A Thesis

On

WEAR CHARACTERISTIC OF RUTILE REINFORCED PARTICLES IN ALUMINUM COMPOSITE

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by

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Dedicated to my Loving Parents

CERTIFICATE

This is to certify that **Mr. RAVINDER SINGH**, Roll No. 601002004 has worked on this thesis report entitled **"WEAR CHARACTERSTICS OF RUTILE REINFORCED ALUMINIUM COMPOSITE"** as a partial fulfillment for award of the degree of MASTERS OF TECHNOLOGY in Material Science and Engineering. I certify that the matter embodied in this report is of the candidate's own record and not submitted to any other university in any part or full form for the award of such kind of a degree.

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(RAVINDER SINGH)

ABSTRACT

The present investigation aims to find the effect of rutile reinforced particle in aluminium composite on the wear behavior. The composites are fabricated by varying the particle size of reinforcement of rutile particles. The wear behavior of composites is compared with different loads and temperature. The different size of rutile reinforcement particles 5-20 µm and 106-125 µm size are used in the present study. The wear test was carried out on pin-on disc machine. Wear track and debris are analyzed by SEM to study the wear mechanism. Study reveals that the fine size rutile particle reinforced composite exhibits better wear resistance than coarse particle at same weight percentage of reinforcement at all the temperature for low and high load both. Microstructural examination shows globular and finely distributed eutectic silicon in the vicinity of the reinforced particles.

CONTENTS

List of Figures I

List of Tables II

Chapter1 Introduction …………………………………………………………...1

1.1 Metal Matrix Composite……………………………………………………….2

1.2 Matrix……………………………………………………………………………..2

1.2.1 Matrix Material & Key Composite…………………………………….......2

1.3 Reinforcement...…........3

1.4 Manufacturing & Forming Methods……………………………………...4

1.4.1 Solid State Methods…………………………………………………….4

1.4.2 Liquid State Methods………………………………………………….4

1.4.3 Vapor Deposition……………………………………………………….5

1.5 Advantages of Aluminum Matrix Composite…………………………………5

1.6 Disadvantage of Aluminum Matrix Composite……………………………….6

1.7 Application of Aluminum Matrix Composite…………………………………6

Chapter 2 Aluminum Matrix Composite……………………………………….7

2.1 Aluminum Matrix Composite…………………………………………………7

2.2 Classification of Aluminum Matrix Composite………………………………8

2.2.1 Short Fibre & Whisker Reinforcement……………………………………..8

2.2.2 Continous Fibre Reinforcement……………………………………...…9

2.2.3 Monofilament Reinforcement………………………………………………10

2.2.4 Particle Reinforced Aluminum Matrix Composite…………………………11

2.3 Processing Route of Aluminum Matrix Composite…………………………..11

2.3.1 Powder Metallurgy for Aluminum Matrix Composite……………………...11

2.3.2 Spray Forming Process for Aluminum Matrix Composite…………………12

2.3.3 Spray Casting………………………………………………………13

2.4 Stir Casting Feature……………………………………………………...16

2.5 Challenges in Stir Casting…………………………………………….17

Chapter 3 Literature View……………………………………………..18-28

Chapter 4 Experimental Work……………………………………………29

4.1 Matrix Material……………………………………………………….29

4.2 Reinforced Material…………………………………………….......29

4.3 Preparation of Composite……………………………………………30

4.4 Characterization…………………………………………………….....31

4.4.1 Wear Testing………………………………………………………..31

4.4.2 Optical Microscopy…………………………………………………33

4.4.3 Scanning Electron Microscopy……………………………………..33

Chapter 5 Work and Discussion…………………………………………..35

5.1Morphological Studies…………………………………………...…35

5.2WearAnalysis…………………………………………………………….39

5.3Effect of Applied Load on Wear Rate………………………..........................39

5.4 Effect of High Temperature on Wear Rate…………………………......41

5.5 Study of Wear Track & Wear Debris……..…………………………………44

Chapter 6 Conclusion & Future Scope…………………………….….57-58

References……………………………………………….………59-62

LIST OF FIGURES

Fig.2.1 Short Fibre Reinforced AMC

Fig. 2.2 Microstructure of Continuous Fibre

Fig.2.3 Microstructure of Hybrid composite containing 10% SiC and 4% graphite particles

Fig.2.4 Microstructures of aluminium matrix composite having high volume fraction of SiC particle reinforcement

Fig.4.1 Stir casting setup (a) d.c.motor mounted on electronic resistance furnace, (b) stir casting in the molten composite in the furnace.

Fig.4.2 Pin-On-Disc Machine

Fig.4.3 Optical Microscope

Fig.4.4 Scanning electron microscope

Fig.5.1 Optical micrograph of composites containing (a) 15% fine particles at 200X, (b) 15 % fine particles at 500X, (c) 15% fine particles (SEM micrograph), (d) 15 % coarse particles at 50X, (e) 15 % coarse particles at 100X, (f) 15% coarse particles (SEM micrograph).

Fig.5.2 (a) Wear rate vs sliding distance of composite-A containing fine particles (5-20µm)

Fig.5.2 (b) Wear rate vs sliding distance of composite-B containing coarse particles (106-125µm)

Fig.5.3(a) Wear rate vs temperature of composite-A

Fig.5.3 (b) Wear rate vs temperature of composite-B

Fig.5.4 The SEM micrograph of worn pin surface of composite-A at 1kg load (a) at 50°C, (b) at150°C, (c) at 300°C

Fig.5.5 The SEM micrograph of worn pin surface of composite-B at 1kg load (a) at 50°C, (b) at 150°C, (c) at 300°C.

Fig.5.6 The SEM micrograph of worn pin surface of composite-A at 5kg load (a) at 50°C, (b) at 150°C, (c) at 300°C.

Fig.5.7 The SEM micrograph of worn pin surface of composite-B at 5kg load (a) at 50°C, (b) at 150°C, (c) at 300°C.

Fig.5.8 SEM images of debris of composite-A 1kg (a) at 150ºC (b) at 300ºC

Fig.5.9 SEM images of debris of composite-A 5 kg (a) at 150ºC (b) at 300ºC

Fig.5.10 Images of debris of composite-B 1kg (a) at 150 ^{0}C (b) at 300 ^{0}C

Fig.5.11 SEM images of debris of composite-B 5 kg (a) at 150ºC (b) at 300ºC

LIST OF TABLES

Table 4.1 Compositional analysis of LM13 alloy

Table 4.2 Chemical composition of rutile

CHAPTER - 1

INTRODUCTION

Aluminium and its alloys are the most used materials for different structural applications in the automotive and aerospace industry due to their high strength to weight ratio as well as because of their high thermal conductivity. Aluminium is mostly used in high temperature applications such as in automobile engines and in other rotating and reciprocating parts such as piston, drive shafts, brake rotors and in other structural parts which require light weight but high strength materials [1,2]. One of the main drawbacks of this material system is that these exhibit poor tribological properties. Hence, the desire in the engineering community to develop new materials with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio has led to the development of metal matrix composites [3, 4]. A composite may be defined as a material system comprising of two or more constituent materials that remain separate and distinct while forming a single component. The bulk material forms the continuous phase that is the matrix (e.g. metals, polymers, etc) while the other acts as the discontinuous phase that is the reinforcements (e.g. fibers, whiskers, particulates, etc). While the reinforcing material usually carries the major amount of load, the matrix enable the load transfer by holding them together [5]. The properties of ceramic reinforced metal matrix composites has been reported much better to that of its unreinforced counterpart [6,7]. The addition of reinforcing phase significantly improves the tribological properties of aluminium and its alloy systems. Aluminium exhibit useful properties such as high strength, ductility, high thermal and electrical conductivity but have low stiffness whereas ceramic reinforcements are stiffer and stronger and have excellent high temperature resistance but they are brittle in nature [8].

1.1 Metal matrix composite

A metal matrix composite (MMC) is material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. An MMC is complementary to a cermet.

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminum matrix to synthesize composites containing low density and high strength. However, carbon reacts with aluminum to generate a brittle and water-soluble compound Al_4C_3 on the surface of the fiber. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride.

1.2 Matrix

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

1.2.1 Matrix materials and key composites

Numerous metals have been used as matrices. The most important have been aluminum, titanium, magnesium, and copper alloys and super alloys.

The most important MMC systems are:

Aluminum matrix

- Continuous fibers: boron, silicon carbide, alumina, graphite
- Discontinuous fibers: alumina, alumina-silica

- Whiskers: silicon carbide
- Particulates: silicon carbide, boron carbid

Magnesium matrix

- Continuous fibers: graphite, alumina
- Whiskers: silicon carbide
- Particulates: silicon carbide, boron carbide

Titanium matrix

- Continuous fibers: silicon carbide, coated boron
- Particulates: titanium carbide

Copper matrix

- Continuous fibers: graphite, silicon carbide
- Wires: niobium-titanium, niobium-tin
- Particulates: silicon carbide, boron carbide, titanium carbide.

1.3 Reinforcement

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. 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, but commonly would need the use of polycrystaline diamond tooling. 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. One of the first MMCs used is boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

1.4 Manufacturing and forming methods

MMC manufacturing can be catagorised into three types: solid, liquid, and vapor.

1.4.1 Solid state methods

- Powder blending and consolidation (powder metallurgy): Powdered metal and discontinuous reinforcement are mixed and then bonded through a process of compaction, degassing, and thermo-mechanical treatment (possibly via hot isostatic pressing (HIP) or extrusion).
- Foil diffusion bonding: Layers of metal foil are sandwiched with long fibers, and then pressed through to form a matrix.

1.4.2 Liquid state methods

- Electroplating / Electroforming: A solution containing metal ions loaded with reinforcing particles is co-deposited forming a composite material.
- Stir casting: Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify.
- Squeeze casting: Molten metal is injected into a form with fibers preplaced inside it.
- Spray deposition: Molten metal is sprayed onto a continuous fiber substrate.
- Reactive processing: A chemical reaction occurs, with one of the reactants forming the matrix and the other the reinforcement.

1.4.3 Vapor deposition

- Physical vapor deposition: The fiber is passed through a thick cloud of vaporized metal where coating on it occurs.

As discussed above there are number of processing techniques, which have been developed in recent years for processing metal matrix composites. According to the type of reinforcements, the fabrication techniques also vary considerably. The different techniques employed for metal matrix composites are powder metallurgy, spray deposition, liquid metal infiltration, squeeze casting, stir casting, etc. All of them have their own advantages and disadvantages. At the early stage of development of metal matrix composites, emphasis was on preparation of fiber-reinforced composites. But the high cost of reinforcement fibers, restricted the commercial exploitation of this class except for some high technology applications. The particulate reinforced metal matrix composites are gaining importance nowadays because of their low cost with advantages like isotropic properties and the possibility of secondary processing. Among the various processing techniques available for particulate or discontinuous reinforced metal matrix composites, stir casting is the technique which is in use for large quantity commercial production. This technique is most suitable due to its simplicity, flexibility and ease of production for large sized components. It is also the most economical among all the available processing techniques.

1.5 Advantages of MMCs

Compared to monolithic metals, MMCs have:

- Higher strength-to-density ratios
- Higher stiffness-to-density ratios
- Better fatigue resistance
- Better elevated temperature properties
- Lower creep rate

The advantages of MMCs over polymer matrix composites are:

- Higher temperature capability
- Fire resistance

- Higher transverse stiffness and strength
- No moisture absorption
- Higher electrical and thermal conductivities
- Better radiation resistance.

1.6 Disadvantages of MMCs

Some of the disadvantages of MMCs compared to monolithic metals and polymer matrix composites are:

- Higher cost of some material systems
- Relatively immature technology
- Complex fabrication methods for fiber-reinforced systems (except for casting)
- Limited service experience

1.7 Application of MMCs

- Carbide drills are often made from a tough cobalt matrix with hard tungsten carbide particles inside.
- Some tank armours are made from metal matrix composites, eg. steel reinforced with boron nitride. Boron nitride is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.
- Some automotive disc brakes use MMCs.
- The F-16 Fighting Falcon uses monofilament silicon carbide fibres in a titanium matrix for a structural component of the jet's landing gear.

In comparison with conventional polymer matrix composites, MMCs are resistant to fire can operate in wider range of temperatures, do not absorb moisture, have better electrical and thermal conductivity, are resistant to radiation, and do not display out gassing. On the other hand, MMCs tend to be more expensive, the fiber-reinforced materials may be difficult to fabricate, and the available experience is limited.

CHAPTER- 2

ALUMINIUM METAL MATRIX COMPOSITE

2.1 Aluminium metal matrix Composite

Aluminium metal matrix composites (Al-MMCs or AMCs) are materials in which reinforcement, typically a ceramic-based material, is added with the purpose of improving the materials properties. In AMCs one of the constituent is aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction.

AMC material systems offer superior combination of properties (profile of properties) in such a manner that today no existing monolithic material can rival. Over the years, AMCs have been tried and used in numerous structural, non-structural and functional applications in different engineering sectors. Driving force for the utilisation of AMCs in these sectors include performance, economic and the environmental benefits. The key benefits of the AMCs in the transportation sector are lower fuel consumption, less noise and lower airborne emissions. With increasing stringent environmental regulations and emphasis on improved fuel economy, use of AMCs in transport sector will be inevitable and desirable in the coming years. AMCs can be viewed either as a replacement for existing materials, but with superior properties, or as a means of enabling radical changes in system or product design.

Moreover, by utilising near-net shape forming and selective-reinforcement techniques AMCs can offer economically viable solutions for wide variety of commercial applications. Recent success in commercial and military applications of AMCs is based on partly such innovative changes made in the component design. Lack of knowledge and information about utilisation possibilities, service properties and material producers have hindered the wider usage of AMCs. The physical and mechanical properties of aluminum–based metal matrix composites have made them attractive materials for automotive and aerospace applications [9,10].

2.2 Classification of aluminium metal-matrix composites

AMCs can be classified into four types depending on the type of reinforcement:

(a) Whisker-or short fibre-reinforced AMCs (SFAMCs)

(b) Continuous fibre-reinforced AMCs (CFAMCs)

(c) Mono filament-reinforced AMCs (MFAMCs)

(d) Particle reinforced AMCs (PAMCs)

2.2.1 Short fibre- and whisker-reinforced aluminium matrix composites (SFAMCs)

These contain reinforcements with an aspect ratio of greater than 5, but are not continuous. Short alumina fibre reinforced aluminium matrix composites is one of the first and most popular AMCs to be developed and used in pistons. These were produced by squeeze infiltration process. Figure 2.1shows the microstructure of short fibre reinforced AMCs.

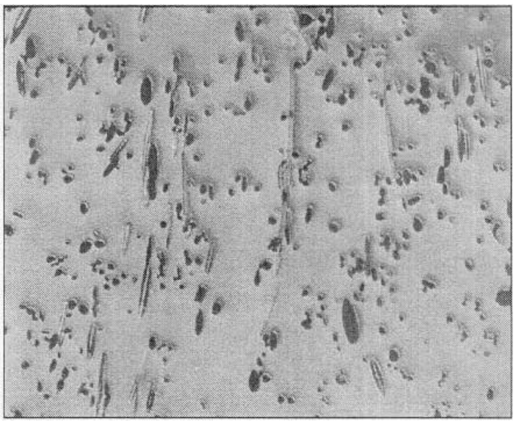


Fig. 2.1: Short fibre-reinforced aluminium matrix composite**.**

Whisker reinforced composites are produced by either by PM processing or by infiltration route. Mechanical properties of whisker reinforced composites are superior compared to particle or short fibre reinforced composites. The whisker based composites are more costly than the particulate based ones, but offer higher strength in general [11].However, in the recent years usage of whiskers as reinforcements in AMCs is fading due to perceived health hazards. Hence, commercial exploitation of whisker reinforced composites has been very limited. Short fibre reinforced AMCs display characteristics in between that of continuous fibre and particle reinforced AMCs.

2.2.2 Continuous fibre-reinforced aluminium matrix composites (CFAMCs)

Here, the reinforcements are in the form of continuous fibres (of alumina, SiC or carbon) with a diameter less than 20 µm. The fibres can either be parallel or pre woven, braided prior to the production of the composite. AMCs having fibre volume fraction up to 40% are produced by squeeze infiltration technique. However, the cost of these systems is very high, mainly because of the high costs of the continuous fibers and of the production [12].

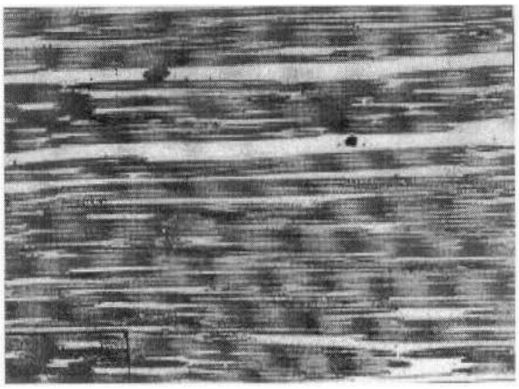


Fig.2.2: Microstructure of continuous fibre-reinforced aluminium matrix composite.

Alumina fibre (continuous fibre) reinforced composite having a tensile strength and elastic stiffness of 1500 MPa and 240 GPa respectively. These composites are produced by pressure infiltration route. Fig. 2.2 shows the microstructure of continuous fibre (alumina) reinforced AMCs.

2.2.3 Mono filament reinforced aluminium matrix composites (MFAMCs)

Monofilaments are large diameter (100 to 150µm) fibres, usually produced by chemical vapour deposition (CVD) of either SiC or B into a core of carbon fibre or W wire. Bending flexibility of monofilaments is low compared to multi filaments. Monofilament reinforced aluminium matrix composites are produced by diffusion bonding techniques, and is limited to super plastic forming aluminium alloy matrices. In CFAMCs and MFAMCs, the reinforcement is the principal load-bearing constituent and role of the aluminium matrix is to bond the reinforcement and transfer and distribute load. These composites exhibit directionality. In particle and whisker reinforced AMCs, the matrix is the major load-bearing constituent. The role of the reinforcement is to strengthen and stiffen the composite by preventing matrix deformation by mechanical restraint shown in fig. 2.3

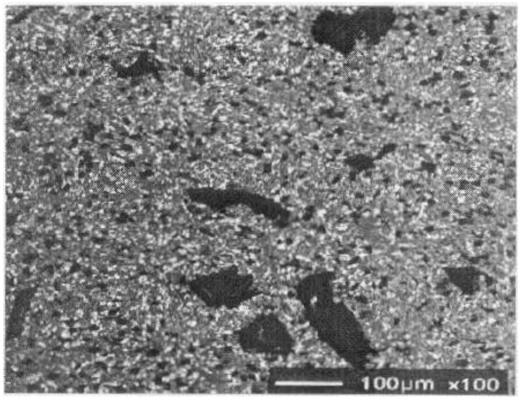


Fig.2.3: Microstructure of Hybrid composite containing 10% SiC and 4%graphite particles.

2.2.4 Particle reinforced aluminium matrix composites (PAMCs)

These composites generally contain equiaxed ceramic reinforcements with an aspect ratio less than about 5. Ceramic reinforcements are generally oxides or carbides or borides (Al_2O_3 or SiC or TiB_2) and present in volume fraction less than 30% when used for structural and wear resistance applications. However, in electronic packaging applications reinforcement volume fraction could be as high as 70%. However, the improvement in strength does not seem to be high and the strain to failure and fracture are low compared to the matrix material [13]. In general, PAMCs are manufactured either by solid state (PM processing) or liquid state (stir casting, infiltration and in-situ) processes.

PAMCs are less expensive compared to CFAMCs. Mechanical properties of PAMCs are inferior compared to whisker/short fibre/con AMCs but far superior compared to unreinforced aluminium alloys. These composites are isotropic in nature and can be subjected to a variety of secondary forming operations including extrusion, rolling and forging. Figure 2.4 shows the microstructure of cast aluminium matrix composite having high volume fraction (40 vol%) SiC particle reinforcements.

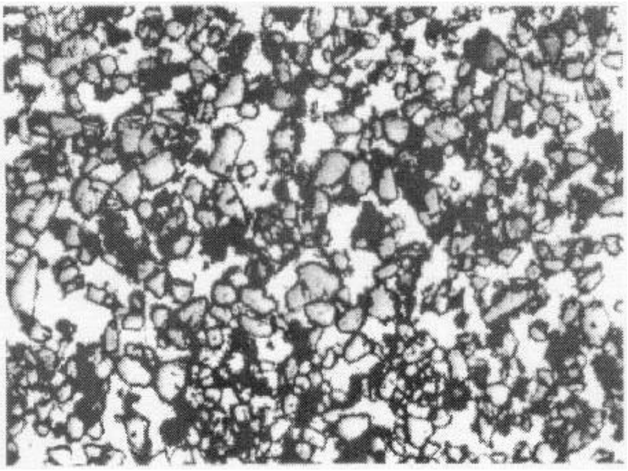


Fig.2.4: Microstructures of aluminium matrix composite having high volume fraction of SiC particle reinforcement.

2.3 Processing route for AMCs

Processing route for AMCs are similar to MMCs, So only stir casting process is described as it used in this study. Mainly the following are used:

1. Powder Metallurgy
2. Spray Forming
3. Stir Casting

2.3.1 Powder metallurgy for aluminium matrix composite

Among all the metal matrix composites (MMCs) aluminium could be the most widely used metal as matrix due to its lowdensity coupled with high stiffness. There are different manufacturing methods which can be applied for this composite. From these, P/M could be remarked as a highly effective and economic method compared with other alternatives.

2.3.2 Spray forming process for producing aluminium matrix composite:

Spray forming is a metallurgical process that combines the main advantages of the two classical approaches to base manufacturing of sophisticated material and performs, i.e.:

1) Metal Casting: involving high-volume production and near-net shape forming.

2) Powder Metallurgy: involving near-net shape forming at small volumes to yield a homogeneous, fine-grained microstructure.

The spray forming process essentially combines atomization and spraying of a metal melt with the consolidation and compaction of the sprayed mass on a substrate. Spray forming is a unique solidification process in which metal melt is atomised by inert gas into droplets of 10-200 microns in size, flying at subsonic speed onto a deposition substrate. During the flight the droplets are rapidly cooled with a cooling rate between 100 to 100,000 degrees per second in a controlled way so that the solidification of the metal is not dependent on the temperature and/or the thermal properties of the deposition surface like a mould. The particles arriving at the mould are in such a condition that welding to the already deposited metal is complete and no inter particle boundaries are developed. As a result, high-quality materials are made with fine, equiaxed and homogeneous microstructures. These features are especially prominent in making high-alloy metal components like for example die inserts and tooling heads.

Generally, spray formed alloys show the following characteristics:

1) High-density typically 96-99% of theoretical are produced.

2) Oxygen content is decreased, compared to P/M products, and degassing operations are not needed.

3) Rapid solidification results in a fine, uniform grain size, typically in the range 20-50 μm.

4) As a result of rapid solidification, macro segregationis sharply decreased.

5) Fine precipitates are produced and uniformly distributed in the microstructure. Although precipitation in the liquids/solidus region occurs very rapidly, any solid-state transformations are relatively slow.

6) Superior fracture properties are obtained in comparison to P/M and I/M products. There are two reasons for this:

  i) Decreased oxidation compared to P/M.

  ii) Absence of coarse precipitates compared to I/M.

2.3.3 Stir Casting

Stir casting is the one of the extensively used and economical synthesis technique for fabricating the particulate reinforced aluminium reinforced composite. It is simpler as compared to other available techniques and flexibility in tailoring the desired properties in the composite.

In stir casting the aluminium is placed in a graphite crucible and melted in a resistance furnace. When the melt is in liquid state, the impeller is introduced in to the melt. The impeller is rotated at specified rotation to create a vortex in the melt. The reinforcement particles are introduced in to the melt through the side of the vortex formed. The vortex sucks the particle and distributes it in to the melt. The vortex method is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy. Stirring for sometime followed by mixing is done to obtain homogeneous distribution of particles. The next step is the solidification of the melt containing suspended particles under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix.

In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including

- Porosity

- The difficulty of achieving a uniform distribution of the reinforcement material
- Wettability between the two main substances

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimised. The porosity levels need to be minimised, and chemical reactions between the reinforcement materials and the matrix alloy must be avoided.

Conventional monolithic materials have limitations in achieving 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 most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. Composites with silicon/SiC as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications. It is therefore expected that the incorporation of silicon or SiC particles in aluminum has the potential for conserving energy intensive aluminum and thereby, reducing the cost of aluminum products. Cast aluminum matrix particle reinforced composites have higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys. The particulate composite can be prepared by injecting the reinforcing particles into liquid matrix through liquid metallurgy route by casting. Casting route is preferred as it is less expensive and amenable to mass production. Among the entire liquid state production routes, stir casting is the simplest and cheapest one. The only problem associated with this process is the non uniform distribution of the particulate due to poor wet ability and gravity regulated segregation. Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. Among discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production, and allows very large sized components to be fabricated. The cost of preparing composites material using a casting method is about one third to half of that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth. In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. Metal matrix composite (MMC) is engineered combination of the metal (Matrix) and hard particle/ceramic (Reinforcement) to get tailored properties. Considerable research from all over the world has been devoted to metal matrix composite (MMC) research over the past few decades involving a broad area of MMC fabrication. In any type of the fabrication method used, wetability and distribution of the reinforcement material in the alloy matrix are among the main problems. Many methods have been proposed to overcome this situation. However, ideas normally suitable for the preparation of materials and their use may not be suitable for different approaches.

In general stir casting of MMC involves producing a melt of selected matrix material followed by the introduction of reinforcement material into the melt and the dispersion of the reinforcing material through stirring. Stirring is carried out vigorously to form a vortex where the reinforcing particles are introduced through the side of the vortex. The formation of the vortex will drag not only the reinforcement particles into the melt, but also all impurities which are formed on the surface of the melt. The vortex will also entrap air into the mould which is extremely difficult to remove as the viscosity of the slurry increase.

2.4 Stir Casting features:

1. Content of dispersed phase is limited (usually not more than 30 vol. %).
2. Distribution of dispersed phase throughout the matrix is not perfectly homogeneous.
3. There are local clouds (clusters) of the dispersed particles (fibers).
4. There may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrix phase.
5. The technology is relatively simple and low cost.
6. Particle density, size, shape and volume fraction plays an important role in the reinforcement settling rate.
7. Surface properties of particles determine the ease or difficulty of wetting.
8. The reaction of the reinforcing particles with each other and with matrix melt influences the rheological behavior of the slurry.
9. During particle addit0ion or stirring, gas entrapment takes place leading to poor distribution of particles due to attachment of particles to gas bubbles and also increase in porosity in the composite.
10. Mixing parameters should be so adjusted that particle distribution in axial and radial directions must be uniform.
11. The settling time should be as minimum as possible during solidification of melt.
12. The reinforcement particles, in general, occupy inter dendritic or between secondary dendrite arm spacing, therefore the matrix grain size or the spacing must be finer for better distribution of particles.

2.5 Challenges in stir casting:

The high cost of production of even minimally complex shape components hinders the widespread adoption of particulate metal matrix composites. Casting technology is the solution to this problem. It is one of the cheapest methods for production of particulate matrix composites at large scale. But there are several technical challenges as mentioned below that need considerable attention before going for this technique [13]

1. The difficulty of achieving a uniform distribution of particles.
2. Wetability between the matrix and the particles.
3. Porosity in the cast metal matrix composites.
4. Chemical reactions between the reinforcement material and the matrix alloy.

The attainment of uniform distribution of particles within the matrix is essential for achievement of optimum mechanical properties. This is the most common problem which remains with most of the processing techniques including stir casting. Porosity is another common problem associated with casting technique.

CHAPTER - 3

LITERATURE REVIEW

Rajan et al. [14] studied the hardness of stir and centrifugally cast Al-SiCp functionally graded metal matrix composites with graded distribution of SiC particles near the outer periphery of the casting. They showed that maximum of 45 and 40% SiC particles are obtained near the outer periphery of the Al(356)-SiC and Al(2124)-SiC FGMMC casting respectively. The maximum hardness obtained at the outer periphery after heat treatment for Al(356)-SiC and Al(2124)-SiC FGMMC are 155 BHN and 145 BHN respectively. The freezing range of the matrix alloy was found to dictate the nature of transition from particle enriched to depleted zone.

Kumar et al. [15] studied the unlubricated sliding wear behaviour of zinc–aluminium alloy composites reinforced with zircon particles of size 30–50 µm. The content of zircon in the alloy was varied from 1–5% in steps of 2wt. %. The liquid metallurgy technique was used to fabricate the composites. The results indicated that the wear rate of the composites was lesser than that of the matrix alloy and it further decreased with the increase in zircon content. However, the material loss in terms of wear rate and the wear volume increased with the increase in load and sliding distance, respectively, both in the case of composites and the alloy. Increase in the applied load increased the wear severity by changing the wear mechanism from abrasion to particle cracking induced delamination wear. It was found that with the increase in zircon content, the wear resistance increased monotonically.

Pandey et al. [16] studied that the emerging demand of light weight alloys and composites for the engineering and structural applications leads to explore the possibility to develop new techniques to achieve materials of high performance. In the present study,Al–Si/zircon sand reinforced composite has been developed via spray forming technique. Dry sliding wear behavior of as cast Al–Si base alloy and spray formed Al–Si/zircon sand reinforced composite containing 8% Vf of zircon sand has been analyzed. An isotropic wear property of spray formed composite has been checked by selecting the spray formed preform in both horizontal and vertical sections of deposit .The wear tests which were carried out at loads of 14.7, 24.5,34.3, 44.1, and 53.9 N have shown that spray formed composite is more wear resistant in comparison to the cast Al–Si alloy. Moreover, wear coefficient in case of composite is also found to be lower than base alloy. Optical and scanning electron microscopies have been carried out to furnish a suitable explanation for observed wear behavior of composite and alloy.

Rao et al. [17] studied the age hardening behaviour of Al-4.5%Cu alloy composite reinforced with zircon sand particulates and produced by stir casting route. Composite was investigated in different quenching media viz, water, oil, and salt brine solution (7wt %). The results of ageing demonstrate that the microhardness of age hardenable Al-Cu based alloy composites depend on the quenching medium in which they are heat treated. Under all the heat treatment conditions, the microhardness increased with the ageing time to a peak value and then decreased with a prolonged ageing time. Salt brine quenching is faster as compared to water and oil, even if higher strength is obtained but cannot be used for complex shapes and thin sections where oil quenching is the alternative due to minimum distortion and cracking problems. Thermal cycling studies of the composite at 25–540°C was also carried out to determine the extent of quenching of the matrix after each solution heat treatment cycle while varying the quenching media.

Vencla et al. [18] investigated the effect of stirring speed and time on the microstrucutre and hardness of the composite. High silicon content aluminium alloy–silicon carbide metal matrix composite material, with 10%SiC were synthesized in the study, using different stirring speeds and stirring times. The microstructure of the produced composites was examined by optical microscope and scanning electron microscope. The Brinell hardness test was performed on the composite specimens from base of the cast to top. The results revealed that stirring speed and stirring time influenced the microstructure and the hardness of composite. Microstructure analysis revealed that at lower stirring speed with lower stirring time, the particle clustering was more. Increase in stirring speed and stirring time resulted in better distribution of particles. The hardness test results also revealed that stirring speed and stirring time have their effect on the hardness of the composite. The uniform hardness values were achieved at 600 rpm with 10 min stirring. But beyond certain stir speed the properties degraded again.

Rao et al. [19] evaluated the effect of sliding distance on the wear and friction behaviour of as cast and heat-treated Al–SiCp composites using pin-on-disc wear testing machine, giving emphasis on the parameters such as wear rate and coefficient of friction as a function of sliding distance (0–5000 m) at different applied pressures of 0.2, 0.6, 1.0 and 1.4 MPa and at a fixed sliding speed of 3.35 m/s. The results revealed that the heat-treated composite exhibited superior wear properties than the base alloy, while the coefficient of friction followed an opposite trend. Moreover, the wear rate of the composite was noted to be invariant to the sliding distance and increased with applied pressures.

Campbel et al. [20] studied the tribological behavior of sintered aluminum metal matrix composites (MMCs) containing various volume fractions of particles made of complex metallic alloys (CMAs) was investigated in a reciprocating dry sliding tribo-tester operated in ambient air against 10mmdiameter Al_2O_3 balls. The Al-based MMCs tested contained either 15μm size AlCuFeB or 25μm size AlCuFeCr-particles. An improvement in the dry sliding wear resistance of aluminum was achieved by the incorporation of these CMA-particles acting as a second phase reinforcement. The wear resistance depends on the volume fraction of CMA-particles but not on their composition, nano-hardness or size. These Al-based

MMCs containing CMA-particles exhibit however a higher coefficient of friction than pure aluminum under dry sliding against a ceramic counterbody.

Akovalli et al. [21] fabricated the nanocomposites of AA 2024 aluminum alloy matrix reinforced with different volume fractions of nanometric $MoSi_2$ intermetallic particles ranging from 0 to 5% by using mechanical alloying technique. For comparison, samples without reinforcing particles and mechanical alloying and a sample with micrometric $MoSi_2$ particles were also synthesized. The prepared composite powders were consolidated by cold and hot pressing and then heat treated to solution and aged condition (T6). The results indicated that although T6 heat treatment increases the hardness of all samples compared to as hot pressed (HP) condition, the age- hardenability (aging induced hardness improvement) decreases after mechanical alloying and with increasing $MoSi_2$ volume fraction due to the high dislocation density produced during mechanical alloying. With increasing the volume fraction of nano-sized $MoSi_2$ particles up to 3–4%, the hardness of the composites continuously increases and then declines most probably due to the particle agglomeration. The wear sliding test disclosed that the wear resistance of all specimens in T6 condition is higher than that of hot pressed condition and increases with increasing $MoSi_2$ content.

Suresha et al. [22] studied the effect of % reinforcement, load, sliding speed and sliding distance on stir cast Al–SiC–Gr hybrid composites, Al–Gr and Al–SiC composites. Parametric studies indicated that the wear of hybrid composites has a tendency to increase beyond% reinforcement of 7.5% as its values are 0.0242 g, 0.0228 g and 0.0234 g respectively at 3%, 7.5% and 10% reinforcement. The corresponding values are 0.0254 g, 0.0240 g and 0.0242 g in Al–Gr composites and 0.0307 g, 0.0254 g and 0.0221 g in Al–SiC composites, clearly indicating that hybrid composites exhibit better wear characteristics. Increase of speed reduces wear and increase of either load or sliding distance or both increases wear.

Surappa et al. [23] examined and compare the structural, mechanical and tribological properties of heat treated particulate composites of A356 aluminium alloy as a matrix reinforced with ceramic particles (Al_2O_3, SiC) and graphite particles. Composites are prepared by compocasting process. The study shows that heat treatment affected microstructure of the composites matrix. The fracture of the composites matrix was ductile, while transition from ductile to brittle fracture occurred in the zone of reinforcing particles. The values of elasticity modulus of all the composites were higher in relation to the matrix alloy. It was also established that wear resistance and coefficient of friction were better at the SiC particulate composites than at the Al_2O_3 particulate composite, while the addition of graphite particles improved tribological properties further.

Hashim et al. [24] analysed that the dry sliding wear of an AA 6061 alloy reinforced with both modified SiC particles and metal coated carbon fibres. SiC particles were coated with a silica layer deposited through a sol–gel procedure to increase the processability of the composite and to enhance the particle–matrix interfacial resistance. The metallic coatings on carbon fibres were made of copper or nickel phosphorus which was deposited through an electroless process. The metallic coatings favoured the wetting of the fibres during processing and then dissolved in the aluminium matrix forming intermetallic compounds that increased its hardness. Wear behaviour of AA 6061–20%SiC and AA 6061–20%SiC–2%C was compared with that of the composites with the same reinforcement content but using coated particles and fibres. The influence that the modification of the matrix because of the incorporation of coatings on the reinforcements had on the mild wear behavior was investigated. The wear resistance of the composites increased when carbon fibres were added as secondary reinforcement and when coated reinforcements were used.

Looney et al. [25] used simulations to investigate the mechanical properties of aluminum matrix nanocomposites reinforced with nanosized silicon carbide. Study shows that reducing the size of the particles to the nanoscale dramatically increases the mechanical strength of these composites even at low particle volume fractions. The mechanical response of aluminum matrix reinforced with nanosized silicon carbide was analyzed using plane strain; discrete dislocation plasticity. The numerical results show improvements in the mechanical strength of the nanocomposite material with increasing particle volume fraction and decreasing particle size.

Farhat et al. [26] statistically analyzed the material related parameter on dry reciprocating wear behavior of aluminium silicon alloy matrix with SiC reinforced particles. The analysis show that the applied load, sliding distance, reciprocating velocity and percentage silicon weight in composite are the four important and controlling factors; counter surface temperature has a minor effect on the wear of the composite specimens in dry condition. The two-factor interactions have strong effect on the wear of the composite especially the interactions between load and sliding distance (8.07%) and that between load and weight percent silicon (3.28%) are influencing more compared to the other interactions.

Looney et al. [27] developed a model to explain the relationship between porosity and pore size. Al-Si alloy with different porosity levels was prepared using powder metallurgy technique. Dry sliding wear behavior was investigated against AISI 52100 bearing steel ball. It was found that the wear rate gradually rises with surface porosity and then drops as porosity and pore size reach critical levels. When pore size is in the same order of magnitude as the contact area between the counter-face and the specimen, the counter-face slides in to the pores; hence, pores become less effective in generating wear debris.

Hashim et al. [28] investigated the effects of supplying iron-oxide or iron particles and influence of the size of supplied powders on the transition from severe running-in to mild steady wear. The test was carried on pin-on disk machine. It was found that the supply of fine oxide particles with diameters of 0.5 μm and less accelerated the severe–mild wear transitions. The sliding distance of the severe–mild wear transition was reduced when finer particles were supplied, suggesting that fine particles easily form compacted layers on the wear surface. On the other hand, employing oxide particles of 1µm, no severe–mild wear transition was observed, producing a wear curve similar to that observed in the test, where no particles were supplied.

Wang et al. [29] reported a comparative study on abrasive wear behavior of aluminum metal matrix composite reinforced with alumina and zircon sand particles. Study mainly focused on the effect of particle size of the reinforcement on the wear and hardness of the composite. Study shows that Abrasive wear resistance of both the composites improves with the decrease in particle size. It was observed that the alumina particle reinforced composite shows relatively poor wear resistance property compared to zircon-reinforced composite. Decrease in particle size improves wear resistance property for both alumina and zircon reinforced composites as smaller particle reinforced composite has higher hardness and was more efficient in blunting SiC abrading surface. Zircon reinforced composite shows better wear resistance than alumina reinforced composite due to its superior particle–matrix bonding.

Lu et al. [30] studied high stress abrasive wear behaviour of aluminium alloy (ADC-12)–SiC particle reinforced composites as a function of applied load, reinforcement size and volume fraction, and was compared with that of the matrix alloy. Two different size ranges (25–50 and 50–80 µm) of SiC particles was used for synthesizing ADC-12–SiC composite. The volume fraction of SiC particles was varied in the ranges from 5 to 15 wt%. It was noted that the abrasive wear rate of the alloy reduced considerably due to addition of SiC particle and the wear rate of composite decreased linearly with increase in SiC content. The wear resistance of composite varies inversely with square of the reinforcement size. The wear rate of the alloy and composite was found to be a linear function of applied load but invariant to the abrasive size; at critical abrasive size, transition in wear behavior was noted.

Emmay et al. [31] investigated the effects of adding copper as alloying element and silicon carbide as reinforcement particles to Al–4 wt% Mg metal matrix. The friction and wear behavior of Al–Mg–Cu alloys and Al–Mg–Cu–based composites containing SiC particles were investigated at room conditions at a pressure of 3.18 MPa and a sliding speed of 0.393 m/s using a pin-on-disk wear testing machine. The wear loss of the copper containing alloys was less than that for the copper free alloys. It was observed that the volume losses in wear test of Al–Mg–Cu alloy decrease continuously up to 5%. Also it was found that the silicon carbide particles play a significant role in improving wear resistance of the Al–Mg–Cu alloying system. The formation of mechanically mixed layer (MML) due to the transfer of Fe from counter face disk to the pin was observed in both Al–Mg–Cu alloys and Al–Mg–Cu/SiC composites.

Wei et al. [32] investigated the effect of macroscopic graphite (Gr) particulates on the damping behavior of commercially pure aluminum (Al). Macroscopic graphite particulate-reinforced commercially pure aluminum metal matrix composites (MMCs) were prepared by pressure infiltration process. The damping characterization was conducted on a multifunction internal friction apparatus (MFIFA). The internal friction (IF), as well as the relative dynamic modulus, was measured at frequencies of 0.5, 1.0 and 3.0 Hz over the temperature range of 25–400 °C. The microstructural analysis was performed using transmission electron microscopy (TEM). The damping capacity of the Al/Gr MMCs, with three different volume fractions of macroscopic graphite reinforcements, was compared with that of unreinforced commercially pure aluminium specimens. The damping capacity of the materials was increased with increasing volume fraction of macroscopic graphite particulates.

Yan et al. [33] have studied an aluminium alloy metal matrix discontinuously reinforced with silicon carbide particulates, was synthesized using the spray atomization and co-deposition technique. Microstructural characterization studies were performed to provide an understanding of the intrinsic effects of carbide particulate co-injection in to the aluminium alloy metal matrix. The results reveal the ageing kinetics to be altered by the reinforcing ceramic particulates. Ambient temperature tensile tests revealed that the presence of particulate reinforcement in the aluminium alloy metal matrix degrades both strength and ductility.

Lavervia et al. [34] has studied the synthesis of discontinuously reinforced Metal-matrix composites using spray atomization and co-injection. Among these, spray processes offer a unique opportunity to combine the benefit associated with fine particulate technology with in situ processing, and in some cases, near-net shape manufacturing. Spray processing generally involves mixing reinforcements and matrix under highly non-equilibrium conditions, and as a result, these processes offer the opportunity to modify the properties of existing alloy systems, and develop novel alloy compositions. In principle, such an approach will inherently avoid the extreme thermal excursions, with concomitant macro segregation, normally associated with casting processes. Furthermore, this approach also eliminates the need to handle fine reactive particulates, normally associated with powder metallurgical processes.

Chaudhury et al. [35] have the synthesized aluminium based metal composites by a new spray forming technique. In their investigation,Al-2Mg-7TiO_2 composite was successfully spray atomized and co-deposited on a rotating substrate. The author described the processing methodology for the fabrication of Al-TiO_2 composites, which involves simultaneous introduction of aluminium melt and rutile particles through concentric tubes followed by inert gas atomization and deposition on a rotating copper substrate placed vertically below the attomiser at some predetermined height. Mechanical and physical properties of as-cast and composite materials were also discussed. For comparison, Al-2Mg-5TiO_2 composite was also prepared by stir cast method and characterized.

Ferrarini et al. [36] have studied the microstructure and mechanical properties of spray deposited hypoeutectic Al-Si alloy. The microstructure and the tensile properties of an Al–8.9 wt.% Si–3.2 wt.% Cu–0.9 wt.% Fe–0.8% Zn alloy processed by spray forming was investigated. The alloy was gas atomized with argon and deposited onto a copper substrate. The microstructure was evaluated by optical microscopy (OM), scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). Small faceted dispersoids observed surrounding equiaxial α-Al matrix were identified by SEM–EDS as silicon particles. Sand cast samples with the same composition showed a columnar dendritic α-Al matrix, Al–Si eutectic, polyhedric α-AlFeSi and needle-like β-AlFeSi intermetallics. In the spray formed material the formation of the Al–Si eutetic was suppressed, and the formation of the α-AlFeSi and β-AlFeSi intermetallics was strongly reduced. The fine and homogeneous microstructure showed an aluminium matrix with grain size ranging from 30 to 40 μm, and particle size of the silicon dispersoids having a mean size of 12 μm. Room temperature tensile tests of the spray formed alloy showed relative increasing of strength and elongation when compared with the values observed for the conventionally cast counterparts. These results can be ascribed to the refined microstructure and the scarce presence of intermetallics of the spray formed material.

Hashim et al. [37] proposed that processing variables such as holding temperature, stirring speed, size of the impeller, and the position of the impeller in the melt are among the important factors to be considered in an impact on mechanical properties. These are determined the production of cast metal matrix composites as these have by the reinforcement content, its distribution, the level of the intimate contact of the wetting with the matrix materials, and also the porosity content. Therefore, by controlling the processing conditions as well as the relative amount of the reinforcement material, it was possible to obtain a composite with a broad range of mechanical properties. The method is potentially very cost effective, but widespread adoption is dependent on a satisfactory resolution of the technical difficulties presented.

Surappa et al. [38] analyse have mentioned that it is necessary to remove various faculty problems in order to intensify the engineering usage of AMCs. Design, research and product development efforts and business development skills are required to overcome these challenges. In this pursuit there was an imperative need to address the following issues. Science of primary processing of AMCs need to be understood more thoroughly, especially factors affecting the microstructural integrity including agglomerates in AMCs. There was need to improve the damage tolerant properties particularly fracture toughness and ductility in AMCs. Work should be done to produce high quality and lowcost reinforcements from industrial wastes and by-products. Efforts should be made on the development of AMCs based on non-standard aluminium alloys as matrices. There is a greater need to classify different grades of AMCs based on property profile and manufacturing cost. There is an urgent need to develop simple, economical and portable non-destructive kits to quantify undesirable defects in AMCs.

Chaudhary et al. [39] have proposed that 11 wt% of TiO_2 could be successfully incorporated into the Al-2Mg melt by vortex method. Greater degree of segregation of TiO_2 was observed at the top and bottom of castings. Micro voids are observed in the particles enriched zone. A phase transformation was observed during the resistivity and DSC measurements owing to the precipitation of $TiAl_3$ phase. Cold and hot rolling of the composite was successfully carried out to 40% and 50% reduction, respectively. Hardness of the composite was greater than the base alloy, which can be attributed to the presence of higher dislocation density in the matrix due to the difference in thermal properties between the matrix and reinforcement.

CHAPTER - 4

EXPERIMENTAL WORK

In the present work LM13 alloy has been chosen for matrix alloy as it is used as commercial piston alloy and contains around 1% Mg which is necessary for wetting of dispersed in the matrix. The reinforcing material selected was rutile of fine particle size (5-20 µm) and coarse particle size (106-125µm). Table-4.1 gives the details of the chemical composition of LM13. Table-4.2 gives the details of the chemical composition of rutile.

4.1 Matrix material

Commercial grade near eutectic Al-Si alloy (LM13) was used in the present investigation. LM13 alloy was obtained in the form of ingots. The compositional analysis of LM13 alloy is given in the Table 4.1

Table 4.1 Compositional analysis of LM13 alloy

Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Pb	Sn	Al
11.800	0.365	1.230	0.411	0.940	0.210	0.0254	0.940	0.0289	0.005	Balance

4.2 Reinforcement material

Rutile is a mineral primarily composed of titanium dioxide, TiO_2. Rutile has highest refractive indices of any known mineral and also exhibits high dispersion as reinforcement material. Rutile was obtained from rare Indian Rare Earth Limited, Orissa.

The powder was ball milled for long duration in batches. Finally it was viewed and two fraction comparising of fine and coarse grade was related to present work.

Table 4.2 Chemical composition of rutile

TiO_2	Fe_2O_3	P_2O_5	ZrO_2
94.40%	1.90%	0.05%	1.80%

4.3 Preparation of composite:

The composites were developed by stir casting route in fig 4.1. the casting unit is shown for prepration of composite. LM13 alloy in the required quantity was taken in a graphite crucible and melted in an electric furnace. The temperature of melt was raised to 750°C. This molten metal was stirred using a graphite impeller at a speed of 630 rpm to create vortex. The impeller blades were designed in such way that helps in vortex formation. Rutile particles of fine grade (5-20µm) and coarse grade (106-125µm) were taken separately. Defined ratio of fine and coarse particles keeping total percentage up to 15wt.% were taken. Rutile powder was preheated at 450°C to drive off the moisture. After the formation of vortex in the melt, the rutile powder was charged inside the vortex at the rate of 20–25 g/min. into the melt with the help of funnel kept on top of vortex. The vortex method is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy. Stirring of melt was continued for another 5 min. even after the completion of particle feeding to ensure homogeneous distribution of the rutile particles. The molten mass was finely poured into the metal mould and allowed to solidify at room temperature. During production of composite, the amount of LM13 alloy, stirring duration and position of stirrer in the crucible were kept constant to minimize the contribution of variables related to stirring on distribution of second phase particles. During fabrication of the composite, rutile particles of two different size ranges were chosen. In order to compare and correlate the effect of particle size on mechanical and tribological properties, two different composites containing a total of 15wt.% reinforcement were fabricated. In the first combination there was 15 percent coarse (106-125 μm) rutile particles, whereas, in the second composite 15 percent fine rutile particles were taken.

(a) (b)

Fig.4.1: Stir casting setup (a) d.c.motor mounted on electronic resistance furnace (b)stir casting in the molten composite in the furnace.

4.4 Characterization:

The cast composite was mechanically polished and etched with Kehler reagent and finally the microstructure was analyzed under optical and scanning electron microscope. For wear test pins were made and tested under different conditions. Details of these are given below.

4.4.1 Wear testing

Wear test were conducted using polished pin samples with flat surfaces in the contact region but rounded in the corner and cleaned with acetone to remove dust or grease from the surfaces. Dry sliding wear tests were carried out against the counterface of a hardened and polished disk made of EN-31 steel having 65 HRC at a relative humidity of 36-56%. A done on pin-on-disc machine supplied by Ducom, Bangalore (model TR20-CH400) as shown in fig. 4.2. The test were conducted at the loads of 1,2,3,4 and 5kg at the constant sliding velocity of 1.6m/s. The wear characteristics has been noted down at different temperatures i.e. 50°C ,100°C,150°C,200°C,250°C,300°C. The wear debris obtained after the 30 min of sliding of each test run were examined under SEM. The worn surfaces of the samples were also examined under SEM to know the wear mode of the worn surfaces.

Fig.4.2: Pin-on-disc machine

4.4.2 Optical microscopy:

The composites produced were examined by optical microscope to analyze the microstructure. A section was cut from the castings which is first belt grinded followed by polishing with different grade of emery papers. After that they were washed and again cloth polishing of the sample was done. After etching with Keller’s reagent they were under optical microscope at different magnifications as shown in fig. 4.3.

Fig.4.3: Optical microscope

4.4.3 Scanning electron microscopy:

Microstructural characterization studies were conducted on reinforced samples. This is accomplished by using scanning electron microscope. The composite samples were metallographically polished prior to examination. Characterization is done in etched conditions. Etching was accomplished using Keller’s reagent. Microscopic studies to examine the morphology, particle size and micro structure were done by a JEOL 6480 LV scanning electron microscope (SEM) equipped with an energy dispersive X-ray (EDX) detector of Oxford data reference system. Micrographs are taken at suitable accelerating voltages for the best possible resolution using the secondary electron imaging as shown in fig.4.4.

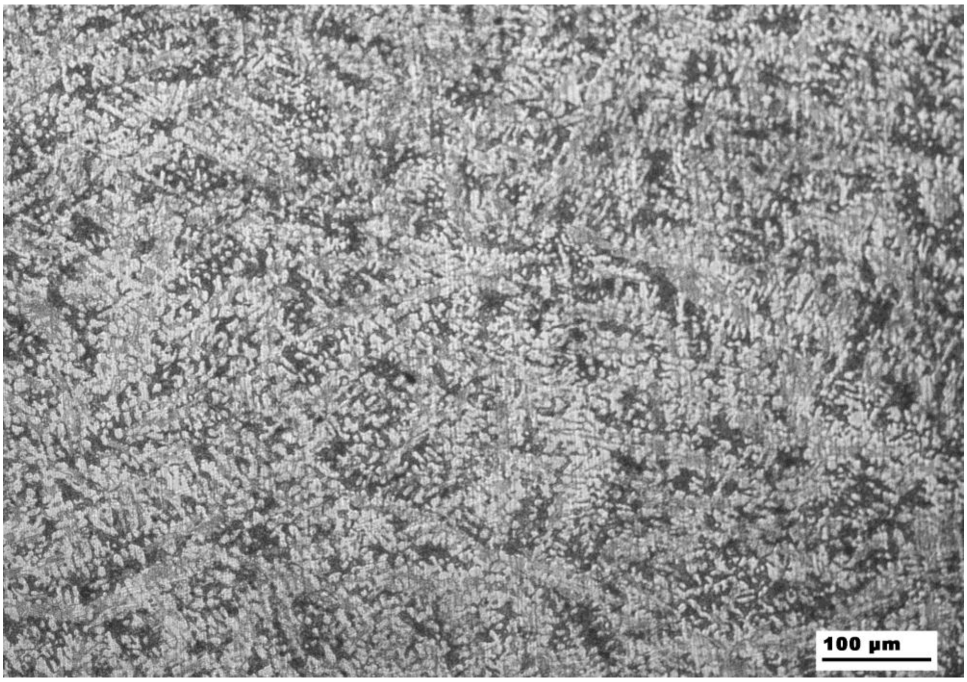
Fig.4.4: Scanning electron microscope

CHAPTER - 5

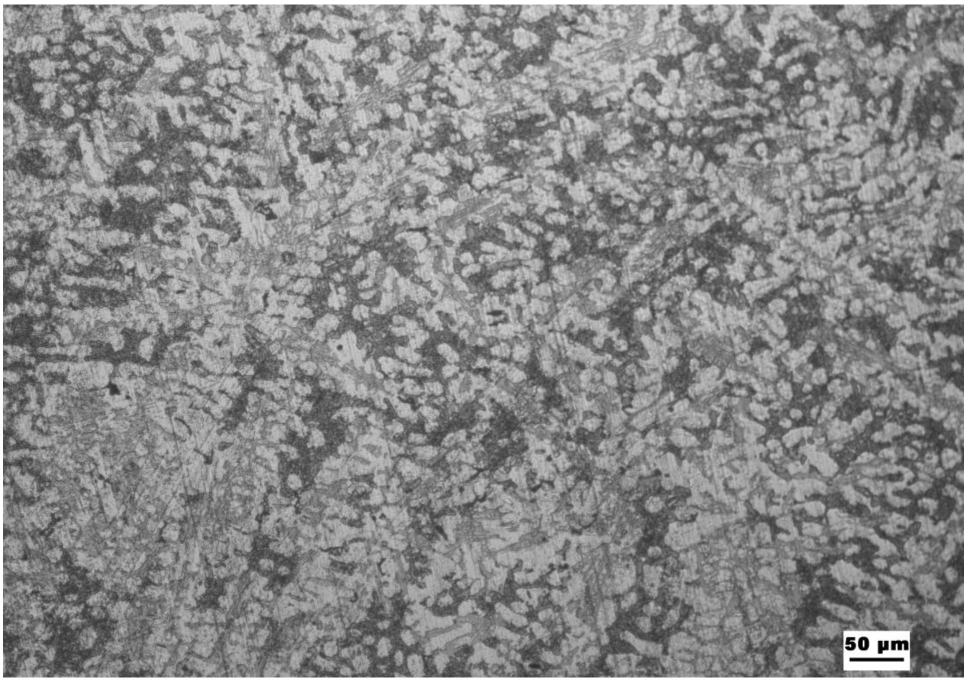
RESULT AND DISCUSSION

5.1 Microstructural Analysis

The optical micrographs of composite-A reinforced with 15 % fine particles (20–32 µm) are shown in Fig. 5.1(a). The micrograph shows fairly uniform distribution of reinforced particles in alloy matrix. Uniform distribution of second phase particles is required for achieving better wear resistance and mechanical properties. Fairly uniform distribution of particles in a molten alloy is achieved due to the high shear rate during stirring which also minimized the particle settling tendency. However, agglomeration of particles is also observed which is visible at certain places (Fig. 5.1 a, b). Figure 2b shows the higher magnification micrograph of the composite-A where fragmented dendrites in the alloy matrix can be seen, though limited dendritic growth in the particle depleted region is also visible. This growth has occurred because of clustering of rutile. Fine size rutile are pushed or engulfed by advancing solid–liquid interface creating sufficient space inside the matrix, which leads to growth of dendrite [40]. Dendritic fragmentation can be attributed to the shearing of initial dendritic arms by the stirring action. During particle addition, local solidification of the melt occurs which is induced by the particles as there is a temperature difference between the particle and the melt. These effects give rise to a dendrite–cell transition as the density of particles is increased. Also the length of the dendrite is reduced in the presence of the particles [40]. SEM micrograph of composite-A also exhibits homogeneous distribution of fine particle whereas at some places particle clustering and porosity due to entrapment of air during pouring are also observed (Fig. 5.1c). Figure 5.1d shows the homogeneous distribution of coarse particles in the alloy matrix. The mechanical stirring not only distributed the particles homogeneously but also delays the particle settling prior to solidification. Good bonding between particle and alloy matrix is exhibited in Fig. 5.1e. The smooth interface provides better mechanical and tribological properties as transfer of load occurs through the interface [1, 2]. Figure 5.1(e) at higher magnification shows the presence of long dendrite in areas where particle is not present. The second phase hard particle restricts the growth of dendrite and modifies the matrix with more refined structure leading to improvement in strength. Similar modification in silicon morphology was reported in earlier work by Kaur and Pandey [41]. SEM micrograph of composite-B depicts homogeneous distribution of coarse particles, which are arranged in random fashion due to limited amount of coarse particle reinforcement (Fig. 5.1f). However, fine particles have the tendency of clustering though it is not much in this case as compared to composite-A.



(a)



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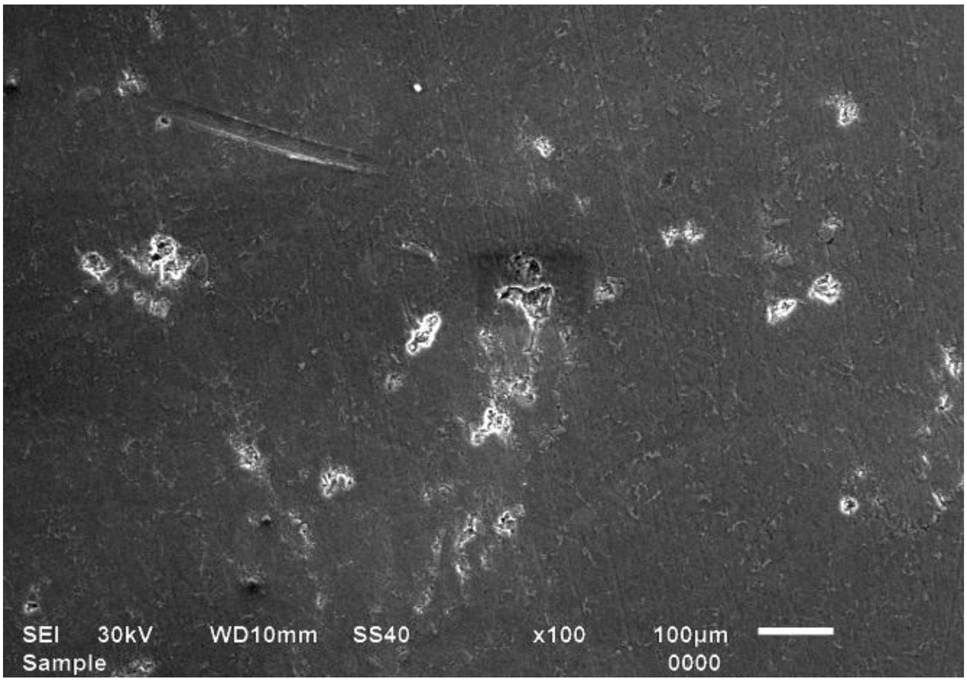

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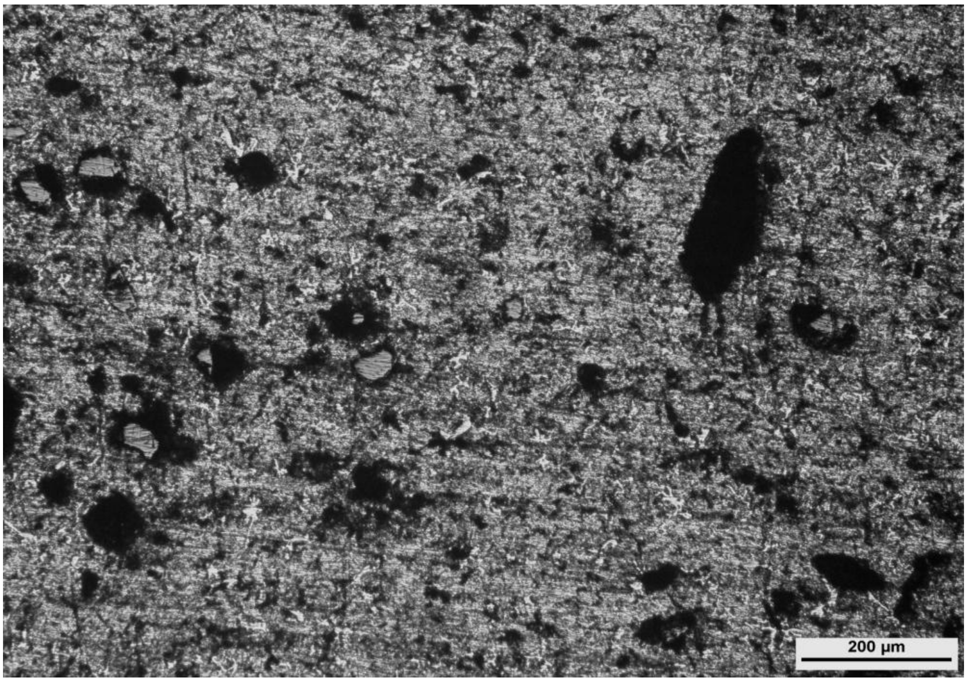

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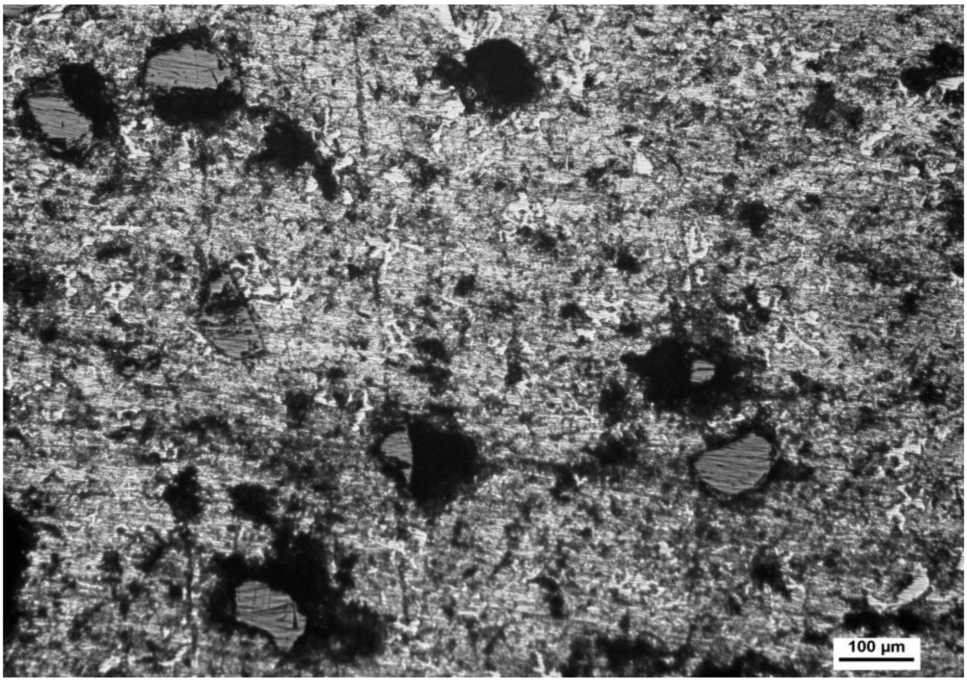
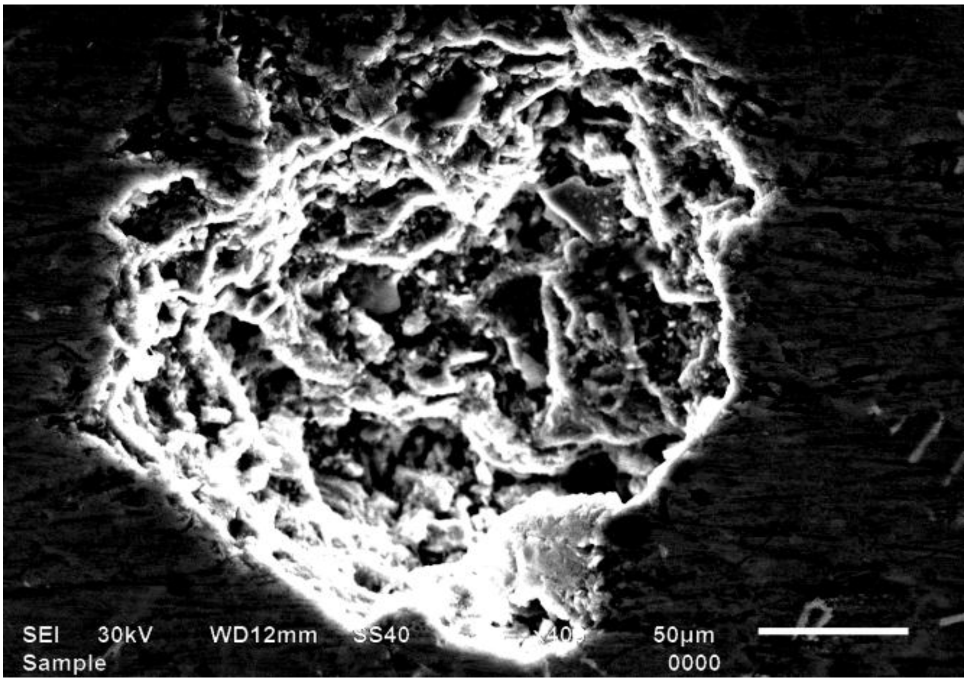


(e)



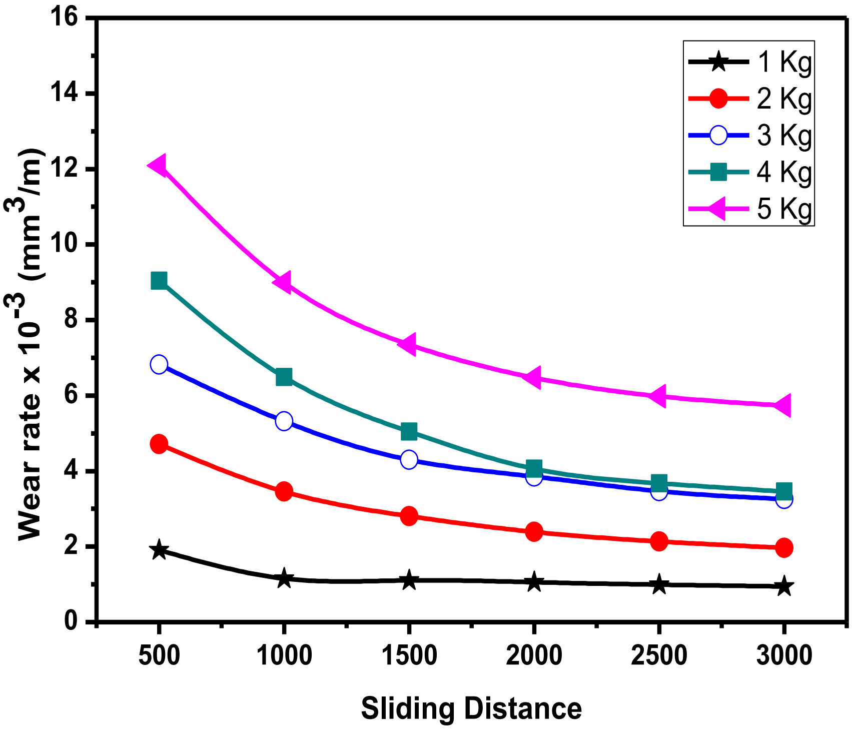
(f)

Fig.5.1: Optical micrograph of composites containing (a)15% fine particles at 200X (b) 15 % fine particles at 500X (c) 15% fine particles (SEM micrograph) (d) 15% coarse particles at 50X (e) 15% coarse particles at 100X (f) 15% coarse particles (SEM micrograph).

5.2 Wear analysis:

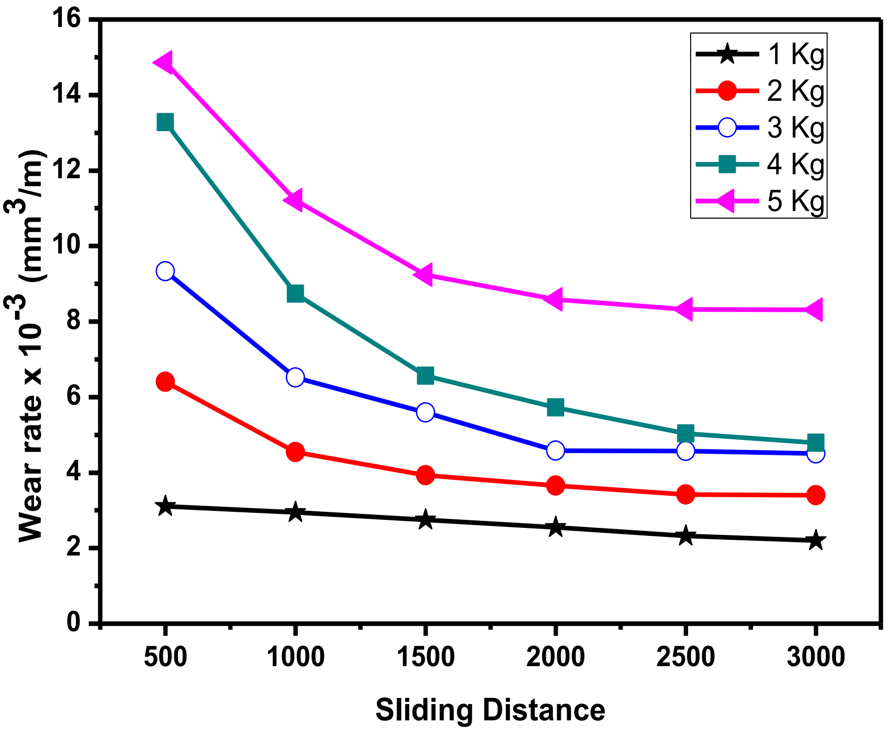
5.2.1 Effect of applied load on wear rate:

The variation of wear rate with sliding distance of the composite has been investigated at five different loads which are shown in Fig.5.2a. It is observed that wear rate of the composites increases with the increase in applied load. The curve reveals two different type of wear behaviour under an applied load. The steep rise in the initial stage gives rise to greater wear corresponding to the run in wear. However, steady state wear is obtained in the later stage. Moreover, with increase in load the run-in and steady state wear rate are also found to increase. These results are analogous to results reported earlier under similar sliding conditions by Chaudhury et al. [35] for stir cast Al-2Mg-11TiO_2 composites. The wear behavior of composite-A shows that steady state wear is approachable after 1000 m sliding distance (Fig 5.2 a) while in composite-B as shown in Fig. 5.2 (b) steady state wear is delayed and occurs after sliding distance of 1500 m at low loads whereas on high loads the steady state wear is approachable at 2000 m sliding distance. Run-in wear of composite-B is higher as compared to composite-A at all applied loads as shown in Fig. 5.2 (a-b). This indicates that fine particle reinforced composite-A exhibits better wear resistance as compared to coarse particle reinforced composites-B. These results are in good agreement with the earlier reported results [21]. After analyzing wear behavior of composites, it is observed that fine particle reinforcement composite containing in 15 wt.% reinforcement is effective for enhancing wear resistance. Fine particles are better reinforcement for wear behavior as compared to coarse particles. Composite-A exhibits better wear resistance due to good interfacial bonding which is necessary as load transfer occurs through interface and also debonding of reinforcement particles results in increase in wear rate.



(a)

Fig: 5.2 (a) Wear rate vs sliding distance of composite-A containing fine particles (0-20μm)



(b)

Fig. 5.2 (b) Wear rate vs sliding distance of composite-B containing coarse particles (106-125µm)

5.2.2 Effect of temperature on wear rate:

Temperature of the environment also plays an important role in the durability of the material. Effect of temperature of the wear behaviour for both the composites was studied with varying the temperature from 50°C to 300°C. Fig 5.3(a) shows the wear rate vs temperature curve for composite-A with varying load from 1kg to 5 kg. Composite-B containing fine particle reinforcement (5-20µm) shows that the wear rate increases slightly with an increase in temperature from 50˚C to 150˚C for all applied loads. Increment in wear rate with increase in temperature is due to the softening of matrix, which supports more material removal during the wear test. However, at high temperature (around 200°C) wear rate of the composite decreases significantly. This decrement in wear rate is due to the formation of oxide layer at near 200°C [27].

Presence of oxide layers on the surface of composite avoid the direct metal to metal contact between the surfaces of sample and steel disc, which helps to improve the wear rate of material. However with increase in temperature (250°C) and at higher load(4kg and 5 kg), tearing of oxide layers during the wear rate expose more area in metal to metal contact which supports the higher wear rate. At the much higher temperature (near 300°C) wear rate of the composite increase significantly which is due to plastic deformation in matrix. At higher temperature due to softening of matrix plastic deformation was observed during the wear test at over all wear rate of the composite at different temperature increases with increase in applied load from 1kg to5 kg. However, for coarse particle composite it decreased slightly. The interesting point is that a sharp transition in wear rate is observed above 150˚C and rate becomes minimum for both the composites at 200˚C. With further increase in temperature, the wear rate increases from 200°C to 300°C. In composite-B at temperature 200°C to 300°C different transitions can be seen in the wear rate which is slightly increased at 1kg, 4kg and 5kg load and slightly decreasing at 2kg and 3 kg loads.

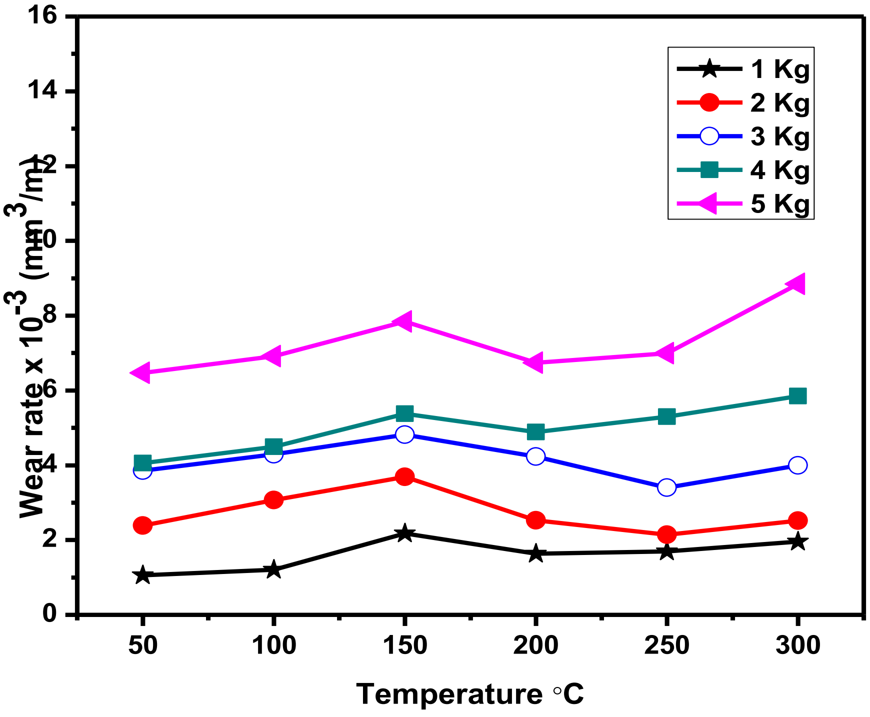


Fig 5.3 (a): Wear rate vs temperature of composite-A.

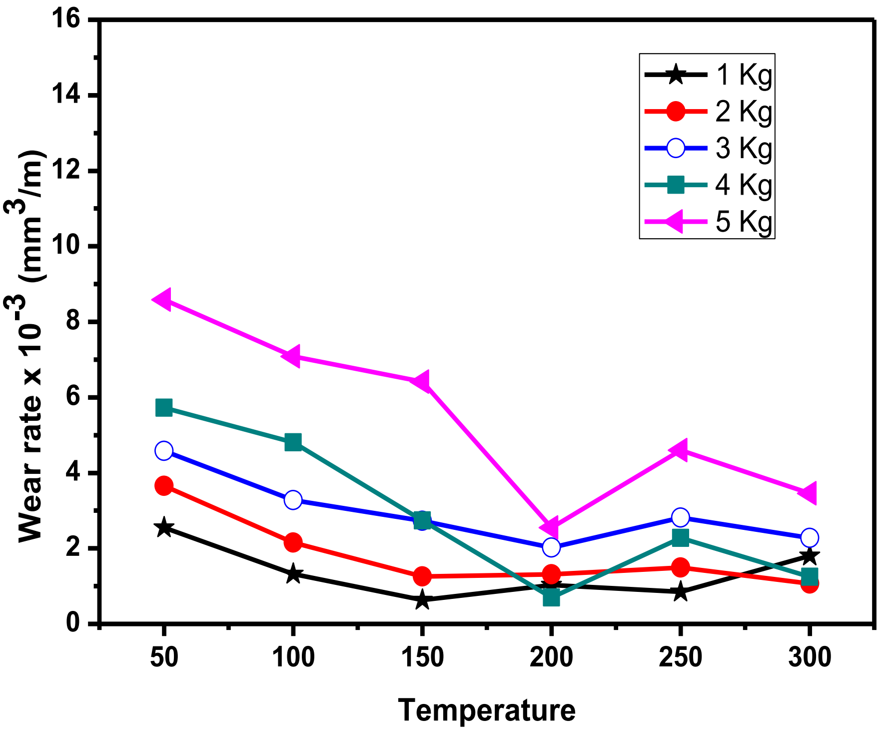
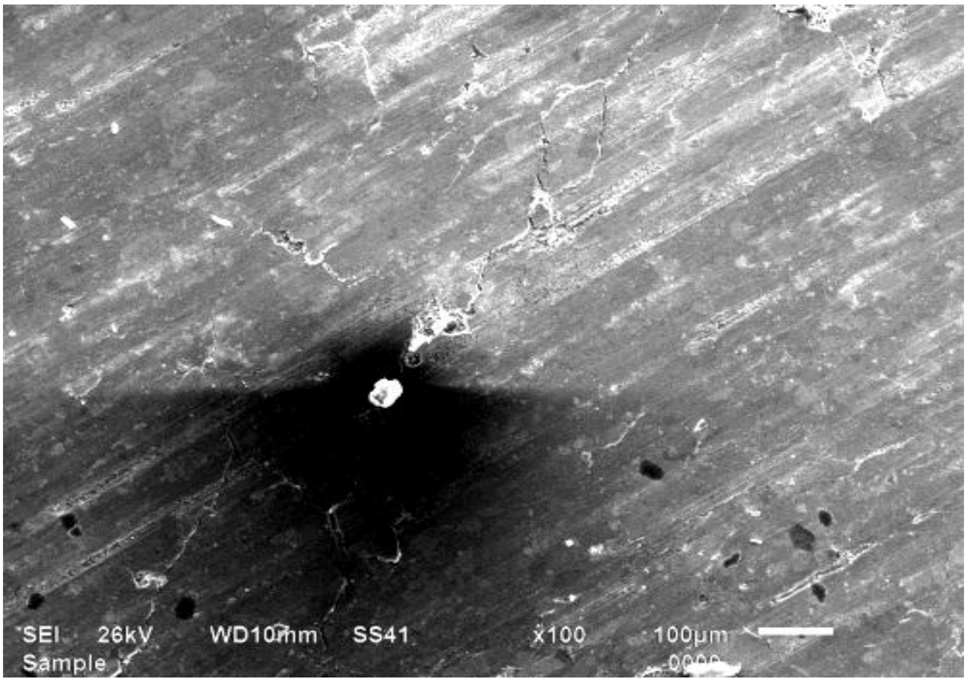


Fig 5.3 (b): Wear rate vs temperature of composite-B

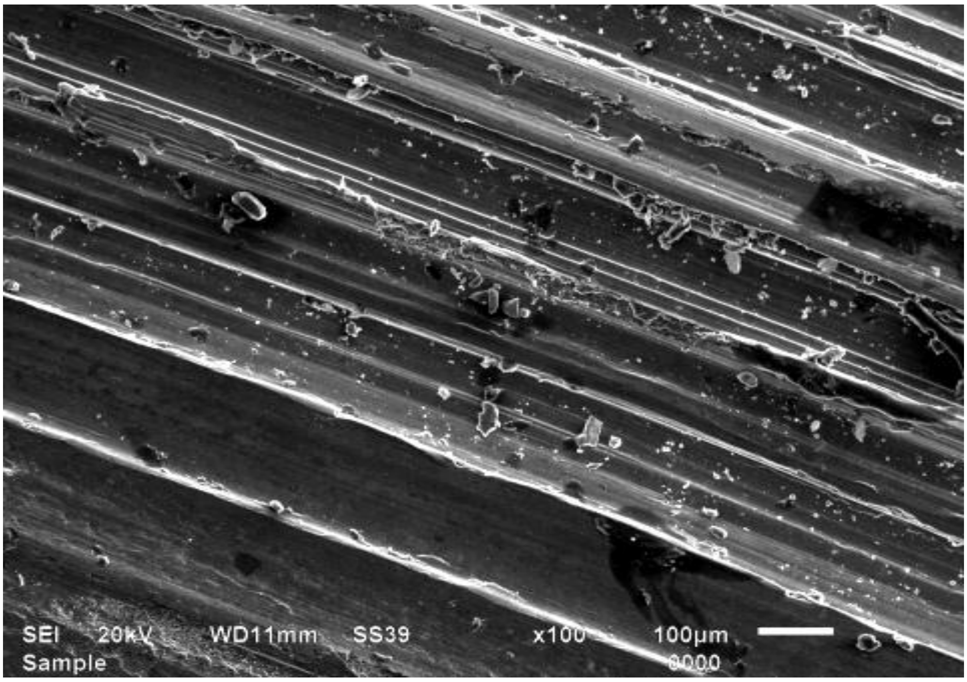
But in the case of the composite-B which contains coarse particles (106-125µm) as shown in fig.5.3b. The wear rate decreases with increase in temperature, this is because there is a lot of porosity and its boundaries get shifted and reinforcement get struck in it and as a result its wear rate decreases with increase in temperature. Gradual decrease slope can be seen from 50°C to 150°C for all the loads but at 200°C the wear rate is lowest for higher loads due to formation of oxide layer. At 250°C the wear rate increases at all loads and then decreases at 300°C due to the entrapment of the reinforcement in the voids shifting its boundaries, except 1kg load at which the wear rate first decreases and then increases at 300°C. The wear rate of all composite at high load (5kg) with variation in temperature from 50˚C to 300˚C is shown in Fig.5.3 (b). The fine particle reinforced composites-A exhibit better wear resistance as compared to coarse particle reinforced composites-B. For better wear behavior good interfacial bonding of reinforcement particle with the matrix is good. In composites, the fine reinforced particles have more interfacial area as compared to coarse reinforced particles and occupy more volume. Moreover, for composite-B the wear rate is higher as compared to composite-A in the lower temperature range (50- 150˚C) and shows almost similar nature as can be seen in Fig.5.3 (b). Wear rate of the all composites decreases with increasing temperature from 150˚C to 200˚C. At this temperature the formation of oxide layer on the sliding surface occurs and the wear rate is decreased for of all composites. Martin et al.[42] have measured the wear rate for 2618 Al alloy reinforced with 15 vol% SiC in the temperature range 20˚C to 200˚C which a transition from mild to severe wear and was observed when temperature was increased. All the composites show the increment in wear rate with increase in temperature from 200˚C to 250˚C followed by further decrease with increasing temperature up to 300˚C at 5kg load. This variation in wear rate is because of removal of oxide layer due to continuous sliding action which results in direct metal to metal contact. However, coarse particle reinforced composites shows the high wear rate as shown in Fig.5.3 (b). At elevated temperatures, the strain transfer phenomenon to the interfaces becomes less effective as the surrounding matrix alloy begins to soften.

5.2.3 Study of wear track and wear debris:

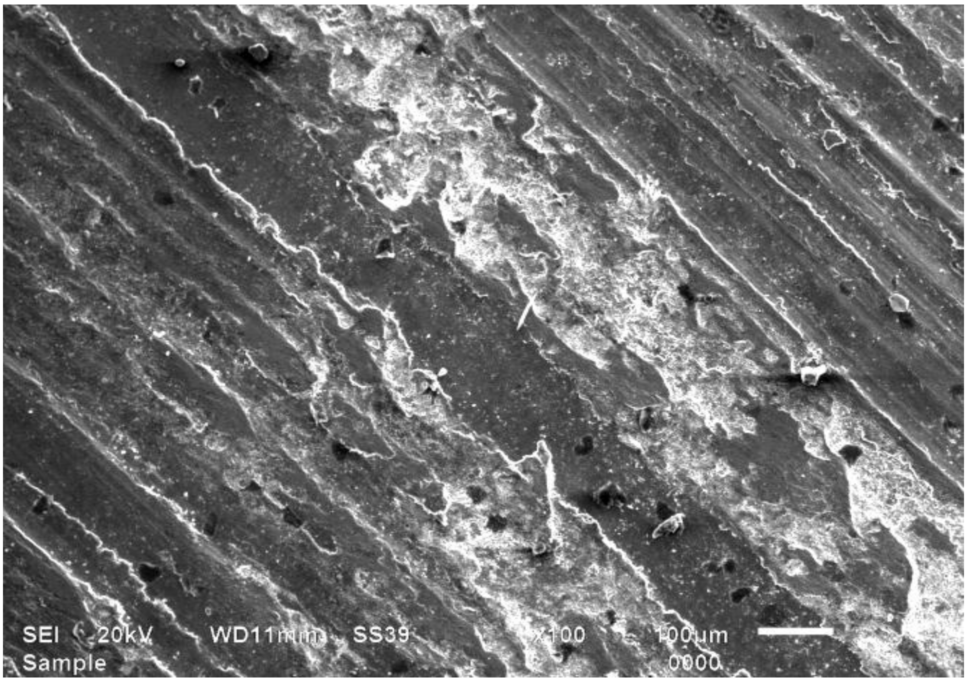
The morphologies of worn out surfaces of pins and debris offer clues to the wear mechanisms involved during sliding the sample against load. The scanning electron microscope (SEM) micrographs of wear tracks of the composites-A tested at a load of 1 kg at 50ºC, 150ºC and 300ºC are shown in fig. 5.4. Onset of transition of mild to severe wear is observed at high temperature by formation and delamination of oxide layers on the wear surface (at 300^0C) as shown in figure 5.4 (c). One of the common feature observed in both lower and higher temperature, is the formation of grooves and ridges running parallel to the sliding direction in composites. The Fig.5.5 shows the SEM micrograph of worn pin composite-B reinforced with coarse size rutile particles at a load of 1kg at 50ºC, 150ºC and 300ºC. The worn surfaces are smooth and ploughing strips are very shallow on the surface and very small damaged spots in the form of craters. The Fig.5.6 (a, b and c) shows the SEM micrograph of worn pin composite-A reinforced with fine size particles of rutile at a load of 5kg at 50ºC, 150ºC and 300ºC. The presence of grooves of varying sizes was observed frequently on the worn surfaces. The formation of such grooves during the sliding of composites observed is on numerous occasions is linked to the process of delamination. At this load higher magnification micrograph shows ploughing marks perpendicular to sliding direction as shown in Fig. 5.6 (b). At 1kg load on 150°C, the craters and patches are observed and ploughing marks got deeper as shown in Fig. 5.6(b). The white small particles are also visible, which are originated from the rupture of mechanically mixed layer, which is shown in Fig. 5.6(c). Flow of materials along the sliding direction, generation of cavities due to delamination of surface materials and tearing of surface materials indicates about the transition from mild to severe wear at high temperature. Figure 5.7 (a, b and c) at 5kg load on 50°C, 150°C and 300°C shows microcrack initiation and delamination of alloy matrix and the ploughing marks become deeper and craters are observed and excessive removal of material is seen. This behavior is characterized as severe wear behaviour, in which material removal is accelerated. Material removal is excessive as craters become deeper. Flakes of wear debris are also visible in this micrograph. At 5Kg load the material removal is excessive due to high load. The craters and ruptured mechanically mixed layer is observed. The crack propagation is along the sliding direction and also in perpendicular direction of sliding, which result in material removal by delamination. As load and temperature increases, the wear rate increase which lead to removal of excessive material. Mondal et al. [30] suggested that the flow of material in wavy form (serration) and large cavity due to delamination indicates the greater degree of softening of surface materials,


SEI 26kV WD10mm SS41 x100 100µm
Sample 0000

(a)

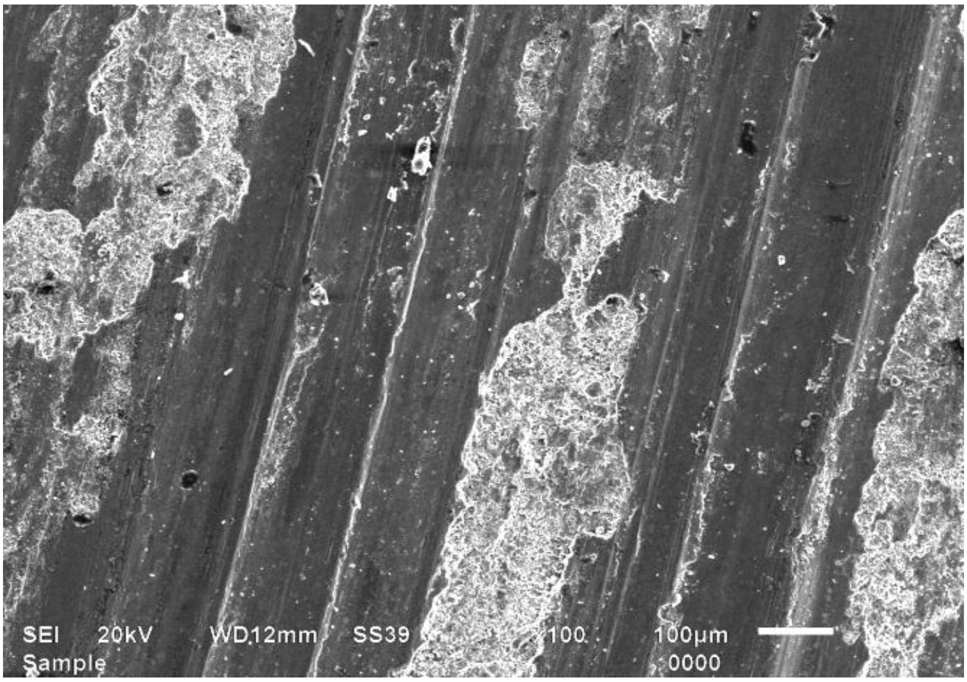

SEI 20kV WD11mm SS39 x100 100µm
Sample 0000

(b)

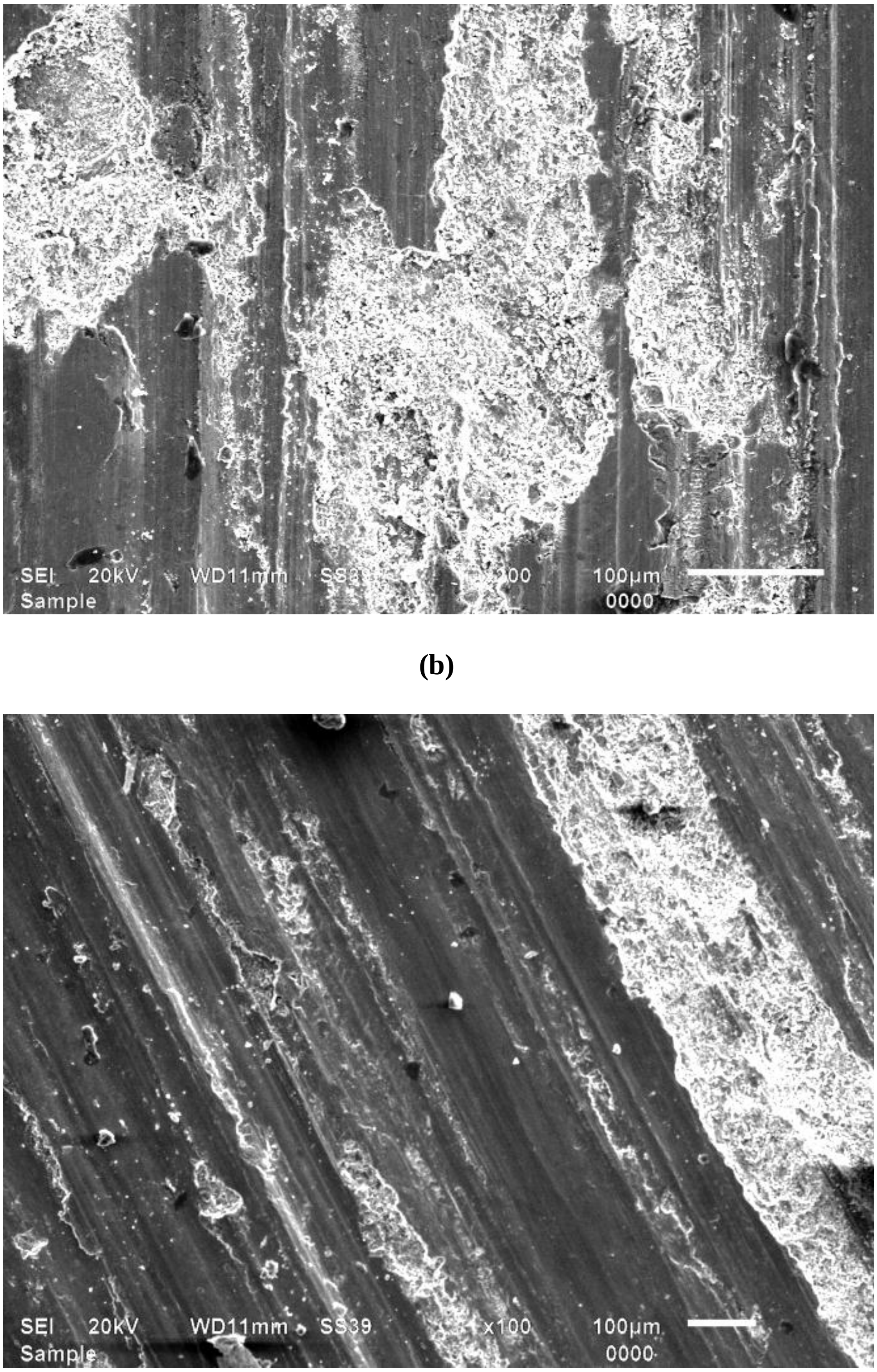


(c)

Fig. 5.4: The SEM micrograph of worn pin surface of composite-A at 1kg load (a) at 50°C, (b) at 150°C, (c) at 300°C.



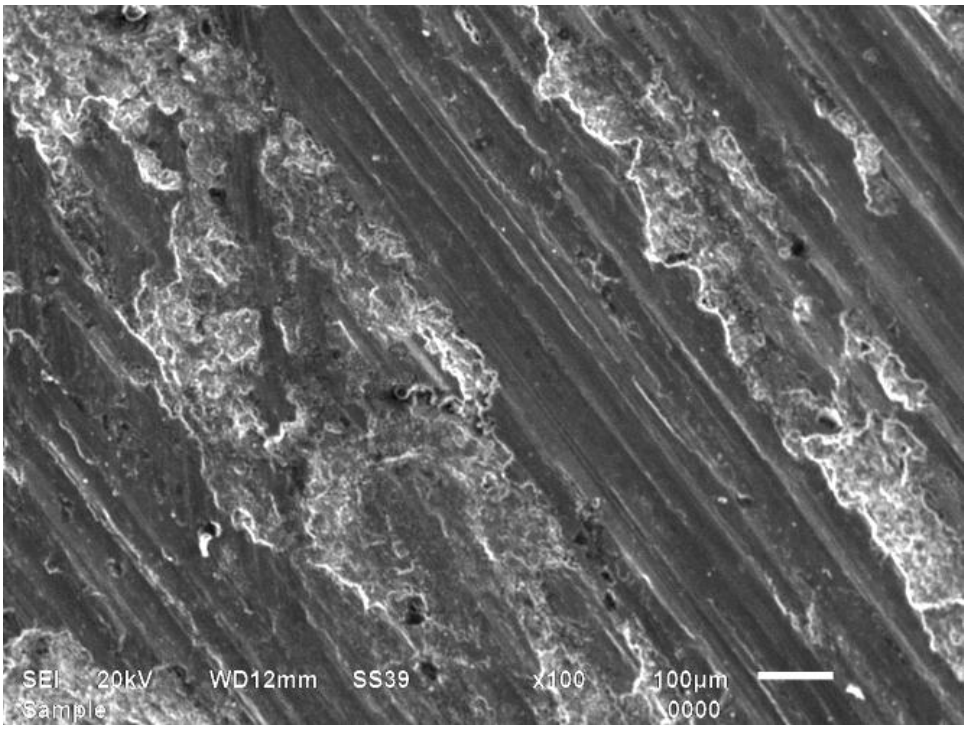
(a)



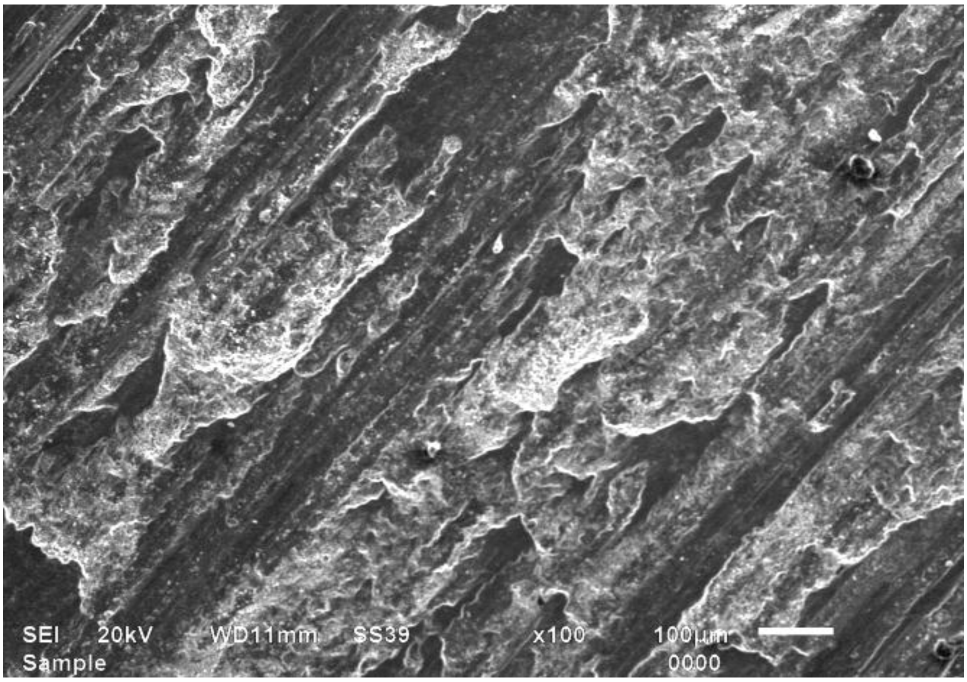
(b)

(c)

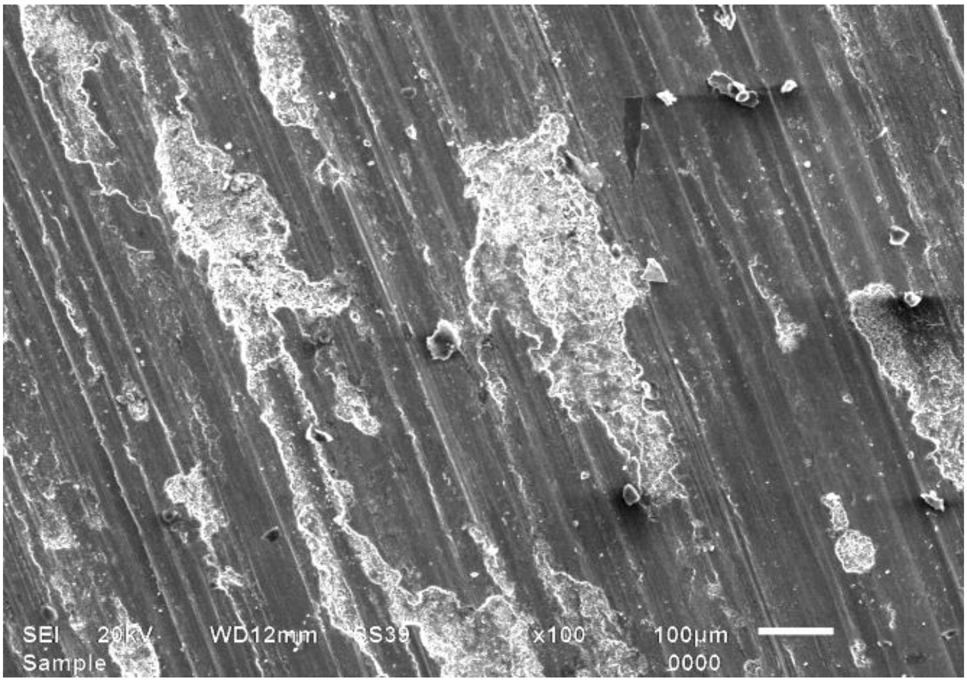
Fig. 5.5: The SEM micrograph of worn pin surface of composite-B at 1kg load (a) at 50°C, (b)at 150°C, (c) at 300°C.


SEI 20kV WD12mm SS39 x100 100µm
Sample 0000

(a)

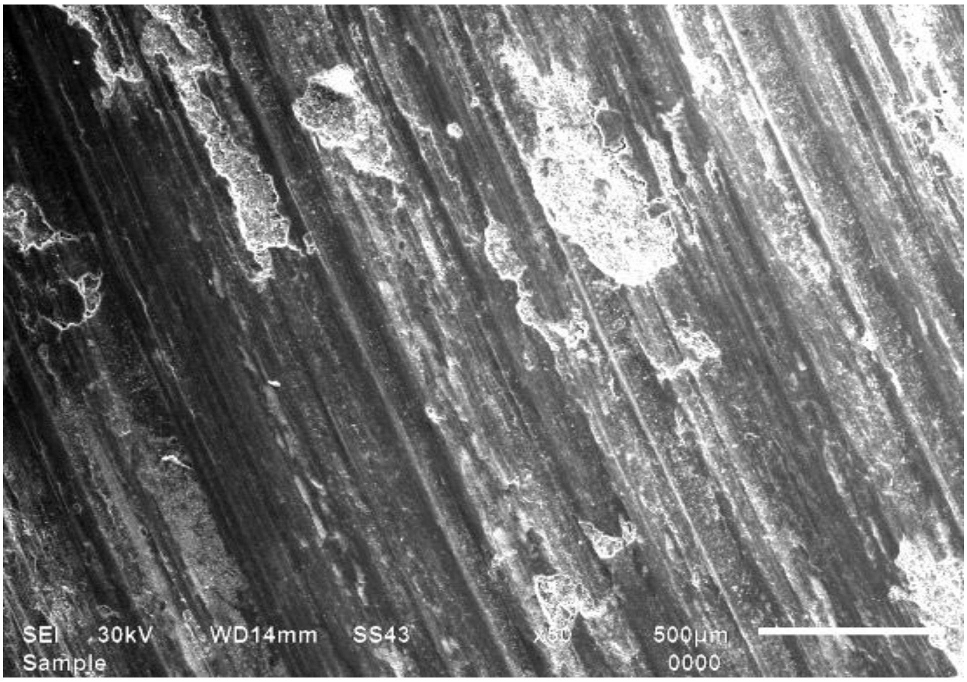

SEI 20kV WD11mm SS39 x100 100µm
Sample 0000

(b)

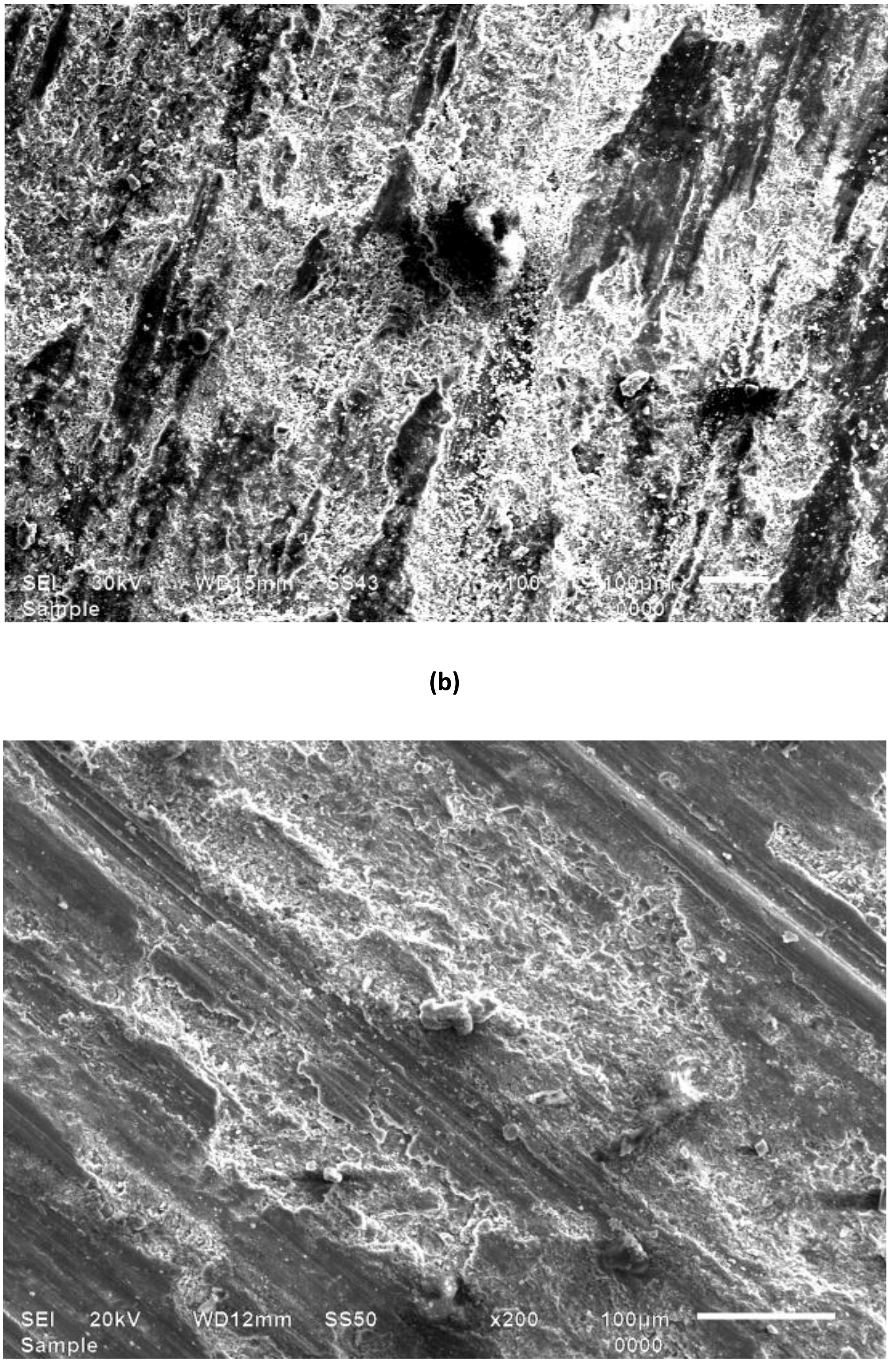


(c)

Fig. 5.6: The SEM micrograph of worn pin surface of composite-A at 5kg load (a) at 50°C,(b)at 150°C,(c) at 300°C.



(a)

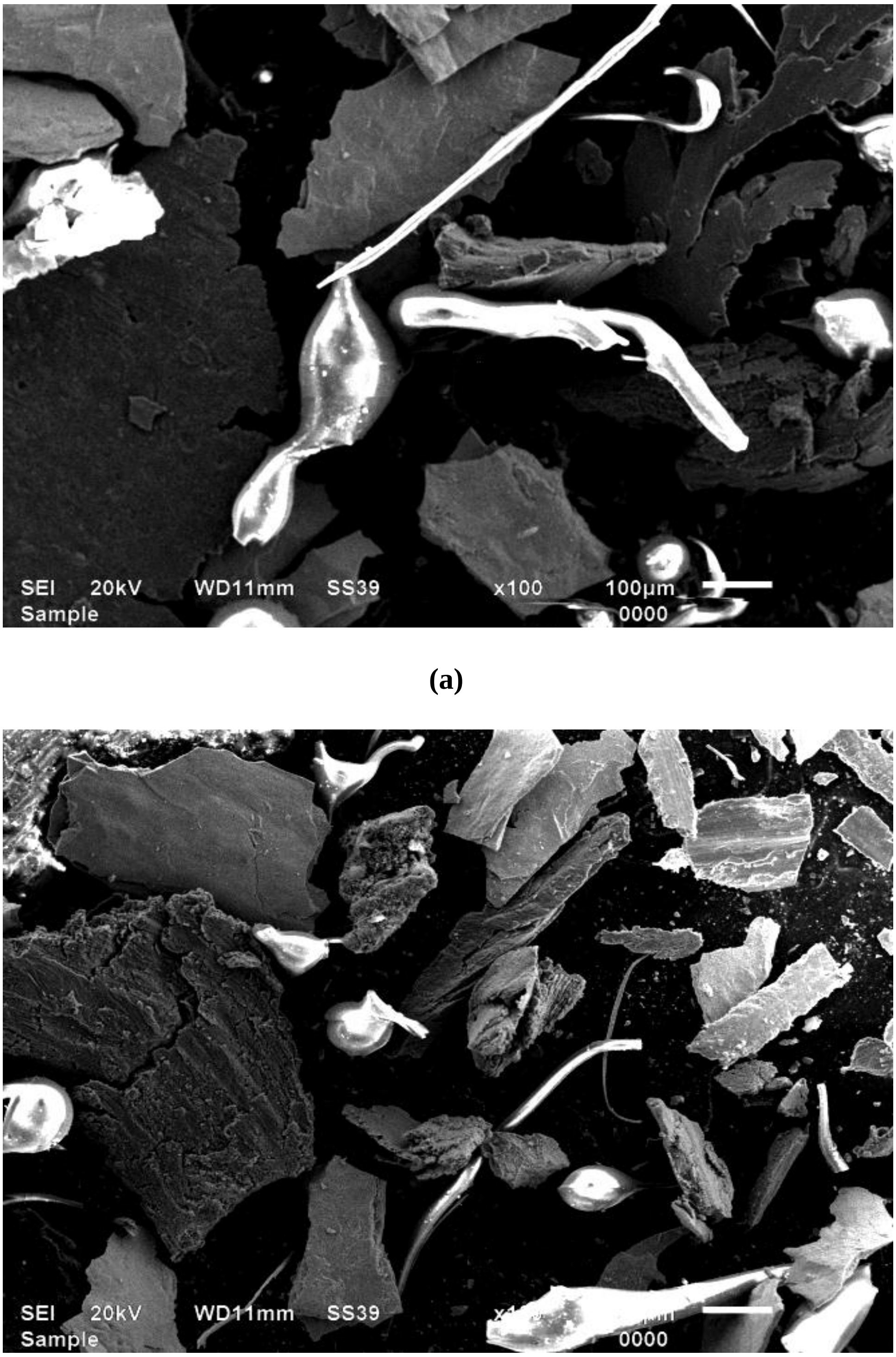


(b)

(c)

Fig. 5.7: The SEM micrograph of worn pin surface of composite-B at 5kg load (a) at 50°C, (b)at 150°C, (c) at 300°C.

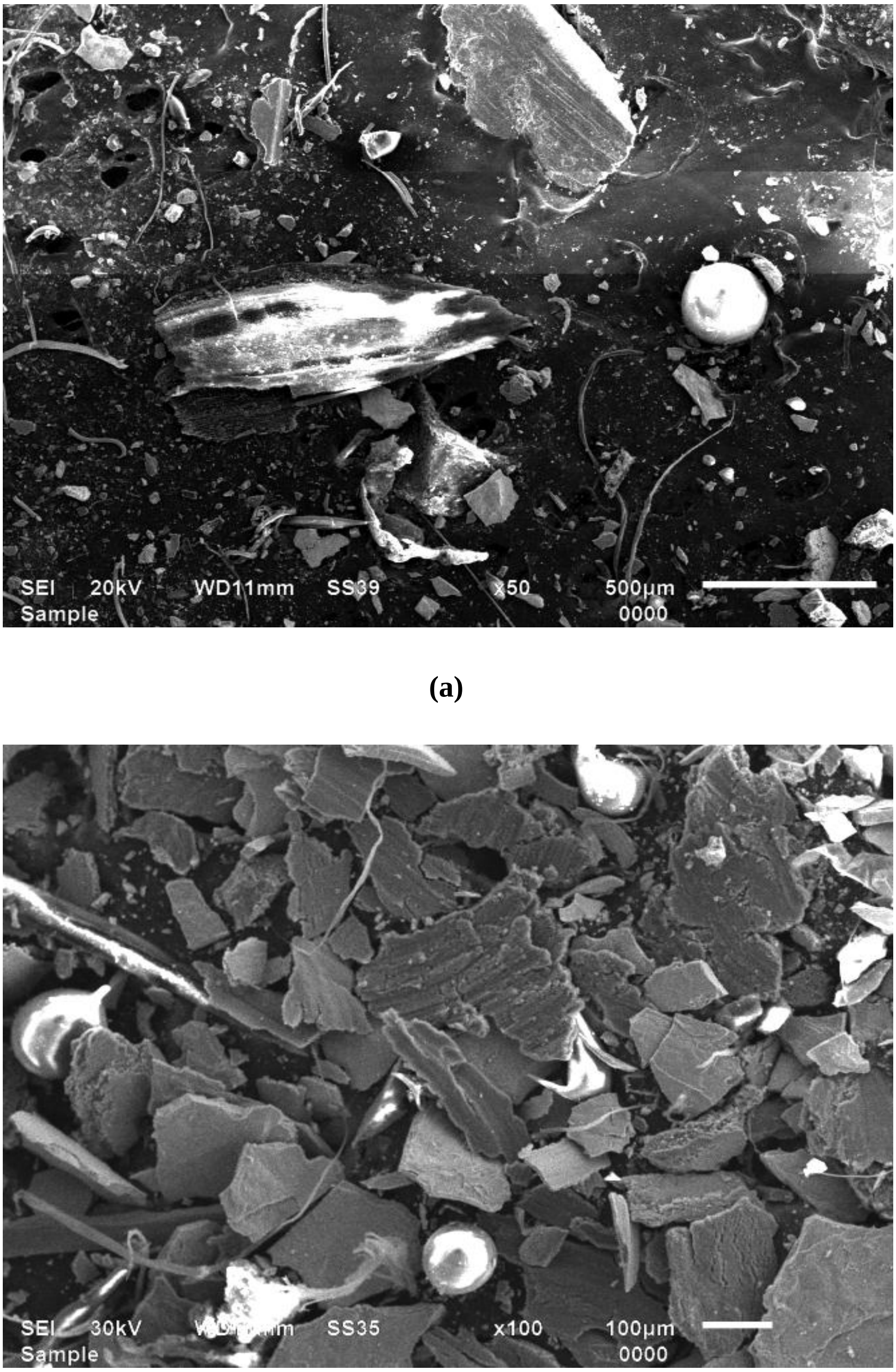
Wear debris of composite-A at 1Kg load at 150° C and 300° C is shown in Fig. 5.8(a& b). Metallic flakes ranging from small to large in size and debonded rutile particles are seen. At 300°C with1kg load the wear debris are corrugated type, this may be due to entrapment of debris during sliding as shown in Fig. 5.8. Wear debris of composite-A at 150°C with 5Kg load EXHIBITS the long metallic flakes with debonded reinforced particles are observed in Fig.5.9. This figure show the SEM micrographs of debris of composite-A at 150˚C and 300˚C for 5 kg load. At 300˚C temperature thread type morphology along with delaminated plates of debris having microcracks are seen. Thread type debris are generated during the pulling out of aluminum metal at 5kg load and 300˚C temperature as described and shown in fig 5.9. Figure 5.10 for composite-B shows the presence of small flakes along with coarse one, which are generated by crushing of flakes at 1kg load and 150˚C temperature. Some reinforced particles having spherical type shape due to entrapment of debris during sliding. Wear debris of composite-B is shown in Fig. 5.10 at 1Kg load and 300°C the metallic flakes along with debris generated by microcutting are observed. Matrix material is removed with embedded reinforced particles, material removed from the area of clustering. Fig.5.11 shows the debris at 5Kg load and at 150°C that is small size due to high load of 5Kg although large metallic and microcutting chips are also seen. Wear debris of composite-B is shown in Fig.5.11at 5Kg load at 300°C exhibits long flakes with microcracks and microcutting flakes are seen. Material containing particles is also visible with debonded reinforced particles. Flakes generated by cutting action along with delaminated flakes are seen.



(a)

(b)

Fig.5.8: SEM images of debris of composite-A at 1kg (a) at 150ºC (b) at 300ºC



(a)

(b)

Fig. 5.9: SEM images of debris of composite-A at 5 kg (a) at 150ºC (b) at 300ºC

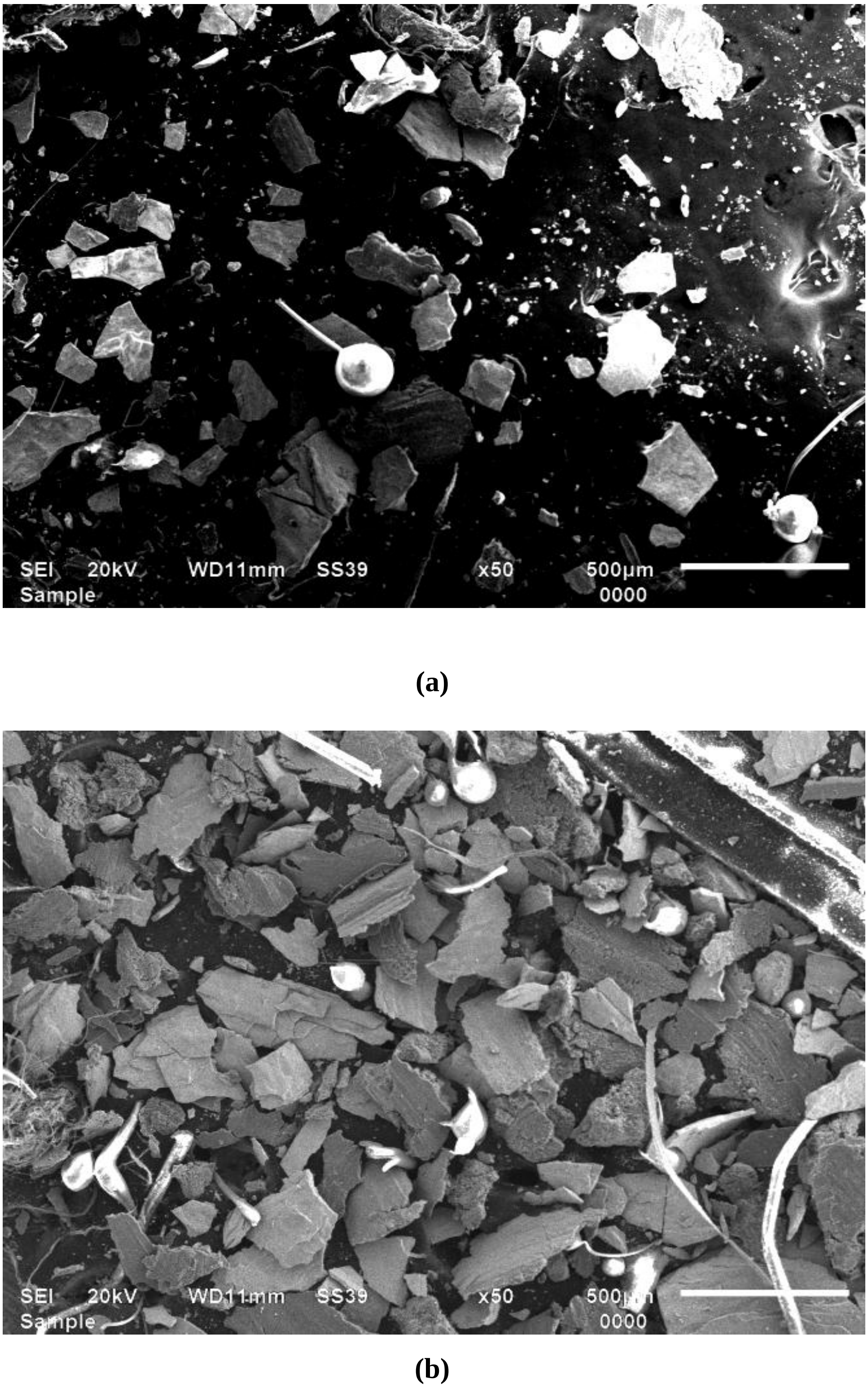
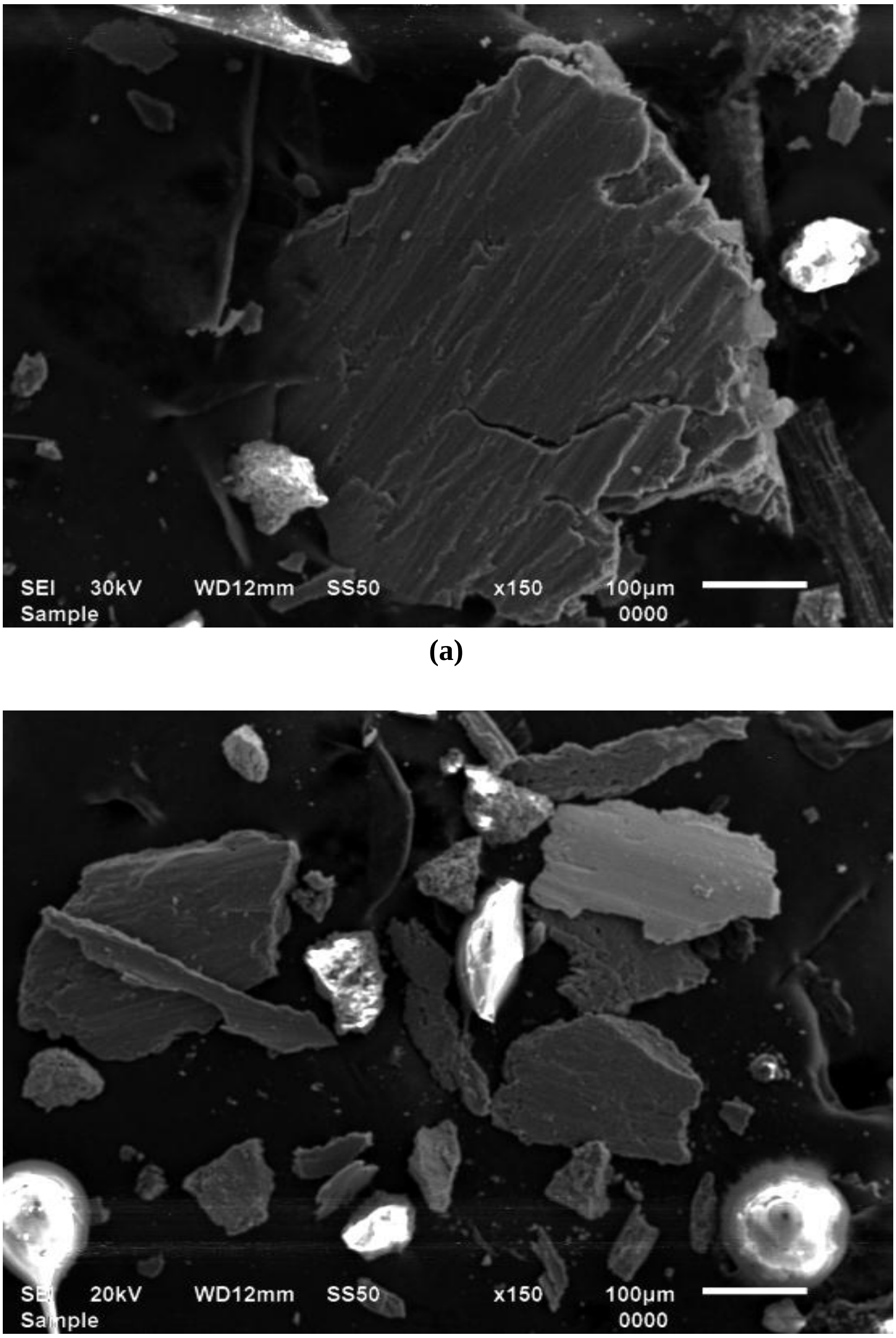


Fig.5.10: SEM images of debris of composite-B at 1kg (a) at 150^0C (b) at 300^0C



(a)

(b)

Fig.5.11: SEM images of debris of composite-B at 5 kg (a) at 150ºC (b) at 300ºC

CHAPTER - 6

CONCLUSION AND FUTURE SCOPE

The rutile particle reinforced LM13 alloy composite is successfully prepared with stir casting technique. The wear characteristics of composites have led to the following conclusion:

1. Fine size rutile particle reinforced composite exhibits better wear resistance than coarse particle at same weight percentage of reinforcement
2. Wear behavior of the composites is increased linearly with increasing the operating temperature. The increase of wear rate is due to formation of the oxide film and glazing layer on sliding components. These layers prevent the direct metal-to-metal contact of sliding surfaces during sliding.

3. The overall wear properties of composite-A containing 15 wt.% fine particles is better at all the temperature for low and high loads both.

4. Wear behavior of composites at temperatures below 100^0C is delamination followed by partial abrasive wear, which leads to plastic deformation. The mechanism of oxidative wear dominates above 150^0C for alloy composite at high temperature.

Future scope of study

One of the major advantages of stir casting is the ability to develop new alloys or products. Stir cast aluminium alloy have been investigated and designed for space and automotive application because of reduced cost as compared to other manufacturing process. Stir cast Al alloy have wide application because of attractive combinations of low coefficient of thermal expansion, good wear resistance , good thermal stability. However, further study is required for different reinforced particle size and alloying elements in different percentage for improving the structural and mechanical properties as compared to present study. For these purpose requirements and fundamental studies, many stir casting R&D plants has been established notably at U.S. Navy Labs, Pennsylvania State University, Applied Research Labs, Advanced Institute of Science and Technology (Korea), National Cheng Kung University (Taiwan), IPEN (Brazil), Oxford University Centre for Advanced Materials and Composites (United Kingdom), Inner Mongolia Metals Institute (China), Bremen University (Germany), and the University of California at Irvine. However, in developing country like India this technique is still under progress for its commercialization. Therefore, a lot of future prospectus is related to this novel technique to develop new alloys and composites.

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