Chapter 1

Introduction

New structural materials will be a deciding factor in the prevailing/existing competitiveness of products in global business environment today for any manufacturing industry. New materials such as composites and ceramics offer superior properties like light weight, high stiffness and high temperature strength etc. compared to conventional materials and alloys. The major advantage of these materials is that they can be tailored to meet the desired properties. These new materials namely composite materials are called advanced materials if they exhibit properties such as high specific stiffness, high temperature strength, light weight coupled with wear resistance, high thermal conductivity with low thermal expansion which are in conflict to traditional metals and alloys. Out of these emerging materials metal matrix composites (MMC) consists of a low density metal such as aluminium or magnesium reinforced with particulate or fibers of a ceramic material such as silicon carbide or graphite. Though metal matrix composites are of primary importance in defence sector they have very high potential applications in aerospace and automotive industry also. In spite of several advantages of MMC their growth is constrained on account of the cost of processing and reinforcement. Cost of processing can be reduced if net shape processing like powder processing can be successfully adapted to MMC. Though these advanced materials are in different stages of technological maturity they all are posed with some challenges. These challenges are processing science, structure property relationships, behavior in severe service environments and matrix-reinforcement interface. In addition the availability of affordable reinforcement in the forms like fibers and particulates are also adding to the above challenges. In order to face these challenges, research needs to focus on understanding the influence of processing variables on the desired properties, cost effective processing methods and reproducibility enabling mass production, the relationship between the internal structure, mechanical properties and failure mechanisms, higher temperature resistivity and corrosive environment exposure.

Apart from applications in defense and aerospace, development has been taking place in automobile parts like cylinder blocks, diesel engine piston, brake rotors, connecting
rods etc. Future applications can be seen for robots, high speed machinery and high speed rotating shafts for ship and land vehicles. Good wear resistance and high specific strength favors MMC use in engine and brake parts. Tailoring thermal expansion and thermal conductivity make them usable for electronic packaging, lasers and precision machinery.

There are two types of reinforcements, namely, continuous type and discontinuous type. Discontinuous type can be further classified into particulates and whiskers. The common types of particulates are alumina, boron carbide, silicon carbide, titanium carbide and tungsten carbide. The most common types of whiskers are silicon carbide, alumina and silicon nitride. Whiskers generally cost more than particulates. In terms of tailorability, a very important advantage in MMC applications is that of particulate reinforcement which offers various desirable properties. Boron carbide and silicon carbide are widely used inexpensive commercial abrasives that can provide good wear resistance as well as higher stiffness. Titanium carbide offers high melting point and chemical inertness which are desirable properties for processing and its stability while in use. Tungsten carbide improves hardness and strength of the MMC considerably. Particulates also being isotropic offer same mechanical properties in all directions. Whiskers are brittle and tend to break during processing reducing the reinforcing efficiency and high cost. Pressure for reduction in energy and lower remission levels make advanced composites a favorable option for automotive sector. The likely applications in automotive industry are pultruded drive shafts, Resin Transfer Molded (RTM) panels, fiber glass/epoxy springs for heavy trucks and trailers, rocker arm covers, suspension arms, fuel tanks, electrical vehicle body components, assembly units, brakes and clutch plates.

MMC can be extruded, forged, investment cast, rolled, machined and heat treated. Turbine and combustion engine components, disk brakes and brake parts, drive shaft components are having the usage of MMCs with significant advantages in performance. Materials with high stress and stiffness normally have low damping. Coated continuous fiber reinforced metal matrix composites have also been reported to have better damping characteristics than monolithic materials. They are also good candidates for thermal management because their properties can be tailored by adding a suitable reinforcement material.
Metallic composites containing nano particles or carbon nano tubes could offer distinct advantages over polymeric composites due to inherent high temperature, stability, high strength, high modulus, wear resistance and thermal and electrical conductivity. Aluminium nano composites are predicted to surpass the weight reduction currently realized through the use of polymer based nano composites and polymer based fiber composites in aerospace applications because of their high strength and stiffness. Metal matrix nano composites, by incorporation of as little as one percentage by volume of nano sized ceramic, has led to a much greater increase in the strength of aluminium/magnesium based composites which was achieved at higher loading levels of micro sized additions. These potential improvements have great implications in automotive and aerospace and in particular defense industries due to the drastic weight saving and exceptional properties that can be achieved. Potential applications are ventral fins for aircrafts and fan exit guide vans for commercial airline jet engines. Both components require higher stiffness and strength, low weight as well as resistance from erosion due to rain, air borne particulates and heat. Components used in the automobile industry are bulk nano composites. They add value for components such as brake system components which require higher wear resistance, thermal conductivity; Intake and exhaust valves which require high creep and wear resistance and piston liners which require high wear resistance, good thermal conductivity and low coefficient of thermal expansion.

MMC can be processed either through liquid state or solid state methodology. The easiest and cheapest method is liquid processing either by stir casting or squeeze casting or die casting. The success of casting method depends on the quality of the preform which presents a homogenous distribution of the reinforcement. Likewise the success of squeeze casting largely depends on fiber /matrix association and processing conditions. Pressure die casting is more common in industry and it presents advantages of much larger cooling rate. They have been used for processing Zn based alloys reinforced with mild steel fibers. Powder metallurgy is the only method for processing high melting point alloys with fibers or particulates. This also being a near net shape process, alloys with lower processing temperature provides greater advantages of minimum interface problems compared with wettability issues seen in stir casting.
In both liquid and solid processing interface adhesion can be modified by adding alloying elements in the matrix. When the processing conditions are properly controlled, continuous reinforced MMC present attractive properties from the point of thermal expansion and creep strength. In composites with low melting point matrices the reduction of fracture toughness and ductility of typical metallic composites can be alleviated without affecting other properties by substituting ceramic fibers with ductile fibers such as steel fibers. Fibers and processing techniques can be used whose cost remains compatible with that of common foundry alloys.

Aluminium matrix composites (AMC) offer superior combination of properties that no monolithic materials or alloys can match. They are used in structural, non structural and functional applications in different engineering sectors. Major reason for this is the advantages of AMC like performance, economic & environmental benefits. The key benefit in automotive sector is better specific fuel consumption, better damping characteristics and emission particles. By using near net shape processing, AMC with selective reinforcements techniques can offer economically feasible solutions for wide variety of cost effective applications. Addition of higher volume fraction of ceramic reinforcements substantially improve the performance of matrices in AMC during manufacturing, heat treatment and their subsequent use in service. It is reported that ceramic reinforcements affect solidification behavior, age hardening characteristics, thermal residual stresses of aluminium alloys .They are also improving sliding wear resistance affecting tribo layer to the advantage of sliding components like brake pads. Particle reinforced AMC constitute large quantity of composites produced and used on volume and weight basis. However it was emphasized by Surappa (2003) that the following challenges to be overcome in order to exploit the advantages of AMC. Processing technology has to be matured to fully understand the factors that affect microstructure integrity and agglomeration. Fracture mechanisms and toughness properties to be understood so as to develop damage tolerant properties.

The tailorable properties of advanced materials offer new opportunities for the designer. However, since advanced materials and structures are more complex than metals, the relationships among the internal structure, mechanical properties, and failure mechanisms are less well understood. A better understanding of the effects of an accumulation of dispersed damages on the failure mechanisms of composites is
especially desirable. The poorly understood interracial region has a critical influence on composite behavior. Particularly important would be the development of interfacial coatings that would permit the use of a single fiber with a variety of matrices.

In order to make present materials more commercially attractive and to develop better materials, the following research and development priorities should receive attention:

Cost effective processes: To develop low-cost, highly reliable manufacturing processes, research should concentrate on optimizing and evaluating processes such as plasma spraying, powder metallurgy processes, modified casting techniques, liquid metal infiltration and diffusion bonding.

Affordable materials: Development of lower cost fiber reinforcements is a major need. Continuous development work on existing materials is important to reduce costs.

Coatings: Research in the area of reinforcement/ matrix interface coatings is necessary. These coatings can prevent deleterious chemical reactions between matrix and reinforcement which weaken the composite, particularly at high temperature, and optimize the interfacial fiber/matrix bond.

On the basis of the literature survey carried out, the following aspects are considered as scope for the present research work.

1. Develop SiC reinforced AA6061 and AA2014 aluminium alloy composites by powder metallurgy process.
2. Assess the influence of process parameters on the properties of the composites.
3. Evaluate the mechanical properties like density, hardness, compressive strength and radial compressive strength of the composites. Study the correlation of microstructure and macrostructure of the composites with the properties.
4. Assess the influence of thermal conductivity and thermal expansion of SiC reinforced composites basically with AA6061 alloy composite and AA2014 alloy composite.
5. Evaluate the influence of electroless copper coated and Nickel coated SiC reinforcement on radial crushing strength of Aluminium alloy composite.
6. Evaluate the tribological performance of SiC reinforced composite by ball on disc testing and interpret the wear mechanism.

7. Though aluminium alloys are understood to have good corrosion resistance, literature reveals that SiC especially under powder processing route was found to reduce the resistance. Hence it is also planned to study the corrosion resistance under aggressive acid atmosphere and study the effect of inhibitors in arresting the dissolution of the matrix/composite.

The thesis is structured into five chapters:

Chapter I summarize the introduction of composites, its types and processes followed in powder metallurgy. This chapter gives an insight about the metal matrix composites prepared by powder metallurgy route as well as other methods which leads to the successful achievement of composites preparation with suitable planning on work to attain improved mechanical properties of metal matrix composites.

Chapter II deals with the background work carried out in this field and mainly focusing on synthesis of metal matrix composites by powder metallurgy along with other methods with through literature survey of evidence. This chapter gives an idea about synthesis of aluminium metal matrix composites which have not been explored so far for achieving enhanced mechanical properties.

Chapter III discusses the experimental methodology adopted to obtain metal matrix composites based on aluminium as matrix and silicon carbide as reinforcement. A detailed procedure followed for synthesis of Al/SiC metal matrix composites has been highlighted with various techniques such as compacting, sintering and compression strength measurement. In order to understand the thermal conductivity and coefficient of thermal expansion experiments have been carried out along with differential thermal analysis and thermo gravimetry are carried out. The metallization process which is first indigenous work in this investigation is helpful in enhancing the interfacial strength of Al/SiC composites which is evidenced from the deposition of Ni and Cu on SiC by electroless plating process. Since the composite has been synthesized using a hard reinforcement (SiC) it is expected to offer good wear resistance which is measured by ball on disc method. The corrosion resistant of
Al/SiC composites is a study of recent trend in particular to aggressive environment. The inhibition action of some green inhibitors has been studied using electrochemical techniques such as potentiodynamic polarization and A/C impedance studies. The quantum mechanical calculations have been performed using Gaussian-03 software to substantiate the effect of green inhibitors on the dissolution of Al/SiC composites in 1N HCl. The incorporation of SiC dramatically changes the morphology of Al/SiC composites which is evidenced from XRD and SEM studies.

Chapter IV discusses the results obtained for Al/SiC metal matrix composites by considering improvement in mechanical properties such as compressive strength, radial crushing strength, micro hardness, and wear and corrosion resistance. A detailed explanation on the results obtained has been presented to validate the performance of Al/SiC metal matrix composites in industrial applications.

Chapter V concludes the results obtained in the present work, highlighting the experimental evidences. This chapter also presents the summary of the investigations carried out in this research work with the scope for further research.