CHAPTER 1

INTRODUCTION

1.1 SIGNIFICANCES OF COMPOSITE MATERIALS

For the last few decades, the development of materials shifted from monolithic alloy to composite materials to meet the global industrial needs. Conventional monolithic materials have limitations to achieve good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever increasing demand of modern day technology, composites are the most promising materials of recent interest, and continuous advancements have led to the use of composite materials in more and more diversified applications such as aerospace, defense, automobile, biomaterials as well as sports components. The scope of applications of composites being unlimited, these materials will dominate the materials field for a very long period in the years to come (Surappa 2003).

Composites can be tailor made to possess high strength, high toughness light weight, low cost, good damping capacity, wear resistance, corrosion resistance, hardness, conductivity, creep strength, fatigue strength, negative thermal expansion coefficient and unusual combinations of electric, magnetic, and optical properties. The examples of naturally occurring composites are shell, wood, bone, and teeth.

Composite materials are engineered materials made from two or more constituents material with significantly different physical and chemical properties which remain separate and distinct on a macroscopic level with the
finished structure. Using this definition, any two-phase (continuous and discontinuous phase) material can be considered as composite. 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’.

The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector, due to the sheer size of transportation industry (Huda et al 1993). Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years.

While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry.

1.2 CLASSIFICATION OF COMPOSITE MATERIALS

Based on the type of the matrix used, composite can be classified as (Huda et al 1993)

1. Polymer Matrix Composites (PMC)
2. Metal Matrix Composites (MMC)
3. Ceramic Matrix Composite (CMC)

1.2.1 Polymer Matrix Composites (PMC)

Polymer matrix composites have the advantage of easy fabrication, low cost, low density, good corrosion resistances, chemical inertness, aesthetic colour effects and variety of fabrication techniques available with
respect to the part geometry. However, the most advanced resin cannot be used above 300°C for prolonged period. The low transverse strength and operational temperature limits the applications of PMC in mechanical parts.

1.2.2 Metal Matrix Composites (MMC)

Metal matrix composites possess some attractive properties, when compared with organic matrices. These include (i) strength retention at higher temperatures, (ii) higher transverse strength, (iii) better electrical conductivity, (iv) superior thermal conductivity, (v) higher erosion resistance etc. Metal matrix composite can also be used at higher temperature ranges of about 1000°C as in the case of fiber reinforced super alloy. However, the major disadvantage of metal matrix composites is their higher density and consequently lower specific mechanical properties compared to polymer matrix composites.

1.2.3 Ceramic Matrix Composite (CMC)

Ceramic composites have the advantage over metal matrix composites at even higher temperature because of their lower chemical reactivity and greater oxidation reaction resistance and also where environment attack is an issue. However, their main disadvantages are:

1. Low strain to failure, which limit the stress in the fiber at low levels.
2. Poor in tension and shear applications.
3. Relatively high modulus and lack of ductility, which prevents accommodation of thermal stresses from, any mismatch in thermal expansion.
1.3 METAL MATRIX COMPOSITES (MMC)

Metal matrix composites in general, consist of two or more chemically distinct macroconstituents, separated by distinct interface. One obviously the primary phase is the metal matrix and the second component is the reinforcement. In the production of the composites, the matrix and the reinforcement are mixed together. This is to distinguish a composite from a two phase alloy where the second phase forms as a particulate, eutectic or eutectoid reaction, etc., in other words a composite initially begins as separate components, i.e., the metal matrix and the reinforcement. In recent years, the development of metal matrix composite has been receiving worldwide attention on account of their superior strength and stiffness in addition to high wear resistance and creep resistance comparison to their corresponding wrought alloys.

The properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. 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.

1.3.1 Classification of the Metal Matrix Composites

The Metal Matrix Composites (MMCs) may be classified in many ways, depending on the concept of interest. One useful classification system is based on micro structural aspects, differentiating between composite materials according to the morphology of the constituent phase (Srivatsan et al 1995).
Using this system composite materials fall into following categories:

1. Dispersion strengthened composites.
2. Particle strengthened composites.
3. Fiber reinforced composites.

1.3.1.1 Dispersion strengthened composites

This composite is characterized by a microstructure consisting of an element matrix within which fine particles are uniformly dispersed. The particle diameter ranges from 0.01 to 0.1 μm and the volume fraction of particle ranges from 1 to 15%.

1.3.1.2 Particle strengthened composites

As the name indicates, the reinforcement is of particle nature. It may be spherical, cubic, tetragonal, a platelet, or of other regular or irregular shape. Particulates are the most common and cheapest reinforcement materials. Particle-reinforced composites have hard particles surrounded by a softer matrix. The particles in these composites are larger than in dispersion-strengthened composites. This composite is characterized by dispersed particles of greater than one-micron diameter with a volume fraction of 5 to 40%. In general, particles are not very effective in improving fracture resistance but they enhance the stiffness of the composite to a limited extent. Particles are widely used to improve the properties of matrix materials. The commonly used particles are SiC, SiO₂, MgO₂, Si₃N₄, TiC, BN, Mica, ZrO₂, B₄C, TiO₂, Al₂O₃, Zircon, Garnet and Glass.
1.3.1.3 **Fiber reinforced composites**

In fiber reinforced composites, fibers are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibers, and protects them from environmental damages due to elevated temperature, humidity and corrosion.

The reinforcing phase in fiber composite materials: (a) spans the entire size range, from a fraction of a μm to several mm in diameter, (b) spans the length from mm to continuous fibers and (c) spans an entire range of volume concentration, from a few percent to greater than 80%. The fiber spans the entire size range, from 0.1 to 250 μm and spans entire range of volume concentrations from few percent to greater than 90%. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. The most important fibers used in metal matrix composites are alumina, boron, carbon, silicon carbide, boron carbide, silica, zirconia, magnesia, alumina-boria-silica, silicon nitride, mullite, boron nitride and titanium diboride.

1.4 **SIGNIFICANCE OF ALUMINIUM METAL MATRIX COMPOSITES**

Composite materials consist of matrix and reinforcement. The main function of matrix is to transfer and distribute the load to the reinforcement or fibers. This transfer of load depends on the bonding which depends on the type of matrix and reinforcement and the fabrication technique. The matrix can be selected on the basis of oxidation and corrosion resistance or other properties (Taya and Arsenault 1989). Generally Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn and Si are used as the matrix material, but Al, Ti, Mg are used widely.
Nowadays the main focus is given to aluminium matrix because of its unique combination of good corrosion resistance, low density and excellent mechanical properties (Huda et al, 1994). Aluminium Matrix Composites (AMC) are usually reinforced by aluminium oxide (Al₂O₃), Silicon Carbide (SiC) and Carbon (C). The reinforcements are in the form of flakes, particulates and fibers. Aluminium matrices are in general Al-Si, Al-Cu, 2xxx, 6xxx, 7xxx alloys.

The major advantages of AMC compared to unreinforced materials are as follows

- Greater strength
- Improved stiffness
- Reduced density (weight)
- Improved high temperature properties
- Controlled thermal expansion coefficient
- Improved abrasion and wear resistance
- Improved damping capabilities

These advantages can be quantified for better appreciation. For example, elastic modulus of pure aluminium can be enhanced from 70 GPa to 240 GPa by reinforcing with 60 vol % continuous aluminium fiber. On the other hand incorporation of 60 vol % alumina fibers in aluminium leads to decrease in coefficient of thermal expansion 60% approximately. Similarly it is possible to process Al-9%Si-20 vol% SiC_p composites having wear resistance equivalent or better than of gray cast iron (Surappa 2003).
The primary disadvantages of all aluminium MMC is, they suffer from low ductility, inadequate fracture toughness and inferior fatigue crack growth and fracture resistance compared to that of the constituent matrix material.

1.5 SIGNIFICANCE OF REINFORCMENTS

The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. Reinforcement increases the strength, stiffness and the temperature resistance capacity and lowers the density of MMC. In order to achieve these properties the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix and the following aspects must be considered while selecting the reinforcement material.

- Size – diameter and aspect ratio
- Shape – Chopped fiber, whisker, spherical or irregular particulate, flake, etc
- Surface morphology – smooth or corrugated and rough
- Crystal – Poly or single crystal
- Structural defects – voids, etc
- Surface chemistry – e.g. SiO$_2$ or C on SiC or other residual films
- Impurities – Si, Na and Ca in sapphire reinforcement
- Inherent properties – strength, modulus and density

The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques. Continuous
reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. Discontinuous reinforcement uses "whiskers", short fibers, or particles. Nowadays various kinds of ceramic particles (Oxide, Carbide, and Nitride) are used as reinforcement (Plazanet et al 1998). Silicon Carbide (SiC) particles reinforced aluminium matrix composite have a good potential for use as wear resistant materials. The particles lead to favourable effects on properties such as hardness, wear resistance and compressive strength. Fibers are expected to effect better improvements in rigidity and tensile strength (Franck et al 1987). Silicon Carbide has advantages over other reinforcement such as thermal conductivity, density, corrosion resistance, machinability and workability of the aluminum alloy-silicon carbide composites (Srivatsan et al 1995). The other particles (Krystyna Imielińska and Yann le Petitcorps 2003) used as the reinforcement in aluminium alloy are graphite, SiO₂, MgO, Si₃N₄, TiC, BN, Mica, ZrO₂, Zircon, Garnet, B₄C, TiO₂, Al₂O₃ and Glass.

1.6 PROCESSING OF METAL MATRIX COMPOSITES (MMCₛ)

The evolution of different metal matrix composites systems has led to the development of newer processing techniques, in addition to conventional metal processing techniques. The major criteria for the selection of a process rely on the type of composite system to be fabricated, the properties to be achieved and the component to be produced.

The processing methods are widely classified into primary and secondary processes. The primary process combines matrix and reinforcements to produce the basic composite systems and their structures.
The major primary liquid state processes are stir casting or vortex method, infiltration, squeeze casting, compo casting, and spray deposition processes and solid state processes are powder metallurgy and diffusion bonding. The secondary process involves processing of primary processed composites with the objective of improving their mechanical properties by further consolidation (reduction or elimination of porosity), break up of dispersed agglomerates, improved interfacial bonding, generating dispersed alignment and/or forming into a required shape to obtain semi finished products. The most commonly used secondary processes for MMCs are extrusion, rolling, forging, superplastic deformation, machining and joining. The primary and secondary processes for producing metal matrix composites are listed in Figure 1.1.

Figure 1.1 Flow chart of MMC processing routes (Surappa 2003)
1.6.1 Primary Liquid State Processes

Most of the MMCs are produced by this technique. In this technique, the ceramic particles are incorporated into liquid metal using various processes. The liquid composite slurry is subsequently cast into various shapes by conventional casting techniques or cast into ingots for secondary processing. The process has major advantage that the production costs of MMCs are very low. The major difficulty in such processes is the non-wettability of the particles by liquid aluminium and the consequent rejection of the particles from the melt, non-uniform distribution of particles due to their preferential segregation and extensive interfacial reaction. The liquid state process includes liquid metal infiltration, squeeze casting process, spray deposition method, stir casting process and compo casting process. A comparative evaluation of all the liquid state processing method is listed in Table 1.1.

### Table 1.1 A comparative evaluation of the different technique for Discontinuously Reinforced Metal Matrix Composite (DRMMC) fabrication (Hashim et al 1999)

<table>
<thead>
<tr>
<th>Method</th>
<th>Range of shape and size</th>
<th>Metal yield</th>
<th>Range of volume fraction</th>
<th>Damage to reinforcement</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid metallurgy (Stir casting)</td>
<td>Wide range of shapes, larger size up to 500 kg</td>
<td>Very high&gt;90%</td>
<td>Up to 0.3</td>
<td>No damage</td>
<td>Least expensive</td>
</tr>
<tr>
<td>Squeeze casting</td>
<td>Limited by preform shape, up to 2 cm height</td>
<td>Low</td>
<td>Up to 0.45</td>
<td>Severe damage</td>
<td>Moderately expensive</td>
</tr>
<tr>
<td>Powder metallurgy</td>
<td>Wide range restricted size</td>
<td>High</td>
<td>-</td>
<td>Reinforcement fracture</td>
<td>Expensive</td>
</tr>
<tr>
<td>Spray casting</td>
<td>Limited shape, large size</td>
<td>Medium</td>
<td>0.3-0.7</td>
<td>-</td>
<td>Expensive</td>
</tr>
</tbody>
</table>
1.6.2 Solid Phase Fabrication Methods

There are several ways to fabricate MMC using solid-phase materials but among them diffusion bonding and the powder metallurgy route are used widely. The powder metallurgy (PM) route is the most commonly used solid state processing method for the preparation of discontinuous reinforced MMCs (Kelly 1985). Several companies are using this technique to manufacture MMC using either particulates or whiskers as the reinforcement materials. In this process powders of matrix materials and reinforcement are first blended and fed into a mould of the desired shape and then pressure is applied to further compact the powder (cold pressing). In order to facilitate the bonding between the powder particles, the compact is then heated to a temperature below this melting point but sufficiently high to develop significant solid state diffusion (sintering). Alternatively, after blending the mixture can be pressed directly by hot pressing, however Hot Isostatic Pressing (HIP) is helpful for securing high-density material. The consolidated product is then used as a MMC material after some secondary operation (Kaczmara et al 2000).

1.7 SIGNIFICANCE OF HEAT TREATMENT

Heat treating refers to any of the heating and cooling operations that is performed for the purpose of changing the mechanical properties, metallurgical structure, or the residual stress state of a metal product. When the term is applied to aluminum alloys, however, its use is frequently restricted to the specific operations employed to increase strength and hardness of the precipitation hardenable aluminium wrought and cast alloys. These usually are referred to as the "heat-treatable" alloys to distinguish them from those alloys in which no significant strengthening can be achieved by heating and cooling (Polmear 2004). The Aluminium alloys of this class belong to systems with limited solubility in solid state. These are precipitation
hardenable alloys. The main characteristic of these alloys system is temperature dependent equilibrium solid solubility, which increases with rise in temperature. In addition the other requirements are possibility of retaining single phase supersaturated solid solution by quenching, and precipitation of coherent/partially coherent phase by decomposition of the super saturated solid solution. Non-heat treatable aluminium alloys do not respond to heat treatment, because they consist of a homogeneous solid solution with or without noncoherent precipitate(s) and show low strength and high ductility. These alloys may be stress hardened. These alloys are used as sheet, bar, plates, wire, extrusion and so on. They are readily bent, formed and welded and possess excellent resistance to corrosion.

1.7.1 Age-Hardening of Aluminium MMCs

The heat treatment for enhance the mechanical properties of aluminium alloy is carried out by precipitate from a supersaturated solid solution. The alloy becomes harder with time or as it ages it develops hardness and strength. The hardness of the quenched alloy increases as a function of ageing time. Ageing of the quenched alloy at room temperature is known as natural ageing while at elevated temperatures is known as artificial ageing. Precipitation in solid solution occurs when the solubility of solute decreases with decreasing temperature. The precipitate of the second phase should be coherent in nature. The object of age hardening is to create in a heat treated alloy a dense of fine dispersions of precipitated particles in a matrix of deformable metal. The precipitate particles act as obstacles to dislocation motion and thereby strengthen the heat-treated alloy. Precipitation hardenable aluminum alloys are heat treated in three-step process: solution heat treatment, quenching and age hardening. The solution treatment aims to dissolve the soluble phases. Quenching aims to preserve the solid solution formed by rapidly cooling to some lower temperature, usually room temperature. Age hardening aims to precipitate out the strengthening phases.
Overheating above or under heating below a specified range of temperatures in the solution treatment and age hardening steps as well as inadequate quenching may cause degradation of mechanical properties (Polmear 2000).

1.8 SIGNIFICANCE OF WEAR BEHAVIOUR ON MMCs

Wear may be defined as the progressive loss of material from contacting surfaces in relative motion and it occurs, when the two surfaces with a relative motion interacts with each other. Scientists have developed various wear theories in which the Physico-Mechanical characteristics of the materials and the physical conditions are taken into consideration. Holm (1938) starting from the atomic mechanism of wear, calculated the volume of substance worn over unit sliding path. Burwell and Strang (1952), Archard (1953) and Archard and Hirst (1956) developed the adhesion theory of wear and proposed a theoretical equation identical in structure with Holm’s equation. In sliding, a fixed volume of material is subjected to many times repeated action, which weakens the material and finally leads to rupture. Though all the theories are based on different mechanisms of wear, the basic consideration is the frictional work. Hence friction is the prime consideration.

In the last two decades numerous studies of wear properties of aluminium based metal matrix composites with different type of reinforcements has been studied. Their results show that the wear behaviour of particulate reinforced aluminum composite is significantly affected by volume fraction of reinforcement and particle size (Prasad and Rohatgi 1987).

1.8.1 Types of Wear

In most of the basic wear studies where the problems of wear have been a primary concern, the so-called dry friction has been investigated to avoid the influences of fluid lubricants. Dry friction is defined as friction under not intentionally lubricated conditions but it is well known that it is
friction under lubrication by atmospheric gases, especially by oxygen (Soda 1975). A fundamental scheme to classify wear was first outlined by Burwell and Strang in 1953. Later in 1957 Burwell modified the classification of wear mechanism to five distinct types, namely (1) Abrasive (2) Adhesive (3) Erosive (4) Surface fatigue (5) Corrosive.

1.8.1.1 Abrasive wear

Abrasive wear can be defined as wear that occurs when a hard surface slides against and cuts groove from a softer surface. It can account for most failures in practice. Hard particles or asperities that cut or groove one of the rubbing surfaces produce abrasive wear. The abrasive wear behaviour of the composites also depends on several factors such as size, shape of abrasive, content, hardness of the sliding surface, loading conditions and environment (Lee et al 1992). Such hard particles may have been introduced between the two softer surfaces as a contaminant from the environment or in the form of reinforcement in composites. According to the recent tribological survey, abrasive wear is responsible for the largest amount of material loss in industrial practice (Zumgahr 1987). A typical abrasive wear is shown in the Figure 1.2.

![Figure 1.2 Schematic representation of the abrasion wear mechanism](image)

1.8.1.2 Adhesive wear

Adhesive wear occurs due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or the loss from either surface. For adhesive wear to occur, it is necessary for the
surfaces to be in intimate contact with each other. Surfaces, which are held apart by lubricating films, oxide films etc. reduce the tendency for adhesion to occur. An example for adhesive wear is shown in the figure 1.3

Figure 1.3 Schematic representation of the adhesive wear mechanism

1.8.1.3 Erosive wear

Erosive wear is the process of metal removal due to impingement of solid particles on a surface. Erosion is caused by a gas or a liquid, which may or may not carry, entrained solid particles, impinging on a surface. When the angle of impingement is small, the wear produced is closely analogous to abrasion. When the angle of impingement is normal to the surface, material is displaced by plastic flow or is dislodged by brittle failure. An example for erosive wear is shown in the Figure 1.4

Figure 1.4 Schematic representation of the erosive wear mechanism

1.8.1.4 Surface fatigue wear

Wear of a solid surface caused by fracture arising from material fatigue. The term ‘fatigue’ is broadly applied to the failure phenomenon where a solid is subjected to cyclic loading involving tension and
compression above a certain critical stress. Repeated loading causes the generation of micro cracks, usually below the surface, at the site of a pre-existing point of weakness. On subsequent loading and unloading, the micro crack propagates. Once the crack reaches the critical size, it changes its direction to emerge at the surface, and thus flat sheet like particles is detached during wearing. The number of stress cycles required to cause such failure decreases as the corresponding magnitude of stress increases. Vibration is a common cause of fatigue wear. The examples are shown in the Figure 1.5.

![Figure 1.5 Schematic representation of the surface fatigue wear mechanism](image)

### 1.8.1.5 Corrosive wear

Most metals are thermodynamically unstable in air and react with oxygen to form an oxide, which usually develop layer or scales on the surface of metal or alloys when their interfacial bonds are poor. Corrosion wear is the gradual eating away or deterioration of unprotected metal surfaces by the effects of the atmosphere, acids, gases, alkalis, etc. This type of wear creates pits and perforations and may eventually dissolve metal parts.

### 1.8.2 Symptoms of Wear

The symptom of different wear mechanism is indicated in Table 1.2 and the same is a systematic approach to diagnose the wear mechanisms.
Table 1.2 Symptoms and appearance of different types of wear (Ko 1987)

<table>
<thead>
<tr>
<th>Types of wear</th>
<th>Symptoms</th>
<th>Appearance of the worn-out surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasive</td>
<td>Presence of clean furrows cut out by abrasive particles</td>
<td>Grooves</td>
</tr>
<tr>
<td>Adhesive</td>
<td>Metal transfer is the prime symptoms</td>
<td>Seizure, catering rough and turnout surfaces</td>
</tr>
<tr>
<td>Erosion</td>
<td>Presence of abrasives in the fast moving fluid and short abrasion furrows</td>
<td>Waves and troughs.</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Presence of metal corrosion products</td>
<td>Rough pits or depressions.</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Presence of surface or subsurface cracks accompanied by pits and spalls</td>
<td>Sharp and angular edges around pits.</td>
</tr>
<tr>
<td>Impacts</td>
<td>Surface fatigue, small sub micron particles or formation of spalls</td>
<td>Fragmentation, peeling and pitting.</td>
</tr>
<tr>
<td>Delamination</td>
<td>Presence of subsurface cracks parallel to the surface with semi-dislodged or loose flakes</td>
<td>Loose, long and thin sheet like particles</td>
</tr>
<tr>
<td>Fretting</td>
<td>Production of voluminous amount of loose debris</td>
<td>Roughening, seizure and development of oxide ridges</td>
</tr>
<tr>
<td>Electric attack</td>
<td>Presence of micro craters or a track with evidence of smooth molten metal</td>
<td>Smooth holes</td>
</tr>
</tbody>
</table>

1.9 ENGINEERING APPLICATIONS OF MMCs

Metal matrix composites have emerged as one of the advanced engineering materials having potential application in the areas of aerospace, automotive, defense, electronics, nuclear, general engineering and other advanced structures.
Aluminium matrix composites have been first developed to meet very high performance defense and aerospace needs. Continuous fiber reinforced aluminium was used in the space shuttle and Hubble space telescope. As material cost became a more significant consideration, the emphasis shifted towards particulate reinforced materials, with the goal of a lower cost, high volume product that could be used in automotive and commercial aerospace applications.

Automotive manufacturers strive to reduce vehicle weight in order to improve performance, lower fuel and oil consumption and reduce emissions. Many automotive components made of steel and cast iron could be replaced by components made from less dense metal matrix composites. In recent years, aluminium metal matrix composites used for tribological components have attracted more and more interests. They are widely used as high speed rotating or reciprocating mass items such as pistons, connecting rods, drive shaft, brake rotors and cylinder liners.

The continuing increase in electronic packaging density has resulted in a need for materials with high thermal conductivities. In addition, to minimize thermal stresses that can cause component or solder failure, packaging materials must have coefficients of thermal expansion (CTEs) matching those of ceramic substrates and semiconductors. Further, low density is desirable in many applications, including portable systems such as lap-top computers, hand-held telephones, and avionics. Table 1.3 provides the some composite components and their area of applications.
Table 1.3 Applications of MMC (Surappa 1997)

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Area of application</th>
<th>Some of the components</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aerospace Industry</td>
<td>Space structures, Antennas, Aircraft primary and Secondary structures, Engine static and</td>
<td>High thrust to weight ratio for engines, High stiffness, low density, controlled thermal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rotating components, transmission static and rotating components, satellite &amp; helicopter</td>
<td>expansion, High wear resistance etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>structures, compressor blades.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Automotive Industry</td>
<td>Piston &amp; Cylinder blocks for I.C engines, drive shaft, connecting rod, wheels Chassis,</td>
<td>High wear resistance, Lower cost, Lower density, Elevated temperature strength, fatigue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fly wheels, Brake rotors, bicycle frames, brake discs</td>
<td>resistance.</td>
</tr>
<tr>
<td>3</td>
<td>Electronic packaging</td>
<td>Substrate and housing for electronic microcircuits.</td>
<td>High stiffness, High heat dissipation capacity, controlled thermal expansion, low density.</td>
</tr>
<tr>
<td>4</td>
<td>Sports Industry</td>
<td>Bicycle frames, Tennis rackets, Golf club shaft, Base ball shafts.</td>
<td>High stiffness, Low density, High fatigue resistance</td>
</tr>
</tbody>
</table>

1.10 SUMMARY

The potential of metal matrix composites as an advanced material for the automotive, aerospace, nuclear, and electronics engineering applications has been demonstrated by the development of various composite systems and their components. Various primary processing methods ranging from stir casting, infiltration, powder metallurgy and diffusion bonding have been developed using different matrix and reinforcement combinations. Some of the above processes have reached commercial production of MMCs. Secondary processing such as extrusion, rolling, forging, machining and
joining for various MMCs have been developed successfully. The replacement of high density conventional materials based on ferrous alloys by Aluminium MMCs has been observed. The light weight, high specific strength and modulus, better high temperature performance and wear and antifriction behaviour are the attractive characteristics of MMCs. However, the cost of reinforcements and production has to be reduced by development of suitable natural reinforcements and mass production techniques for near net shape components with consistent properties.

As such in the present study, the stir casting process is employed to fabricate aluminium metal matrix composites and an attempt is made to study the wear behaviour of fabricated composites on pin-on-disc wear test rig. The influence of various factors such as reinforcement type, volume fraction, size and extrinsic parameter like applied load, sliding speed, sliding distance and abrasive mesh size on wear rate and frictional coefficient have been studied. Also the model for wear rate prediction has been developed by Response Surface Method (RSM) and Adaptive Neuro Fuzzy Inference System (ANFIS).