is possible due to due only to the existence of an interfacial bond between the particulate reinforcement and the matrix [2].

Metal matrix composites have received substantial attention from the aerospace and automotive industries because of their improved strength, high elastic modulus and increased wear resistance over conventional monolithic base alloys during the last decade. Improvements in mechanical properties and wear resistance of MMCs have already been demonstrated for a variety of reinforcements [48].

The wear of particulate reinforced aluminium metal matrix composites has been studied by numerous researchers [46, 49-53] since these MMCs are currently being considered as promising tribolgical materials with applications in the aerospace, aircraft and in particular the automotive industries [56]. the high strength-to-weight ratio of
aluminium MMCs makes it possible that the substitution of steel engine efficiency and a reduction in noise and friction.

MMCs containing hard particulates offer superior operating performance and resistance to wear. In industrial processes, elements fabricated from MMC materials give higher abrasive resistance and so a longer service life.

MMCs containing hard particulates offer superior operating performance and resistance to wear. In industrial processes, elements fabricated from MMC materials give higher abrasive resistance and so a longer service life. Al based discontinuously reinforced MMC is not as high as that of continuously reinforced composites, but the properties and cost of discontinuous MMCS make them useful as wear resistance materials [54].

2.12 Particulate Reinforced Metal Matrix composites:

Particulate reinforced aluminium alloy composites have shown a significant improvement in tribological properties including sliding and abrasion wear resistance, and seizure resistance [48, 55-58]. Thus, much research has been conducted on particulate metal matrix composites for tribological applications due to the advantages of MMCs such as good wear resistance, high load carrying capacity and light weight. Some studies show that these composites have potential for applications subjected to abrasive wear conditions. High wear resistance of particle reinforced MMCs is due to the ceramic particle content, which protects the metal matrix from wear. One of the major problems with the aluminium alloys that limit their tribological performance is their relatively poor seizure resistance in comparison to cast iron under dry sliding conditions [59].

The incorporation of ceramic materials in an alloy increases, its load carrying capacity and hence the load and sliding speed range within which dry sliding wear is mild [60, 61]. This has been investigated in detail by many researchers and opens new opportunities for the employment of Al-based metal matrix composites in applications where sliding resistance is of concern. The investigation of the wear behaviour of Al-MMCs against friction materials has received particular attention because of the possibility of using these materials for disc brakes in an automotive application. With respect to the conventional cast iron, Al-MMCs discs offers promising advantages, such as lower density and higher thermal conductivity.

Particulate reinforced aluminium alloy based composites have found commercial use in some areas and are rapidly becoming candidate structural materials for high temperature and aerospace applications [4, 62]. Relatively low ductility of most metal
matrix composites has restricted their use commercially. Considerable work has been carried out to investigate the ductility and behaviour of metal matrix composites at different temperatures under isothermal and thermal cycling conditions [63–71]. It is referred that under different thermal and loading conditions particulate reinforced composites exhibit super plastic behaviour [72–74]. With the simultaneous application of a small applied stress and thermal cycling, these composites undergo large percentages of plastic deformation, known as internal stress super-plasticity [75–82].

2.13 Aluminium Matrix Particulate Composites:

Alluminium based composites find extensive commercial applications in several sectors such as aerospace, space, automotive and structural applications [47, 2]. Although composites are widely accepted materials, they have certain limitations with regard to secondary forming process which do pose a real challenge to further widen the scope of applications of alluminium based composites. This limitation is mainly due to the anisotropic nature of the formed composites. Among all the alluminium alloys, Al6061 posses excellent formability in addition to high strength and good corrosion resistance. Hence it is the most sought after matrix alloy for alluminium based composites which needs secondary processing [66].

Al-alloy matrix composites (AMCs) containing hard dispersoids are gaining immense industrial importance because of their excellent combination of physical, mechanical and tribological properties over base alloys [83]. These include high wear and seizure resistance, high specific strength and stiffness, improved high temperature strength, controlled thermal expansion coefficient and high damping capacity [83–90]. This leads to the use of these composites in several automobile and engineering components where wear, tear and seizure are the major problems in addition to the weight saving. Some of these components are pistons, brake drums, cylinder heads, connecting rods and drive shafts for automobile sectors and impellers, agitators, turbine blade, valves, pump inlet, vortex finder for marine and mining sectors [92, 93]. In recent years, fabrication of several such components from AMCs, reached the commercial production stage [89–93, 43]. Most of the aforesaid components are subjected to different kinds of wear and tear related failure. In this context, it is required to characterize Al-composites in terms of wear under different experimental conditions.
2.14 Heat Treatment of Aluminium Alloy based MMCs:

Benal et al [94] have reported the effects of heat treatment on Al6061 based hybrid composites on the wear behaviour.

It is well known that the heat treatment is one of the important methods for improving the mechanical properties of aluminum alloys. The heat treatment of age hardenable aluminium alloys involves solutionizing the alloys, quenching, and then ageing at room temperature (natural ageing) or an elevated temperature (artificial ageing)[23]. Among all steps quenching is a crucial step to suppress the precipitation to retain the supersaturation of solid solution, control the distortion and minimize the residual stress in aluminium alloys. Quenching media commonly used for aluminium include brain solution, water polymer oil solutions and ice [95, 96].

2.15 Primary processing of AMCs:

Primary processes for manufacturing of AMCs on industrial scale can be classified into two main groups. (1) Solid state processes. (2) Liquid state processes. Powder blending followed by consolidation (PM processing), diffusion bonding and vapour deposition techniques come under solid state processing. Liquid state processes include stir casting or compo casting, infiltration, spray casting and in situ (reactive) processing. The selection of the processing route depends on many factors including type and the level of reinforcement loading and the degree of microstructural integrity desired. It is evident that very often it is possible to manufacture AMC of specific formulation (having the same matrix and reinforcement combination) by more than one route.
2.15.1 Solid state processing:

2.15.1.1 Powder metallurgy.

Early attempts to manufacture particle reinforced MMCs by incorporating ceramic particles into metallic melts had limited success because most metals do not wet ceramic particles. The powder metallurgy route was developed to overcome this difficulty. The main notable features of this method are that [97].

Fig. 2.1: Powder Metallurgy Route

1. High volume fractions of reinforcement can be used, thereby maximizing the modulus and minimizing the coefficient of the thermal expansion.
2. Practically any metal alloy can be used as the matrix.
3. Any type of reinforcement is allowed since reaction between the matrix and reinforcement can be reduced by using solid state processing.
In the powder metallurgy process, the matrix alloy powder is blended with the reinforcing particles to achieve a homogeneous mixture. The blending can be carried out dry or in liquid suspension. To achieve homogeneity, the sizes of the metal powders and the ceramic particles need to be carefully chosen so that agglomerates are not left after blending. The appropriate size ratio will depend on the blending process used. Lewandowski et al [98] have reported that a SiC/Al particle size ratio of 0.7:1 gives more uniform reinforcement distribution than the ratio of 0.3:1. Typically the atomized metal powered is in the size range of 20-40μm and the reinforcing particle are 3-20μm with aspect ratio <5:1. Cold isostatic, compaction, canning, degassing and a high temperature consolidation operation (e.g. hot isostatic pressing (HIP) usually follow the blending operation. The final rough product is obtained by extrusion with an extrusion ratio of about 20:1 or higher [97]. A high extrusion ratio is required to disrupt the oxide film between matrix powder particles allowing metal-to-metal contact thereby developing a good bond between matrix particles. A higher extrusion ratio also improves the distribution of reinforcement because the plastic flow associated with extrusion tends to disperse any clusters of reinforcing particles.

The powder metallurgy technique has some shortcoming. One of the main disadvantages of this approach is that the material handling procedures are cumbersome and the fabrication route is relatively complex. Hence, the product is expensive relative to wrought products prepared via conventional casting routes. The brittle ceramic particles are susceptible to particle fracture during powder blending and this may lead to less interfacial contact between the reinforcing particles and the matrix [99]. Detailed discussions concerning the various producers involved in the manufacture of powder metallurgy MMCs are given elsewhere [99, 100].

The powder process for MMCs is more economical than many other fabrication techniques and several advantages such as:

1. A lower temperature can be used during preparation of a powder metallurgy based composite compared to preparation of a fusion metallurgy based composite. This results in less interaction between the matrix and the reinforcement, consequently minimizing undesirable interfacial reactions, which leads to improved mechanical properties.

2. The preparation of particulate or whisker reinforced composites is easier using the powder metallurgy blending technique than the casting technique.
2.15.1.2 Diffusion Bonding of Foils.

Monofilament reinforced MMCs are mainly produced by the foil-fiber-foil (diffusion bonding) route or by the evaporation of relatively thick layers of matrix material onto the surface of the fiber. Work in this area is very much oriented towards titanium and titanium based matrices [101]. Fortunately, titanium diffusion bonds to itself readily, mainly because it dissolves its own surface oxide layer at elevated temperature in controlled atmosphere. Titanium reinforced with long fibers is commercially produced by the placement of arrays of fibers between thin metallic foils, often involving a filament winding operation, followed by hot pressing [102]. One of the main problems lies in avoiding excessive chemical reaction at the fiber/metal interface. Additions of Al, Mo or V slow the kinetics of interfacial reaction, but also tend to make the rolling of thin foil more difficult. There is interest in fiber coatings designed to reduce these problems of interfacial attack [103]. In general, the foil- fiber- foil route is cumbersome and is difficult to obtain high fiber volume fractions and homogeneous fiber distributions. Also, the process becomes difficult when the objective is to produce parts of complex shape. Diffusion bonding has also been used to fabricate laminates composed of alternate layers of metal and ceramic [104].

2.15.2 Liquid state processing

2.15.2.1 Stir casting:

This involves incorporation of ceramic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller.
Lloyd reports that vortex-mixing technique for the preparation of ceramic particle dispersed aluminium matrix composites was originally developed by Surappa & Rohatgi at the Indian Institute of Science. Subsequently several aluminium companies further refined and modified the process which are currently employed to manufacture a variety of AMCs on commercial scale. Microstructural inhomogeneties can cause notably particle agglomeration and sedimentation in the melt and subsequently during solidification. Inhomogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification [105]. Generally it is possible to incorporate upto 30% ceramic particles in the size range 5 to 100 μm in a variety of molten aluminium alloys. The melt–ceramic particle slurry may be transferred directly to a shaped mould prior to complete solidification or it may be allowed to solidify in billet or rod shape so that it can be reheated to the slurry form for further processing by technique such as die casting, and investment casting. The process is not suitable for the
incorporation of sub-micron size ceramic particles or whiskers. Another variant of stir casting process is compo-casting. Here, ceramic particles are incorporated into the alloy in the semi solid state.

2.15.2.2 Compo-casting:

The casting of a mixture prepared by stir mixing a liquid metal with solid ceramic particles is referred to as compo-casting. It is the simplest and most economically attractive method of manufacturing MMCs. In this method, liquid alloy at a temperature of 30 to 50°C above the liquidus is agitated vigorously and allowed to cool slowly to the semisolid range. As the agitation continues, the reinforcing ceramic particles are added to the slurry. In principle, this can be done using fairly conventional processing equipment and can be carried out on a continuous or semi-continuous basis. The composite mixture (with a relatively low viscosity) can be cast directly into a simple billet. Alternatively, if the semisolid composite slurry is reheated just above the liquidus and die-cast into net shape components, the process is called compocasting. The reheating is needed to reduce the viscosity so as to allow the composite slurry to flow into complex die moulds.
Compocasting is now in commercial use for producing Al-SiC_p composites [105]. One notable disadvantage of this method is that stir casting involves prolonged liquid/ceramic contact and this can cause excessive interfacial reaction [105, 106]. Another difficulty encountered with compocasting and rheocasting is microstructural inhomogeneity that could be caused by either agglomeration or sedimentation in the melt, gas bubble entrapment, porosity from inadequate liquid feeding during casting or particle segregation.

2.15.2.3 Spray co-deposition method:

Fig.2.3 shows the schematic diagram of spray deposition method of manufacturing of MMCs. The spray forming process was originally developed by Singer [101] for unreinforced alloys and was put into commercial use by Osprey Metals [102]. It is being used to manufacture MMC’s in the basic form of spray, a molten stream of metal is disintegrated by impingement with a high pressure inert gas jet to form an atomized spray of droplets and the droplet spray is then propelled away from the atomization zone by fast flowing gas to deposit on a collector plate interspersed in the spray plume. Synchronous scanning and withdrawal of the collector plate relative to the molten metal stream can be used to manufacture cylindrical, tubular, and slab shaped billets of spray formed material.

The potential for adopting the spray forming procedure for manufacturing particle-reinforced MMC’s was recognized at an early stage and has been developed by a number of metal producers. This is achieved by injecting ceramic particles into the spray (a variant of co-deposition process) as shown in Fig.2.3. The deposition rate is in the range of 6-10kg/min [107].
The ceramic particles are usually injected into the gas stream rather than the melt stream, and do not normally become appreciably heated in flight. In principle, the ceramic content can be controlled by relative feed rates of melt and ceramic. However, in practice the overspray loss rate for ceramic gets higher as feed ratio is increased. Therefore, 20-25 vol. % of particles is the upper limit for successful reinforcement incorporation [108].

The notable advantages of the spray forming methods include, (i) the absence of organic binders, (ii) the short contact time between the reinforcement and the molten metal, (iii) the use of fewer processing steps than the powder metallurgy routes, (iv) the ability to make near-net shapes, (v) the low oxide contents and (vi) the wide choice of suitable alloy. The drawbacks include difficulties in obtaining homogeneous distribution of reinforcement and the presence of significant porosity levels. The cost of spray co-deposition is reported to be intermediate between powder metallurgy and casting techniques of producing MMCs [107].
2.15.2.4 Squeeze casting.

Squeeze casting is a one-step metal forming process in which a metered quantity of liquid metal in a reusable die is subjected to a rapid solidification under high pressures (50 to 100 MPa) to produce close-tolerance, high-integrity finished shapes. The fabrication process of MMC by squeeze casting is shown in Fig. 2.2. The preform of the ceramic fibre is pre-heated to several hundred degrees centigrade below the melting temperature of the matrix and then set into a metal die. Al or Mg alloy is heated to just above its melting temperature and is then squeezed into the fibre preform by a hydraulic press to form a mixture of fibre and molten metal.

This process can be used for large scale manufacturing but it requires careful control of the process variables, including the fiber and liquid metal preheat temperature, the metal alloying elements, external cooling, the melt quality, the tooling temperature, the time lag between die closure and pressurization, the pressure levels and duration and the plunger speed. Imperfect control of these process variables results in various defects, including freeze choking, preform deformation, fiber degradation, oxide inclusions and other common casting defects. However, in practical use, squeeze casting is the most effective method of constructing a machine parts with a complex shape in a short time.
2.16 Secondary Process:

The melt-stirring method to mix the reinforcements with the molten metal has the problems as follows; the homogeneous distribution of the reinforcements is disturbed due to the low wettability and the density difference between the molten metal and the reinforcement.

When the composites are fabricated by the melt-stirring and the squeeze casting, the bonding strength may be lowered by the porosity and the segregation at the interface between the matrix and the reinforcement. The secondary deformation processing as hot extrusion produces the more homogeneous distribution of particles and improves the mechanical properties. Therefore, in the particulate reinforced metal matrix composites, it is important to estimate quantitatively the improvement of the mechanical properties by the secondary process. Okumiya et al. [109] examined the alignment and length of fibers in $\text{Al}_2\text{O}_3$/Al composites during hot extrusion. Stanford-Beale et al. [110] have studied the high-temperature deformation of fiber re-reinforced aluminium during hot extrusion and compression. Inmai et al. studied the extrusion behaviour and the mechanical properties at high temperature for short alumina fiber reinforced aluminum alloy composites fabricated by squeeze casting [111]. The extrusion of particle-reinforced aluminium billets made by direct-chi (DC) casting was suggested by Brusethaug et al. [112]. Lieblich et al. have studied the extrusion of 2124 aluminium alloy powders reinforced with SiCp [113]. Some works on extruded particulate-SiC-reinforced 6061 alloy composites fabricated by melt-stirring and squeeze casting, have been published. Most of the earlier studies have treated only the secondary process, i.e., the extrusion of particle or short fiber-reinforced aluminium. No correlations between the primary and secondary processes have been reported.

The primary process was melt-stirring, followed by squeeze casting [114]. The secondary process was hot extrusion. Tensile tests and hardness tests were used for observation of the correlation between particle fracture, particle orientation, and mechanical properties. The tensile properties and microstructure of extruded specimens were compared with those of melt-stirred and squeeze-cast specimens.

2.16.1.1 Extrusion:

Extrusion is the process by which a block metal is reduced in cross section by forcing it to flow through a die or orifice under high pressure. In general, extrusion is used to produce cylindrical bars or hollow tubes, but shapes of irregular cross section may be produced from the more readily extrudable metals like aluminium. Because of the large forces required in extrusion, most metal are extruded hot, under the conditions where the metals have become an important commercial process. The reaction of the billet with the container and the die results in high compressive stresses, which are effective in reducing the cracking of materials during primary breakdown from the ingot. This is an important reason for the increased utilization of extrusion in the working of metals difficult to form, like stainless, nickel based alloys and other high temperature materials.

Aluminium and its alloys are the most commonly extruded materials. Most of the commercially available aluminium alloys can be extruded. Principle application includes parts for the aircraft and aerospace industries, pipes, wire, rods, tubes, hollow shapes, cable sheathing, architectural and structural sections, and automotive parts. Sections cannot be extruded from heat treatable high strength aluminium alloys [115]

2.16.1.1.1 Direct extrusion

To prevent bulging and / or buckling, and thus to overcome the reduction limitations in open die extrusion, direct extrusion is used. This is the simplest form of extrusion as shown in Fig. 2.8(b). Here, a billet is placed in a chamber which has an opening on one end. This opening is known as the die. As the ram or mandrel advances
through the chamber, the billet is pushed ahead of it to escape plastically through the die. Many shapes can be extruded, depending upon the shape of the opening.

Since the billet is confined by the walls of the chamber, these walls are subject to high pressures. The amount of reduction is no longer restricted by the tendency of the work piece to bulge or buckle, but only by the force that can be applied to it and by the strength of the confining chamber and the other components of the equipment.

2.16.1.1.2 Indirect extrusion

In indirect extrusion as shown in Fig. 2.8 (c) the billet moves forward in the chamber as a rigid body, travelling at the same speed as the ram. The longer the billet the more pronounced will be the friction between chamber and billet, and the higher will be the extrusion force. To reduce the power loss due to friction, the process of indirect extrusion has been devised.

2.16.1.2 Rolling:

![Figure 2.7: Schematic diagram of the rolling process](image)

Rolling is a process where the metal is compressed between two rotating rolls for reducing its cross sectional area. This is one of the most widely used of all the metal working processes, because of its higher productivity and low cost. Rolling is normally a hot working process unless specifically mentioned as cold rolling. The metal is taken into rolls by friction and subsequently compressed to obtain the final shape. The reduction that could be achieved with a given set of rolls is designated as the angle of bite and is shown in Fig. 2.9.
2.16.1.3 Forging:

Forging or cold forming are metal forming processes. There is no melting and consequent solidification involved. Plastic deformation produces an increase in the number of dislocations resulting in a higher state of internal stress.

![Figure 2.7: Spanners produced through three different methods.](image)

Indeed, strain hardening is attributed to the interaction of dislocations with other dislocations and other barriers (such as grain boundaries). Simultaneously, the shape of primary crystals (dendrites) changes after plastic working of the metal. Dendrites are stretched in the direction of metal flow and thus form fibers of increased strength along the direction of flow. We may distinguish hot working from cold working. Hot working is performed above the recrystallization temperature; cold-working is performed below it. In hot working strain hardening and distorted grain structure are very rapidly eliminated by the formation of new strain-free grains as the result of recrystallization. Rapid diffusion at hot working temperatures aids in homogenizing the preform. Initial porosity can also be significantly reduced, eventually completely healed. Metallurgical phenomena such as strain hardening and recrystallization are important because these changes in structure result in an increase in ductility and toughness over the cast state.

2.16.1.3.1 Advantages of Forging

- **Directional Strength**: Controlling deformation during the forging process results in improved metallurgical properties. The forging process produces directional alignment (grain flow) for important directional properties of strength, ductility, and resistance to impact and fatigue.
❖ **Impact Strength:** Through proper grain flow orientation, the forging process can develop the maximum impact strength and fatigue resistance possible in a metal.

❖ **Structural Integrity:** As is well known a forging’s structural reliability is excelled by no other metalworking process. There are no internal gas pockets or voids that may cause unexpected failure under conditions of high stress or impact. This means more realistic safety factors based on material that will respond predictably to its environment without costly special processing to correct internal defects.

❖ **Size Range:** Forged parts are economically produced in a broad range of sizes and shapes.

❖ **Uniformity:** The consistency of material and dimensions from one forged part to the next, and from separate production lots of forgings produced months or years apart, is extremely high. Forgings are made through a carefully controlled sequence of production steps, in contrast to a random flow of material into the desired shapes. Uniformity in composition and structure, piece to piece, insures reproducible response to heat treatment, minimum variation in machinability, and consistent property levels of finished parts.

❖ **Strength-To-Weight Ratio:** The higher strength-to-weight ratio can be used to reduce section thickness in part design.

❖ **Compatibility:** Forging components have superior response to all forms of heat treatment. Due to the near absence of structural defects, forgings offer the best opportunity for strong, efficient welds. Due to the lack of internal discontinuities and surface inclusions, forgings provide a dependable machining micro-structure for most metal-cutting processes. Forged parts can be readily fabricated by welding, bolting, or riveting, and are suited for most surface conditioning. A forging can also be designed to eliminate multiple assembly components.

❖ **Economic Advantages:** Forging’s superior functional advantages of strength, fatigue resistance, reliability, and high quality combine into economic benefits. Uniform dimensional relationships result in consistent machinability and predictable response to heat treatment. This, combined with obvious strength-to-weight ratios, make forgings a top priority of the cost-conscious user.
2.17 Mechanical Properties.

2.17.1 Hardness:

Hardness is the resistance of metal to plastic deformation, usually by indentation. However, the term may also be referred to resistance to scratching, abrasion or cutting. In general, addition of hard reinforcement in the matrix alloy results in improved hardness of the composites. However, presence of soft reinforcement in the matrix alloy reduces the hardness of the obtained composites. The type and extent of incorporation of the reinforcement has a profound influence on the hardness of the composite [116].

Ramesh et al. have reported that the addition of SiC to copper enhances the hardness of the composites, as it is a very hard phase. Further, increased content of SiC has resulted in increased hardness of the copper composites [117]. Ramesh et al. have reported that, in cast and extruded conditions, the microhardness of Al6061 composites increases with increased content of the reinforcement. However, for a given reinforcement, extruded composites possess higher microhardness when compared with the cast ones [118]. Ramesh et al., have reported that the increased content of TiO₂ in Al6061 enhances the hardness of composites. Ramesh et al., have studied the Wear and corrosion behavior of Al6061- TiO₂ composites. An increase in solutionising time increases the hardness of the composites [119].

2.17.2 Strength:

The attractive physical and mechanical properties that can be obtained with metal matrix composites, such as high specific modulus, strength and thermal stability, have been documented extensively [120, 121]. The various factors controlling the properties of particulate MMCs [50] and the influence of the manufacturing route on the MMC properties has also been reviewed by several investigators [122-124]. Improvement in modulus, strength, fatigue, creep and wear resistance has already been demonstrated for a variety of reinforcements [125, 126]. Of these properties, the tensile strength is the most convenient and widely quoted measurement and is of central importance in many applications. It is apparent from the literature that parameters controlling the mechanical properties of particulate reinforced composites are still not understood in any detail. However, some of the important factors are.
The strength of particle-reinforced composites is observed to be most strongly dependent on the volume fraction and particle size of the reinforcement. The greatest concern appears to be the introduction of defects and inhomogeneities in the various processing stages, which has been found to result in considerable scatter in the mechanical properties. The application of the forging process gave rise to an increase in yield and ultimate strength at room and high temperature. A similar behaviour was reported for similar composites after forging, hot extrusion and hot rolling and the improvement in the material strength was explained with the effect of declustering of particles induced by the plastic deformation.

Umit CO cenen et al. [32] have reported that, the yield strength and tensile strength of the composites increase with the volume fraction SiCp up to 17vol.% and then decrease with further additions of reinforcement. With the application of extrusion, the yield strength and the tensile strength values are improved by approximately 40%. In the extruded samples the yield and tensile strength increases continuously with the volume fraction of reinforcement.

The behaviour of the extruded composites is not in agreement with the previous observations by Ozdemir et al. [31] in the as forged composite specimens of corresponding compositions. In their work they found that, the application of hot forging process gave rise to a substantial increase in yield strength, which reached a maximum value in the specimens with 13–17 vol.% SiCp, and then decreased slightly with further additions of reinforcement. A similar observation was reported by Tan et al. [33], who investigated the behaviour of powder processed and extruded Al−Li alloy based SiCp reinforced composites and found that the addition of over 20 wt.% reinforcement caused a substantial decrease in yield strength and ductility. In addition, Davies et al. [34] have reported that in advanced 7000 series Al alloy based SiCp reinforced composites, the yield and tensile strength values exhibited an increase with the addition of up to 10 and 20 vol.% SiCp, in the peak aged condition and in the overaged condition, respectively. After the addition of reinforcement exceeding these volume fraction values, the yield strength and tensile strength started decreasing significantly. Zhong et al. [35] have reported that Al−Mg (5083) alloy based SiCp reinforced composites the addition of the oxidised SiCp decreases the strength as a result of some interfacial reactions in which MgO layers form at the particle−matrix interfaces at the expense of Mg in matrix.
2.18 Tribological Properties:

Wear may be defined as the progressive loss of substance from the operating surface of a body occurring as a result of relative motion of the surface with respect to another body. The concept embraces metal-to-metal, metal to other solids and metal to fluid contact and the definition clearly associates the process with the surface of materials. The rate at which the material removed depends upon working conditions. Eg. loading, lubrication and environment.

Anwar Khan et al [136] have reported the adhesion wear for Al6061-10wt % SiCp using pin-on-disc machine. For both the matrix alloy and the cast composites the wear loss increased with increase in time. The composites exhibited higher wear resistance than the matrix alloy. The wear rate of composite increases with increase in load. Ramesh, Keshavamurthy .et.al [137] have studied the Friction and Wear behaviour of Ni-P coated Si₃N₄ reinforced Al6061 composites they have stated that the co efficient friction of composites reduces with increased content of Ni-P coated silicon nitride particles. Ramesh et.al. [138] have studied the Prediction of Wear coefficient of Al6061 – TiO₂ composites and reported that, at all the sliding distances studied, the volumetric wear loss of the composites were much lower than when compared with the matrix alloy and reduced with increased content of TiO₂ in the composites. Kasim et.al. [139] have reported that, the abrasion resistance of the composites increased with increasing the volume fraction of SiCp. Lee et al. [140] have investigated the effect of porosity, volume fraction and size of silicon carbide particles on the abrasion resistance of powder metallurgy aluminium alloy 6061 matrix composites. They have found that the abrasion resistance of the aluminium alloy decreased drastically with increasing porosity. However, for the composites, the porosity effect was less significant. They also found that the abrasion resistance of the composites increased as the amount of SiC increased. Also for the composites containing the same amount of SiC reinforcements, the abrasion resistance increased by increasing the size of SiC particles. Axen et al. [141] have studied the abrasion resistance of alumina fiber reinforced aluminium using a pin-on-drum abrasion wear tester. The composites were manufactured by a hot liquid infiltration technique. They concluded that fiber reinforcement significantly improved the abrasion resistance in milder abrasive situations,
Sliding wear behaviour of AMCs have been studied by many investigators [45, 142–145]. However, limited attempts have been made to study the abrasive wear characteristics of Al based composites [145–149]. According to these reports, wear and seizure resistance of AMCs is considerably higher than that of the base alloys. On the other hand, few investigators have reported a transition of abrasive wear behaviour of composites which was dependent on abrasive size and applied load [147, 149,151,155]. According to these investigators, above a critical value of load and abrasive size, AMCs exhibit higher wear rate than the alloys [151–159,2]. Under such circumstances, the depth and width of wear track become larger than the size of dispersoid. This leads to the scooping off of the dispersoid from the surface of the composites samples [147,149,151]. Furthermore, it is evident from the literature that the wearing surface and the subsurface undergo plastic deformation, and this deformation becomes more severe when the abrasive size is coarser and the applied load is higher [148, 150]. As a result of such plastic deformation, the hard ceramic dispersoid gets fractured and fragmented into finer ones, and/or debonded from the matrix [151–155,150]. In due course, these fragmented particles come out from the specimen surface. Thus the abrasive wear behaviour of composite depends on the material characteristics like shape, size, distribution and volume fraction of the dispersoids and experimental parameters like applied load and abrasive size [150,155-157]. It has been reported that the wear resistance of composite increases with increase in volume fraction and size of the dispersoids [151,140]. One of the prime factors that contribute to the improvement in wear resistance is increased in hardness of the Al-alloy due to the addition of hard dispersoids [150-157] and more protection of the matrix from the destructive action of the abrasive as the mean free path between the SiC particles is reduced with increase in volume fraction of SiC particle [2]. Several investigators have also proposed that wear resistance of a material not only depends on its hardness and strength but also on its ductility and toughness [158, 159]. The Al₂O₃ particle of size 16μm strengthens the aluminum matrix and enhances the wear resistance. However, coarse particles of 66μm of Al₂O₃ shows higher wear loss. The operating wear mechanism is mainly plastic deformation of the matrix material [160]. The hardness as well as toughness of a composite material depends significantly on the matrix microstructure, size and distribution of the dispersoids and the interfacial bonding characteristics [2]. The hardness of the composite increases with increase in the volume fraction of the dispersoid but at the same time its toughness decreases. Additionally, the casting defects may increase or the possibility of clustering of dispersoid particle may be more as one increases the dispersoid content. These may reduce the wear resistance of the
composite [156]. Thus the overall improvement in wear resistance of the alloy, due to addition of more dispersoid may not be so high especially at severe wearing conditions (i.e., at higher applied load and coarser abrasive size). The mechanical and tribological properties of the composite also depend upon the matrix microstructure; hence, the properties of composite can be improved by heat treatment. Attempts have been made to improve strength, hardness and toughness of Al–Si alloy and Al–Si alloy reinforced with hard particle composites by altering the matrix microstructure through heat treatment. Studies on sliding wear characteristics reported that the wear and seizure resistance of the alloy or composite are improved by heat treatment [161, 162].

2.19 Corrosion:

Corrosion is the deterioration of materials by chemical interaction with their environment. The term corrosion is sometimes also applied to the degradation of plastics, concrete and wood, but generally refers to metals.

2.19.1 The Consequences of Corrosion:

The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than the simple loss of a mass of metal. Failures of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small. Some of the major harmful effects of corrosion can be summarised as follows:

1. Reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown. When the metal is lost in localised zones so as to give a crack like structure, very considerable weakening may result from quite a small amount of metal loss.

2. Hazards or injuries to people arising from structural failure or breakdown (e.g. bridges, cars, aircraft).

3. Loss of time in availability of profile-making industrial equipment.

4. Reduced value of goods due to deterioration of appearance.

5. Contamination of fluids in vessels and pipes (e.g. beer goes cloudy when small quantities of heavy metals are released by corrosion).

6. Perforation of vessels and pipes allowing escape of their contents and possible harm to the surroundings. For example a leaky domestic radiator can cause expensive damage to carpets and decorations, while corrosive sea water may enter the boilers of a power station if the condenser tubes perforate.
7. Loss of technically important surface properties of a metallic component. These could include frictional and bearing properties, ease of fluid flow over a pipe surface, electrical conductivity of contacts, surface reflectivity or heat transfer across a surface. Mechanical damage to valves, pumps, etc, or blockage of pipes by solid corrosion products.

8. Added complexity and expense of equipment which needs to be designed to withstand a certain amount of corrosion, and to allow corroded components to be conveniently replaced.

2.19.2. Forms of Corrosion:

Almost all corrosion problems and failures encountered in service can be associated with one or more of the eight basic forms of corrosion: general corrosion, galvanic corrosion, concentration-cell (crevice) corrosion, pitting corrosion, intergranular corrosion, stress corrosion cracking, dealloying, and erosion corrosion.

2.19.2.1 General Corrosion.

The general corrosion behaviour of aluminum alloys depends basically on three factors: (1) the stability of the oxide film, (2) the environment, and (3) the alloying elements; these factors are not independent of one another. The oxide film is considered stable between pH 4.5 and 9.0; however, aluminum can be attacked by certain anions and cations in neutral solutions, and it is resistant to some acids and alkalies. In general, aluminum alloys have good corrosion resistance in the following environments: atmosphere, most fresh waters, seawater, most soils, most foods, and many chemicals. Since "good corrosion resistance" is intended to mean that the material will give long service life without surface protection, in support of this rating is the following list of established applications of aluminum in various environments:

- In Atmosphere: Roofing and siding, truck and aircraft skin, architectural. With Most Fresh Waters. Storage tanks, pipelines, heat exchangers, pleasure boats.
- In Seawater: Ship hulls and superstructures, buoys, pipelines.

It is generally true that the higher the aluminum purity, the greater is its corrosion resistance. However, certain elements can be alloyed with aluminum without reducing its corrosion resistance and in some cases an improvement actually results. Those elements having little or no effect include Mn, Mg, Zn, Si, Sb, Bi, Pb, Ti; those having a detrimental effect include Cu, Fe, Ni. Al-Mn Alloys. Al-Mn alloys (3xxx series) have
good corrosion resistance and may possibly be better than 1100 alloy in marine environments and for cooking utensils because of reduced effect by Fe in these alloys. Al-Mg alloys (5xxx series) are as corrosion resistant as lxxx alloys and even more resistant to salt water and some alkaline solutions. In general, they offer the best combination of strength and corrosion resistance of all aluminum alloys.

Al-Mg-Si alloys (6xxx series) have good resistance to atmosphere corrosion, but generally slightly lower resistance than Al-Mg alloys. They can be used unprotected in most atmospheres and waters.