CHAPTER 1
INTRODUCTION

Aluminium alloys are increasingly finding an important role in low strength to weight ratio at low cost (compared to titanium alloys) coupled with good corrosion resistance. These alloys have been widely used in aeronautical components, automotive parts, instrumentation cases and electric motors. Nevertheless, one of the major drawbacks of these alloys is their low wear resistance. Al–Si base alloys are commonly used due to very attractive characteristics such as high strength to weight ratio, good workability, good thermal conductivity, corrosion resistance and excellent castability. Al-Si alloy family is widely used in wear applications like brakes, pistons, cylinder liners and motor casing. By improving the wear characteristics of these alloys, the functionality of these alloys can be broadened and used in many more applications. The properties of the monolithic materials modified by alloying are limited by solution of one or more phases in another. In addition, it is a narrow range, controlled by growth kinetics and equilibrium conditions. To overcome this deficiency and to satisfy the constantly growing demand of current technology, composites have emerged as strong contenders in wear related applications.

1.1 INTRODUCTION TO COMPOSITE MATERIALS

A composite is a structural material that consists of two or more constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in
which it is embedded is called the matrix, which is generally continuous (Kaw 2010). Depending on the reinforcement phases incorporated, composites are classified as fibers, whiskers and particulates. However, other classifications based on the matrix materials as polymer, carbon, metal matrix and ceramic matrix composites also exists. In some investigations, Intermetallic-Matrix Composites (IMCs) are also categorized distinctly from MMCs.

1.1.1 Polymer Matrix Composites

Polymer Matrix Composites (PMCs) have reinforcements (fibers, whiskers or particulates) embedded in a polymer resin matrix (e.g. Polyesters, vinyl esters, PEEK, PPS). These composites are used in a broad range of application from aircraft structures for office furniture. Among the PMC’s Glass Fibre Reinforced Polymer (GFRP) composites find a wide range of application from automobile bodies to containers. Epoxy based polymer matrix composites exhibit high strength to weight ratios and are used in aerospace and space technologies. In addition, Carbon Fiber Reinforced Polymer (CFRP) composites are used in sports and recreational equipments, rocket motor cases, pressure vessels, aircraft structural components and furthermore, automotive industries are consuming increasing amounts of PMCs in an attempt to reduce the weight of the vehicle weight inorder to improve the fuel efficiencies.

1.1.2 Ceramic Matrix Composites

Ceramic Matrix Composites (CMCs) are a combination of ceramic particulates, fibers, or whiskers with a matrix of another ceramic. CMCs display enhanced high temperature creep behaviour and resistance to thermal shock. Several CMCs finds their use in high temperature and high stress applications such as in automobile and aircraft gas turbine engines. In addition, some tool inserts for machining hard metal alloys are Alumina composites reinforced with SiC whiskers.
1.1.3 Metal Matrix Composites

Metal Matrix Composites (MMCs) are prepared by dispersing a reinforcement material into a metal matrix. The majority of industrial MMCs uses aluminium, magnesium, copper or titanium alloys as a matrix with Silicon Carbide (SiC), Aluminium Oxide (Al₂O₃) as reinforcements. Based on their reinforcement they are classified as fibre reinforced Metal Matrix Composite (FMMC), Whisker reinforced Metal Matrix Composite (WMMC) and Particulate reinforced Metal Matrix Composite (PMMC). Of the various MMCs, Aluminium Matrix Composites (AMCs) are widely used in diverse industrial areas like automotive, aerospace, electronics, equipments manufacture and sports goods.

1.2 Aluminium Matrix Composites (AMCs)

In AMCs, the major constituent is aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase. AMCs generally have improved specific stiffness, elevated temperature strength, wear resistance, capabilities and corrosion resistance with tailorable thermal expansion coefficients. Surappa (2003) classified AMCs into four types depending on the type of reinforcement.

(a) Particle-reinforced AMCs (PAMCs)
(b) Whisker or Short Fibre reinforced AMCs (SFAMCs)
(c) Continuous Fibre reinforced AMCs (CFAMCs)
(d) Mono Filament reinforced AMCs (MFAMCs)

1.2.1 Particle Reinforced Aluminium Matrix Composites (PAMCS)

PAMCs contain equiaxed reinforcements with an aspect ratio less than five. These reinforcements are basically ceramic materials like SiC or
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$\text{Al}_2\text{O}_3$ or $\text{TiB}_2$. PAMCs are manufactured using powder metallurgy techniques or liquid state (stir casting, infiltration and in-situ) processes. Particulate composites are isotropic and can be subjected to a range of secondary forming operations like extrusion, rolling and forging. PAMCs are less expensive compared to other classes of AMCs.

1.2.2 Short Fibre and Whisker-reinforced Aluminium Matrix Composites (SFAMCs)

SFAMCs contain reinforcements with an aspect ratio greater than five, but are not continuous. Mechanical properties of whisker-reinforced composites are better than particle or short fibre reinforced composites. Nevertheless, the usage of whiskers as reinforcements in AMCs is on the decline due to alleged health hazards.

1.2.3 Continuous Fibre-Reinforced Aluminium Matrix Composites (CFAMCs)

CFAMCs have the reinforcements in the shape of continuous fibres (of $\text{Al}_2\text{O}_3$, SiC or carbon) with a diameter less than 20 µm. The fibres can be either parallel or pre-woven, braided prior to manufacture the composite. These composites are produced by pressure infiltration route. These have better mechanical characteristics but are expensive than other SFAMC and PAMCs.

1.2.4 Mono Filament Reinforced Aluminium Matrix Composites (MFAMCs)

MFAMCs have reinforcements as monofilaments of large diameter (100 to 150 µm). These composites are produced by diffusion bonding techniques and are limited to super plastic forming aluminium alloy matrix.
1.3 PRODUCTION OF PAMCs

Manufacturing of PAMCs, the least expensive of AMC with better wear properties are discussed in detail. Manufacturing methods of PAMCs on industrial scale can be classified into two main groups. (1) Liquid state processing (2) Solid state processing. These two classes are briefly discussed below.

1.3.1 Solid state processing

In solid-state processing, reinforcement is embedded in the matrix through diffusion at high pressures and high temperatures. Solid state processing of MMCs is done mainly using powder metallurgy processing. In powder metallurgy process, production of composites consists of three stages.

In the first stage, the aluminium alloy powder is blended in dry or liquid suspension with the particulates to produce composite powders. Mechanical alloying may also be employed to produce composite powders. Mechanical alloying, involves the introduction of hard dispersed particles in a relatively soft metal matrix with the aid of a high-energy ball mill (attritor).

The second stage involves the compaction of powders under pressure to prepare a precursor. Compaction of the precursor may be performed either by die pressing, cold isostatic pressing, extrusion or forging. This is followed by a third stage wherein the green compact is heated to a sufficiently high temperature (>0.7 $T_m$, where $T_m$ is the melting point of matrix material in K) to promote the solid-state diffusion and facilitate bonding between the powder particles.
Stage three may also be performed by thixo-casting, hot forming, hot extrusion, forging, cold massive forming or super plastic forming. Stage two and three may be performed in one step as in the case of Hot Isostatic Pressing wherein heat and isostatic pressure are simultaneously applied to produce the final component.

1.3.2 Liquid State Processing

In liquid state processing, liquid metal is infiltrated into the reinforcements. Infiltration may be carried out under atmospheric or inert gas pressure or under vacuum. The different techniques used for producing cast particulate composites using liquid metallurgy are stir casting, infiltration process, spray deposition and insitu methods.

1.3.2.1 Stir casting

The simplest and most commercially viable technique is the vortex technique or stir casting technique. The stir casting setup consists of a furnace, an electric motor with a stirrer arrangement and temperature sensors. In this method, ceramic particulates are incorporated into liquid metal melt and the mixture is allowed to solidify. It is important to create a good wetting between the particulate reinforcement and the liquid metal. The vortex technique requires the introduction of pre-treated ceramic particles into the vortex of the molten matrix created by a rotating impeller. Generally, it is possible to incorporate up to 30% ceramic particles in the size range 5 to 100 \( \mu \)m in a variety of molten aluminium alloys.

1.3.2.2 Infiltration technique

In the infiltration technique, a liquid alloy matrix is injected/infiltrated into a porous pre-form of continuous fibre/short fibre or
whisker or particle. Depending on the nature of reinforcement and its volume fraction, preforms can be infiltrated, with or without the application of pressure or vacuum. PAMCs having a reinforcement volume fraction ranging from 10 to 70% can be manufactured by means of infiltration. Some amount of porosity and local variations in volume fractions of the reinforcement are often noticed in the PAMCs processed by infiltration technique. The process is widely used to produce aluminium matrix composites having particle/whisker/ short fibre/continuous fibre as reinforcement.

1.3.2.3 Spray deposition

Spray deposition techniques fall into two distinct classes, depending on whether the droplet stream is produced from a molten bath (Osprey process) or by continuous feeding of cold metal into a zone of rapid heat injection (thermal spray process). In the thermal spray process ceramic particle/whisker/short fibre are injected into the spray to produce PAMCs. PAMCs produced in this technique often exhibit an inhomogeneous distribution of ceramic particles. Porosity in the as sprayed state is typically about 5–10%. Depositions of this type are typically consolidated to full density by subsequent processing.

1.3.2.4 Insitu methods

In insitu process, ultrafine ceramic particles are formed by the exothermic reaction between the elements or their compounds with molten matrix alloy. These insitu routes provide advantages such as uniform distribution of reinforcement, finer particle size, clean interface, thermodynamically stable reinforcement phase and process economy in comparison with the conventional ex-situ processes. One example is the directional oxidation of aluminium also known as DIMOX process.
1.4 MECHANICAL AND TRIBOLOGICAL BEHAVIOUR OF COMPOSITES

PAMCs offer a unique balance of physical and mechanical properties. These composites produced embrace new properties in terms of mechanical and tribological behaviour, thermal and electrical conductivity, resistance to aggressive environments, impact resistance, erosion resistance, fatigue and fracture properties. There are various mechanisms like particle pullout, increased resistance to wear offered by particulates and change in density, which causes the change in properties. These properties are different in comparison with the base alloy from which it derives its name and has to be an establishment for every composite developed. The properties of the composite depends on

- Properties of alloy
- Properties of particulates
- Type of manufacturing
- Manufacturing condition
- Reinforcement percentage
- Wetting of particulates
- Post heat treatment
- Particulate size
- Reaction of particulate with alloy

1.5 ORGANISATION OF CHAPTERS

Chapter 2 presents a survey of literature that deals with matrix material and reinforcement materials used in PAMCs, processing and
properties, dry sliding, abrasive and corrosive wear behaviour of the metal matrix composites and hybrid metal matrix composites. Chapter 3 explains materials, methods used for production and characterisation of composites. Chapter 4 studies the mechanical and tribological properties of Al-Si10Mg/SiC<sub>p</sub> composites. Chapter 5 describes the mechanical and tribological properties of Al-Si10Mg/MoS<sub>2p</sub> composites. Chapter 6 examines the mechanical and tribological properties of the wear behaviour of Al-Si10Mg/SiC<sub>p</sub>/MoS<sub>2p</sub> hybrid composites together with the derivation of optimum conditions. Conclusions and scope of further study are given in the chapter 7.

1.6 SUMMARY

Aluminium alloys finds application where cost effective high strength to weight ratio is needed. However, the poor tribological behaviour of these alloys hinders the use of these alloys. Mechanical and Tribological behaviour of these alloys may be improved by reinforcing them with other materials forming composites. The properties of these composites vary with the content and type of reinforcement added. Of these composites, PAMCS have evolved as a cost effective isotropic material. Stir casting is found to be a successful as well as an economical method of producing the composites. The subsequent chapter will present a detailed account of the research work carried out in the area of tribological and mechanical characterisation of PAMCs.