CHAPTER 1

INTRODUCTION

1.1 COMPOSITE MATERIALS

Mankind has been aware of composite material for several hundred years and has been applying innovations to improve the quality of life, although it is not clear how man had understood the fact that mud bricks made sturdier houses if lined with straw. Moreover men used them to make buildings that lasted. Ancient Egyptians used bricks with straw to enhance the structural integrity of their buildings, some of which testify the wisdom of the old civilization. Ironically, despite the growing familiarity with composite materials and their ever increasing range of applications, the term defies a clear definition. Terms like ‘materials composed of two or more distinctly identifiable constituents’ are used to describe natural composites like timber, organic materials like tissue surrounding the skeletal system, soil aggregates, minerals and rocks.

Composite materials are the most innovative materials in use today and the innovations in the field of composites are breaking the limits of conventional materials making futuristic designs in aerospace, automobile and structural engineering a reality. Composite materials were named as the ‘materials of the future’ in 1970’s when they were introduced in engineering applications (Foltz and Blackman, 1997). Composites that are from heterogeneous structures which meet the requirements of specific design and function, are imbued with desired properties which limit the scope for classification. However, this lapse is made up for by the fact that new types of composites are being innovated all the time and each with their own specific
purposes like filled, flake, particulate and laminar composites. Among the constituents of composites, one phase is called reinforcing phase or reinforcement in the form of fibres, sheets or particulate and it is embedded into another material, the matrix (Hull, 1991).

Composites are hybrid of two or more materials such as reinforced plastics, metals and ceramics. The reinforcements may be in the form of fibres, particles, whiskers or lamellae and are incorporated in a suitable matrix, thereby providing a material that combines the most useful properties of the constituents. Generally, the properties of a composite are superior to those of its individual constituents like

- Light in weight
- Good wear resistance
- High strength to weight ratio
- Free from rust and corrosion
- Higher strength and stiffness
- Improved joining characteristics
- Easy to cast etc.

1.1.1 Matrix materials

A variety of matrices polymer, metal, alloy, intermetallic, ceramic, carbon, etc. have been used for making composites. The matrix material serves several functions which are vital to the performance of the composite material. These functions also depend upon the type of reinforcement such as dispersions, particulates, whiskers, discontinuous or continuous fibres. In addition to retaining the composite mass in a solid form, the matrix binds are the fibres aligned in the important stressed direction and contribute to strengthening of the composite through load transfer or improving the fracture toughness by deflecting the crack propagation in the fibre or relaxation of stress
due to the breakage of fibres. The matrix enables the composite to withstand compression, flexural and shear forces or tensile loads. Depending upon the requirements, the matrix will protect the reinforcing fibres from abrasion, corrosion, oxidation and other mechanical and environmental attacks.

Metals are called versatile engineering materials because of their favourable properties of strength and easy fabrication. The prominent metallic matrices include aluminium base alloys, titanium base alloys, magnesium base alloys, copper and beryllium. Metal matrices can be used for high temperature applications compared to that of polymer matrices.

1.1.2 Reinforcements

The prime role of the reinforcement is to carry the applied load. The reinforcements are typically hard and stiff materials usually of glass, ceramics or metals. The matrix materials are generally ductile and tough but brittle matrices are also used. Composites can be classified according to morphology of reinforcement viz., fibre, particulate reinforced and laminate composites and matrix materials viz., metal, ceramic, polymer matrix composites (Chawla et al, 2006). By selection of reinforcement, matrix materials, composition, volume fraction and arrangements of reinforcements, a very wide range of microstructures can be achieved including anisotropic and isotropic behaviour (Kelly et al, 1965). The discontinuous reinforcement offers isotropic properties and amenability to be processed by conventional secondary metal forming techniques. Particulates are most common and least costly reinforced materials, SiC, TiN, TiC, Al₂O₃ are the common reinforcement materials. The fibres may conduct or resist heat and electricity. Among these, the incorporation of SiC and Al₂O₃ into the aluminium matrix results in improved properties such as high specific modules, strength, enhanced directional properties, retention of properties at elevated temperature and wear resistance. This has led to large
research activities in developing aluminium matrix composites reinforced with aluminium oxide (alumina) and silicon carbide (SiC). A variety of continuous fibres of glass, carbon, kevlar, silicon carbide, alumina, boron, tungsten etc. are used as reinforcements. These fibres exhibit different combinations of physical, chemical and mechanical properties.

1.1.3 Reinforcement matrix interface

The interface formed between the matrix and ceramic reinforcement is of interest, since the characteristics of interface determine the load transfer and crack resistance of the Metal Matrix Composites (MMCs) during deformation. The load transfer is associated with phenomenon such as poor adhesion, reaction products, reinforcement degradation and long range residual stresses, etc, which in turn depend on other processes such as chemical reaction, wetting and bonding of the matrix with the reinforcement. During composite fabrication, three primary techniques of controlling interfacial reactions occur and they are reinforcement surface modification, matrix chemistry alteration and process parameter control. For fibre surface modification, coating is the most common practice and process parameter control is probably the most important. At interface, a variety of discontinuities such as interface bonding, crystallography, moduli and coefficient of thermal expansion may occur.

1.2 METAL MATRIX COMPOSITES

The ever increasing demand for higher strength, toughness, thermal resistance, wear resistance, etc, has led to the search for improved new materials. The quest for the excellent performance has been instrumental in the development of metal matrix composites as one of the new emerging materials. They have a wide range of applications from automotive to aerospace. MMCs combine metallic properties of matrix alloys of good ductility and toughness,
with ceramic properties of reinforcements of high strength and high modulus, leading to greater strength in shear, compression and higher service temperature capabilities. MMCs are gaining increasing importance because of their attractive properties of light weight, better specific strength, specific stiffness, wear resistance, excellent corrosion resistance and high elastic modulus.

The MMCs are especially reinforced with fibres, whiskers, or particulates. The properties of discontinuous MMCs make them attractive for wear resistance materials. MMCs are fabricated by addition of a reinforcement phase to the matrix by the suitable method. Several factors influence the quality of the MMCs. One of the most important factors is the metal melt’s ability to wet the ceramic particulates. MMCs are common due to availability, low cost, independence of mechanical properties from particulate orientation and production. Aluminium based metal matrix composites offer potential for advanced structural applications with high specific strength and modulus, as well as good elevated temperature resistance and superior wear resistance.

Depending upon the shape and the type of reinforcement, MMCs can be divided as particle reinforced MMCs, short fibre of whisker reinforced MMCs and continuous fibre or sheet reinforced MMCs. Processing technique is decided based on the matrix material, shape of the reinforcement and shape of the composite (Clyne and Withers, 1993). Particle reinforced composites are inexpensive vis-a-vis continuous fibre reinforced composites. Conventional metallurgical processing techniques such as casting or powder metallurgy, followed by conventional secondary processing by rolling, forging, and extrusion can be used.
1.3 FABRICATION METHODS OF MMCs

In past decades, new fabrication methods of MMCs were developed. Improved processing leads to a near net shape composite component in an economic manner and is the need of the hour. Although numerous techniques are available for manufacture of MMCs, there is no independence in this respect. These techniques depend on choice of matrix and reinforcement materials. Generally, MMCs are fabricated by the following methods:

- Liquid state fabrication technique
- Solid state fabrication technique
- In situ fabrication technique

1.3.1 Liquid state fabrication technique

Various techniques have been developed which involve the matrix becoming at least partially molten as it is brought into contact with ceramic reinforcement. This generally favours intimate interfacial contact and hence a stronger bond occurs. Different types of liquid phase fabrication methods are as follows.

1.3.1.1 Stir casting

The simplest and most economically attractive method of MMC manufacturing is to simply stir and mix the liquid metal with solid ceramic particles and then allow the mixture to solidify. This type of processing is now in commercial use for Al-Al₂O₃, Al-SiC composites. It is also known as combo or slurry casting.
1.3.1.2 **Squeeze casting and squeeze infiltration**

In squeeze casting, pressure is imposed on a solidifying system via a single hydraulically activated ram. This leads to a tendency towards fine microstructure and low porosity level. Squeeze infiltration involves the injection of liquid metal into the interstices of an assembly of short fibres, usually called preform.

1.3.1.3 **Pressure die casting**

Die casting is a manufacturing process for producing accurately dimensioned, sharply defined, smooth or textured surface metal parts under a liquid state fabrication technique. The Pressure Die Casting (PDC) process is a further example of permanent mould casting. Pressure die casting is one of the near net shape manufacturing methods and it is mainly used for lesser or preventing secondary machining. It is accomplished by injecting liquid metal at fast velocity with high pressure into reusable steel dies. Compared to other casting processes, die casting is at the top end of both velocity and pressure. The molten metal is forced into the die cavity at pressures ranging from 0.7 MPa to 700 MPa. The high velocity translates into a very turbulent flow condition. The term die casting is also used to identify the cast product. The two basic types of die casting processes are hot chamber and cold chamber die casting processes.

1.3.1.4 **Spray deposition**

The process in which, a stream of metallic droplets impinge on a substrate in such a way to build a composite deposit. It is characterized by rapid solidification, low oxide contents and significant porosity levels.
1.3.2 Solid state fabrication techniques

It is possible to produce MMCs without the matrix ever becoming even partially liquid while in contact with the ceramic, although this may result in less intimate interfacial contact. Among the various methods available to produce MMCs, using this technique, powder metallurgy and diffusion bonding are extensively used.

1.3.2.1 Powder metallurgy technique

This is the most preferred method used for the manufacture of MMCs with discontinuous reinforcements. In this method, the mixture of powdered matrix material and reinforcement are fed in to a mould of required shape. It is then compacted under pressure, called as cold pressing. Then the compact is sintered at high temperature to develop solid state diffusion to facilitate bonding between the powdered particles. The blended mixture can also be directly pressed by hot pressing. This improves the strength of the composite by introduction of plastic deformation in matrix and removes voids to densify the composite. After few secondary operations, the consolidated product is used as MMCs. In this process, mixing of metallic powder and ceramic fibre or particulate is a consistent and versatile technique for MMCs production offering excellent control over the ceramic content across the complete range.

1.3.2.2 Diffusion bonding

Generally, MMCs with sheets or foils of matrix are fabricated by this method. It involves chemical surface treatment of the metal in the form of sheet and reinforcing material fibres for efficient inter diffusion. The fibres are later oriented in a predetermined fashion on the metal foil and pressed to ensure bonding. The bond strength prior to diffusion bonding can be enhanced by
coating the reinforcement by plasma spray technique or ion deposition. Good adhesion between the fibres and matrix can be obtained in sheets of large width using plasma spraying which is also an economic technique. Application of pressure and temperature either by hot rolling or cold pressing provides good bonding between the fibre matrix in the preform. This improves the strength of the composite by introduction of plastic deformation in matrix and removes voids to densify the composite. Vacuum conditions exhibit more effective diffusion bonding than other unders atmospheric conditions.

1.3.3 In situ fabrication technique

Directional solidification has been used to produce anisotropic material often with a high degree of microstructural regularity and perfection. The reinforcement is formed inside the metal matrix by controlled chemical reaction. Promising materials have been made in this way particularly with good creep resistance.

1.4 ALUMINIUM METAL MATRIX COMPOSITES

Aluminium alloy based MMCs are gaining increasing importance because of their attractive properties of light weight, better specific strength, specific stiffness, wear resistance, excellent corrosion resistance and high elastic modulus. Among the various types of MMCs, aluminium based composites have been involved in numerous engineering applications such as cylinder block liners, vehicle drive shafts, automotive pistons, bicycle frames, etc. The vortex mixing technique is used for the preparation of ceramic particle dispersed aluminium matrix composites. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. The pressure die casting technique appears to be an effective process. It offers an improvement in wettability and the
elimination of porosity due to solidification under pressure. To widen the application range of MMCs in the automotive industry, it is necessary to establish a low cost manufacturing process. Owing to the small gate area, the loss of molten metal in the die casting process is small in comparison with that of the squeeze casting process. Further the injection velocity is greater than that of squeeze casting. Therefore, the die casting technique seems to be the most suitable one to obtain economic parts of near net shape for MMCs amongst the fabrication processes. The main advantage of high pressure die casting is to obtain a fine microstructure casting part as it solidifies in the high precision mould cavity.

With the particular attributes of aluminium composites it is also possible to tailor the mechanical and thermal properties of these materials to meet the requirements of a specific application. To do this, there are a number of variables which need to be considered, which include the type and level of reinforcement, the choice of matrix alloy, and the composite processing route. All these factors are inter-related and should not be considered in isolation when developing a new material. The type of reinforcement also influences the method of manufacture. Continuous monofilament needs to be handled in a different way compared to particulate or even short fibre reinforcement.

1.5 SUMMARY

This chapter elucidates the importance of Aluminium Metal Matrix Composites (AMMC). The need for aluminium based metal matrix composites is revealed. AMMCs are newer materials having many favourable mechanical properties like high strength, hardness, wear resistance and strength to weight ratio. They have a wide range of applications from automotive to aerospace industries. AMMCs combine metallic properties of matrix alloys of good ductility and toughness with ceramic properties of reinforcements of high
strength and high modulus, leading to greater strength in shear, compression and higher service temperature capabilities.

In the present work, on ‘Processing and Performance Characteristics of Aluminium Alloy based Metal Matrix Composites’, new aluminium alloy - aluminium oxide / silicon carbide composites of different compositions are developed by a new combination of vortex method and pressure die casting technique. The improved properties of these new aluminium alloy - aluminium oxide (Al₂O₃) and aluminium alloy - silicon carbide (SiC) composites can be used for the advantage of many engineering applications especially in the automobile and the aerospace industries. The Tribological, Drilling, Milling and Electric Discharge Machining studies have been conducted on the newly developed aluminium alloy - aluminium oxide / silicon carbide composites to study their performance characteristics on processing for engineering applications. Hence, the second chapter Literature Review describes the state-of-the-art of the processing and the performance characteristics of aluminium based metal matrix composites.