INVESTIGATION OF MECHANICAL AND WEAR PROPERTIES FOR SiC/Gr REINFORCEMENT Al359 ALLOY BASED METAL MATRIX COMPOSITE

A Dissertation Submitted
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by

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CERTIFICATE

I hereby declare that the dissertation entitled **"Investigation on Mechanical and Wear Properties for SiC/Gr Reinforced Al359 Alloy based Metal Matrix Composite"** is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **CAD/CAM Engineering** at **Thapar University, Patiala** under the supervision of **Dr. Jaswinder Singh Saini, Assistant Professor, Mechanical Engineering Department,** Thapar University, Patiala during Jan, 2015 to June, 2015. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

29/06/15

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It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

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Dedicated to

My Parents

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SHUBHRANSHU BANSAL

Abstract

Aluminium alloys are widely used in engineering applications due to their numerous properties such as high wear resistance, good tensile strength, high electrical conductivity etc. To further enhance their properties, the alloy can be reinforced with the hard particles. In the present work Al359 alloy was reinforced with Silicon Carbide and Silicon Carbide/Graphite particles using stir casting process. Thereafter their mechanical and wear properties were investigated. It was found that the hardness of the Al359-Silicon Carbide composite is better than Al359-Silicon Carbide-Graphite composite. The Silicon Carbide/Graphite reinforced composite exhibits a superior ultimate tensile strength and elongation against Silicon Carbide reinforced composite. The wear test was conducted at different loading, sliding velocities and sliding distances conditions. Results showed that the wear resistance of Al359 alloy increased with the reinforcement of Silicon Carbide/Graphite material for higher loading, high sliding velocities and high sliding distance. SEM images of the worn surface of the pin specimens were examined to study their wear mechanism.

Key words: Metal Matrix Composite, Wear, Hardness, Tensile Strength, Scanning Electron Microscopy.

Contents

List of Figures

List of Tables

Acronyms

1.	SiC	Silicon Carbide
2.	Gr	Graphite
3.	MMC	Metal Matrix Composite
4.	SEM	Scanning Electron Microscope
5.	Al	Aluminium
6.	Al359	Aluminium 359 Alloy

Chapter 1

Introduction

1.1 Composite Materials

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from individual components [1].

The composite generally has superior characteristics than those of each of the individual components. The primary reason for choosing composite materials is its light weight for its relative stiffness and strength. When the matrix is a metal, the composite is termed a Metal-Matrix Composite (MMC). In MMCs, the reinforcement usually takes the form of short fiber, particles, whiskers or continuous fibers.

1.1.1 Types of Composite materials

Composite materials are basically divided into following four categories.

i. **Particulate Reinforced Composite**

   These are the most widely used and cheapest composite. In these the filler material is roughly round in shape [2].

ii. **Long fibre Composites**

   Long fiber composites are those composites in which the filler material length to diameter (l/d) ratio is greater than 1.

iii. **Short fibre Composites**

   Short fiber composites are those composites in which filler material length to diameter (l/d) ratio is less than 1.

iv. **Structural Composites**

   Structural composite are those composite in which the filler material is in the form of sheets instead of fiber or round particles. These are further divided into two categories *i.e.,* Laminated and Sandwich composite [3].

In Laminated composite, the different orientation of high strength sheets are glued and stacked together. These composite have an isentropic strength in all plans. The examples of such composite are modern skis and plywood.

In Sandwich composite, the sheets are bounded in the form of light weight structure, for instance honeycomb which produces high strength to shear ratio. They are used in aircraft structures, walls and roofs [3].

1.1.2 Merits of Metal Matrix Composites

The composite materials have distinct merits against other type of compositions. These are

i. High Strength
ii. High impact and toughness properties
iii. High modulus
iv. High wear resistance
v. Reduce Weight
vi. Good dimensional stability
vii. Good fatigue resistance
viii. Excellent reproducibility of properties
ix. Low sensitivity to density ratio
x. Higher temperature capabilities
xi. Higher thermal and electrical conductivity
xii. Excellent technological background with respect to design, manufacturing, shaping and forming etc.

1.1.3 Demerits of Metal Matrix Composites

The demerits of the metal matrix composites are

i. High cost of some material systems
ii. Relatively immature of technology
iii. Complex fabrication methods for fiber-reinforced systems (except for casting)

1.1.4 Application of Metal Matrix composites

The main applications of MMC are

i. Automobile
ii. Space

iii. Electronic and Electrical Industries
iv. Heavy Machinery
v. Military
vi. Transportation

1.2 Matrix

In a composite material, the structural reinforcement is held in place by a binder known as matrix. In the case of metal matrix composites, the metal is a matrix. In the present work the Aluminium alloy is a matrix which was used to make the composite [4].

1.2.1 Aluminium Alloy

Pure aluminium is a ductile, corrosion resistant, soft and has a high electrical conductivity. It is widely used in conductors cables and foil [5]. To increase its strength and wear resistance, aluminium is to be mixed with other elements *i.e.,* silicon carbide, graphite, copper etc.
There are two principal classifications of aluminium alloys *i.e.,* casting alloys and wrought alloys; which are further subdivided into the heat treatable and non-heat-treatable. About 85% of aluminium is used for wrought products such as plate, rolled, foils and extrusions. Cast aluminium alloys yield cost-effective products due to their low melting point and have lower tensile strengths as compare to wrought alloys [6]. Figure 1.1 shows the different type of aluminium alloys.

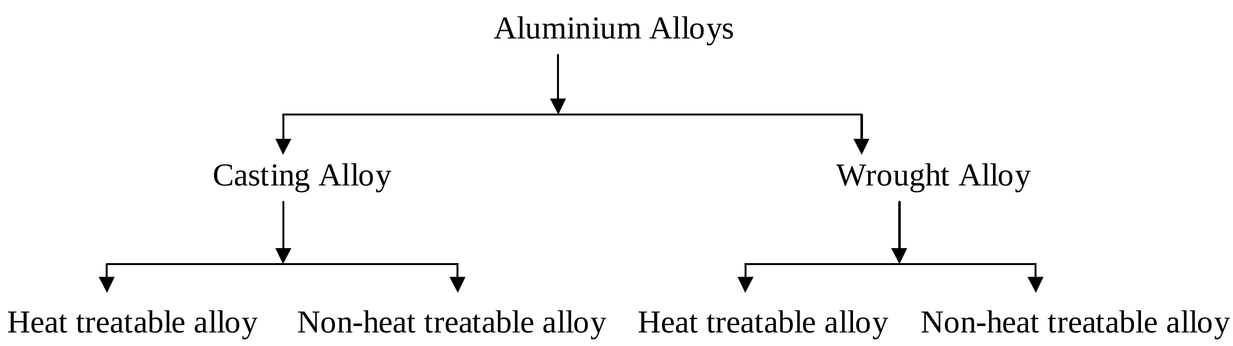


Figure 1.1: Types of Aluminium Alloys

Aluminium 359 (Al359) alloy is one such Al alloy with large number of individual applications. These application ranges from automobile, aerospace, military equipments and sports equipments.

Al359 alloys are metals that contain a mixture of aluminium and other chemical elements. These alloys have very high wear resistance and tensile properties. They are light in weight with the ability to withstand extreme temperatures.
The physical properties of Al359 alloys are given in Table 1.1.

Table 1.1: Physical properties of the Al359 alloy

Properties	**Values**
Boiling Pont	3733ºF
Melting Point	1050-1220ºF
Specific Gravity	2.7 g/m^3
Appearance	Gray to silver
Poisson Ratio	0.33
Tensile Strength	330 MPa
Elastic Modulus	70-80 GPa

1.3 Reinforcement

The main aim of reinforcement material in metal matrix composite is to improve the properties of the composite material. The different particulate / fiber reinforcement affects the properties of the metal matrix composite.
In the present work Silicon Carbide and Graphite are the two reinforcements selected for Aluminium matrix composite material.

1.3.1 Silicon Carbide

Silicon Carbide (SiC) is the only chemical compound of silicon and carbon. SiC in the powdered form is shown in Fig 1.2. Silicon Carbide is produced in two ways, sintering and reaction bonding. These production techniques highly influence the end microstructure [7]. Both the production methods give good mechanical and wear properties. SiC is mainly used in wear plates, heat exchangers, bearing and moving turbine components.

Figure 1.2: Silicon Carbide Powder [7]

SiC particulates have excellent wear and hardness resistance, good strength, low density, high thermal conductivity, high thermal shock resistance and high elastic modulus.

The physical properties of SiC are given in Table 1.2.

Table 1.2: Physical Properties of SiC

Properties	**Values**
Bulk Density (g/cm^3)	3.1
Modulus of Elasticity (GPa)	410
Compressive strength (MPa)	3900
Flexural strength (MPa)	550
Coefficient of Thermal Expansion ($x10^{-6}$ °C)	4.0
Thermal conductivity (W/m.°K)	120

1.3.2 Graphite Reinforcement

Graphite name obtain from the Greek word "graphein". It is a slippery, soft, greyish black colour material having unique properties in both non metal and metal state. Graphite is shows in Fig. 1.3 is one of the naturally produced polymers of carbon. It is planar crystal and two dimensional structures. Graphite maintains its stability and strength at temperature even above 3500º C [8]. Graphite is one of the lightest reinforcing material in all the reinforcing agents with high natural lubricity. Graphite is normally used in carbon brushes, moderator rod in nuclear power plant, batteries and aerospace applications.

Figure 1.3: Graphite [8]

The physical properties of graphite are given in Table 1.3.

Table 1.3: Physical properties of graphite

Properties	**Values**
Bulk Density (g/cm^3)	1.3-1.95
Porosity (%)	0.7-53
Modulus of Elasticity (GPa)	8-15
Compressive strength (MPa)	20-200
Flexural strength (MPa)	6.9-100
Coefficient of Thermal Expansion ($x10^{-6}$ °C)	1.2-8.2
Thermal conductivity (W/m.K)	25-470

1.4 Mechanical and Wear Properties

The present work deals with the mechanical and wear properties of Al359 metal matrix composite reinforced with the SiC and SiC/Gr reinforcement particles.

1.4.1 Tensile Strength

The tensile strength of a material is the maximum amount of tensile stress that it can take before the failure, such as permanent deformation or breaking. Tensile strength specifies the point when a material starts plastic deformation [9]. It is define as the minimum tensile stress needed to split the material apart.

The tensile strength are categorized in to three category:

i. **Yield strength**: The stress a material can withstand without permanent deformation.

ii. **Ultimate strength:** The maximum stress a material can withstand.
iii. **Breaking strength:** The stress coordinate on the stress-strain curve at the point of rupture.

Tensile strength is a limit state of tensile stress that leads to tensile failure in one of two manners:

i. **Ductile failure**: In ductile materials the yield is the first stage of failure, some hardening as the second stage and breakage after a possible "neck" formation.
ii. **Brittle failure**: in brittle materials the sudden breaking in two or more pieces at a low stress state.

Tensile strength testing for particular metal will determine how much particular alloy will elongate before touching ultimate tensile strength and how much load a particular piece of metal can withstand before it loses structural integrity.

1.4.2 Hardness

Hardness is a resistance of metal to plastic deformation, usually by indentation. The term may also refer to temper or stiffness or to resistance to scratching, cutting or abrasion. It is the property of a metal, which gives it the ability to resist being permanent deformation (broken, bent, or shape changed), when load is applied. The greater the hardness of the material, the greater resistance it has to deformation.

Hardness of a material is determined by forcing an indenter such as a Vickers or Knoop indenter into the surface of the material under 15 to 1000 gf load; usually, the indentations are so small that they must be measured with a microscope [10]. Capable of determining hardness of different micro constituents within a structure, or measuring steep hardness gradients such as those encountered in casehardening. The indenters works by pressing a tip into a sample and continuously measuring: applied load, penetration depth and cycle time.

1.4.3 Wear

Wear is defined as a process where interaction between two surfaces or bounding faces of solids within the working environment results in dimensional loss of one solid, with or without any actual decoupling and loss of material. Aspects of the working environment which affect wear include loads and features such as unidirectional sliding, reciprocating, rolling, and impact loads, speed, temperature [11].

The following four wear modes are generally recognized as fundamental and major ones

i. Adhesive and
ii. Abrasive wear
iii. Fatigue wear
iv. Corrosive wear

i. Adhesive wear: Adhesive wear are wear generated under plastic contact. In the case of plastic contact between similar materials, the contact interface has adhesive bonding strength. When fracture is supposed to be essentially brought about as the result of strong adhesion at the contact interface, the resultant wear is called adhesive wear, without particularizing about the fracture mode. Figure 1.4 shown the phenomenon of the adhasive wear.

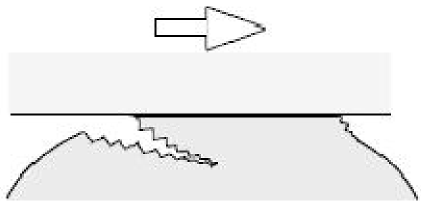


Figure 1.4: Adhesive Wear [12]

ii. Abrasive Wear: The plastic contact between sharp and hard material and relatively soft material, the harder material penetrates to the softer one. When the fracture is occurring in the manner of micro-cutting by the indented material, the resultant wear is known as abrasive wear. Figure 1.5 shown the phenomenon of the abrasive wear.

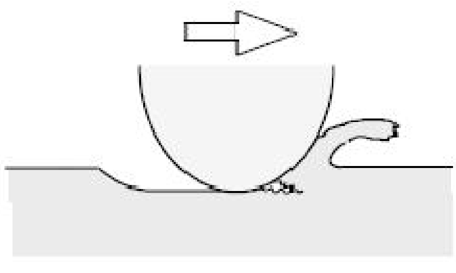


Figure 1.5: Abrasive Wear [12]

iii. **Fatigue Wear:** In the case of contact in the running-in state, fatigue fracture is generated after repeated friction cycles. When surface failure is generated by fatigue, the resultant wear is called fatigue wear. Figure 1.6 shown the phenomenon of the fatigue wear.

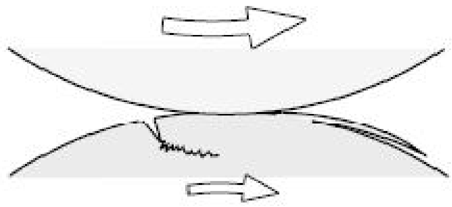


Figure 1.6: Fatigue Wear [12]

iv. **Corrosive Wear:** When the contact in corrosive media, the chemical reaction at the contact interface is start. When the chemical reaction in the corrosive media is considered to be rought about by material removal, the resultant wear is known as corrosive wear. Figure 1.7 shown the phenomenon of the abrasive wear.

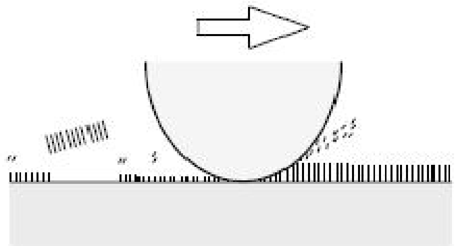


Figure 1.7: Corrosive Wear [12]

Table 1.4 indicate the symptoms of different type of wear and appearance of worm surface during the wear mechanism.

Table 1.4 : Symptoms and appearance of wear

Type of Wear	Symptoms	Appearance
Adhesive	Metals rub together is main symptoms	Catering rough, seizure and turnout surfaces
Abrasive	Presence of micro-cutting by the indented material	Grooves
Fatigue	Presence of surface cracks due to repeated friction cycle	Sharp edges and pits
Corrosion	Presence of Chemical reaction at the contact interface	Depressions and rough pits

Chapter 2

Literature Review

In this chapter a review of literature on the mechanical and wear properties of different Al alloys reinforced with different particles are presented.

2.1 Literature Review

Apachitei and Duszczyk [13] investigated the wear resistance of Al 6060 alloy with coating of nickel-phosphorus with two different phase. The coating of Al6061 were carried out using three different solutions of electroless to achieved the distinct phosphorous content. The nanocrystalline supersaturated solid solution of phosphorus in nickel ($P \leq 6$ wt.%) was converted into amorphous nickel -phosphorus phase ($P \geq 10$ wt.%) while increasing the weight percentage of the phosphorous content. The heat treatment of the coated materials was conducted at temperature of 220ºC with 1 hour holding time. The hardness test was performed on the Vickers hardness tester machine at 0.98 N load and the wear test was conducted on pin and disc type wear machine at 0.98 N load and constant sliding velocity of 400 cycles (40 cycles/ min).

It was concluded that there was improvement in wear and hardness of the aluminium 6061 with low phosphorous coating as compared to high phosphorous amorphous coating. It was due to the presence of nano crystalline structure in low phosphorous coating.

Tham *et al.* [14] studied the mechanical properties of the aluminium-silicon carbide. The composite was prepared using the DMD technique with two different microstructures for different range of the contact time between silicon carbide and molten Al during the processing. The particle size of the reinforced material was 34.4 µm. The tensile test was performed on cylindrical specimen in Instron 8051 automated servo hydraulic testing machine at room temperature as per ASTM E8M-96 standard.

It was concluded that the ultimate tensile strength, work hardening rate, composite yield strength and work fracture improved due to the formation of thin Al_4C_3 layer which strengthen the bond between the matrix and reinforced material.

Hemanth [15] studied the effect of wear on Al-boron composite, which was produced by the route of sand casting process with metallic (Cast Iron, Steel and Copper) and non metallic (Silicon carbide) chills. The particle size of the boron was varied from 30 µm to 100 µm and the weight percentage of boron was 3, 6 and 9 wt.% respectively. The wear test was carried out under the load of 14.8 kgf, sliding distance of 400 m and at sliding speeds of 0.52, 1.15, 1.98 and 3.64 m/s. Figure 2.1 shows the effect of sliding speed on wear of Al-6 wt.% boron MMCs Cast with various chills.

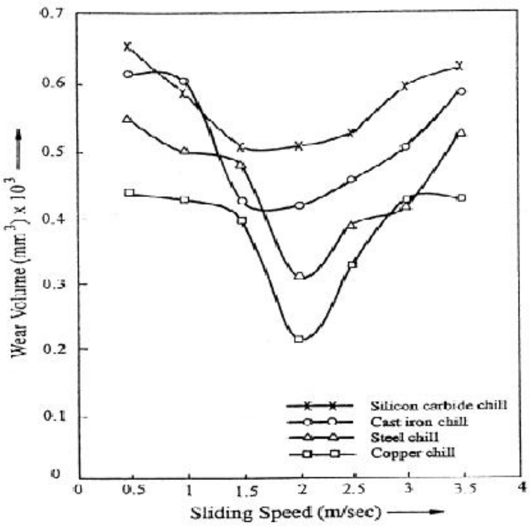


Figure 2.1 :Effect of sliding speed on wear of Al-6 wt.% boron MMCs Cast with various chills

It was concluded that the wear resistance was highly dependent on the rate of chilling during the casting process. The wear rate of Al boron composite was better due to improved rate of chilling.

Torres *et al.* [16] observed the behaviour of mechanical properties of Al2124 alloy reinforced with 15 vol. % of $MoSi_2$, Ni3Al, Cr_3Si, NiAl which was prepared using powder metallurgy. Cylindrical specimens were used to perform the tensile test with 10 mm gauge length and 3 mm diameter on Universal Testing Machine at constant crosshead velocity 1.5 m/s. The tensile strength, yield strength and elongation to facture were determined at room temperature with employing strain rate of 10^{-4} /sec.

It was found that Al2124 alloy reinforced with $MoSi_2$ had better mechanical properties such as yield strength, ultimate tensile strength and elongation of fracture as compared to other reinforced materials. The $MoSi_2$ reinforced material was most thermal stable as compared to other composites.

Seah *et al*. [17] noticed the behaviour of the Al/quartz particulate composite casted with the metallic (cast Iron, copper, steel) and non metallic (silicon carbide) chills. The size of the quartz particles was varied between 30 to 100 µm. The quartz content in the aluminium was 3, 6 and 9 wt.%. Instrom tensile test was used to carry out the tensile test according to AFS standard. Table 2.1 represent the wt.% of Al/quartz contents cast using different chills.

Table 2.1 : UTS of Al/quartz composites with various quartz content cast using different chils

Type of chill	**UTS at the chill end (MPa)**		
	3 wt. % quartz	**6 wt. % quartz**	**6 wt. % quartz**
Copper	116	134	129
Steel	114	128	122
Cast Iron	102	125	119
Silicon Carbide	97	119	112

It was concluded that the ultimate tensile strength and toughness of the cast specimen were improved with increase in weight of quartz up to 6 percent, beyond which these two mechanical properties reduced. There was brittle fracture of the metal matrix composite cast without using chills which was due to the separation of quartz particulates from the matrix material.

Metha *et al.* [19] investigated the effect of wear on aluminium alloy *i.e.*, Al-CA 313 and two magnesium alloys *i.e.*, AS21 and AZ91D. The wear test was performed under two different loading conditions such as 0.715 and 0.215 N at sliding velocity of 1.5 m/s. Table 2.2 shows the test parameters which were used for wear test.

It was concluded that the performance of the aluminium alloy was better as compared to the magnesium based alloys because of improved hardness. It was also observed that the material removal of aluminium composite during wear was due to delamination and oxidation at the edge of wear track. The wear track was found to be shallow and narrow.

Table 2.2: Test parameters for wear test

Parameter	Value		
	Constant	Varying	
		High	Low
Sliding speed (m/s)	0.259	-	-
Sliding distance (km)	1.33	-	-
Test duration (min)	90.0	-	-
Test Temperature	Room temperature	-	-
Applied load (N)	-	2.55	0.714
Bearing Pressure (kPa)	-	1.216	0.340

Ramachandra and Radhakrishna [20] observed that the wear rate of the Al-Si (12%)-SiC metal matrix composite which was synthesized by the stir-casting method. The reinforcement content were 5, 10, 12 and 15 wt.% respectively. The wear résistance increased with increase in weight percentage of silicon carbide due to uniform reinforced material and good interfacial bonding between the aluminium alloy and reinforced material. It was also noticed that the addition of 15% wt. of silicon carbide content had superior wear properties as compared to the matrix material.

Kang and Chan [21] investigated the tensile properties of the aluminium matrix composite reinforced with the Al_2O_3 particulates. The fraction volumes of the Al_2O_3 particles were varied between 1 to 7 %. The composite was prepared using the powder metallurgy process. The hardness test was performed on Rockwell hardness tester with a steel ball indentor at constant load 60 Kg. The tensile test was carried out at room temperature with a strain rate of 1.67×10^{-4} /sec in Shimadzu material testing machine.

It was concluded that the tensile strength and hardness were improved with the addition of nano-Al_2O_3 particles in aluminium matrix. It was also seen that the mechanical properties of the composite were improved upto 4 vol. % of Al_2O_3, beyond which the mechanical properties were reduced due to agglomeration.

Kok [22] studied the hardness and tensile behaviour of the Al 2024 composite reinforced with the Al_2O_3 particles. The composite was prepared by the route of vortex method with three different sizes (16, 32 and 64 µm). The weight percentage of aluminium oxide particulates was varied up to 30 wt. %. The Brinell hardness tester machine was used to determine the value of hardness at the applied load of 187.5 kg. The tensile test was conducted in Hounsfield testing machine at a constant cross head velocity of 0.5 mm/s. Figure 2.2 shows the variation of tensile strength with Al_2O_3 particle content and size.

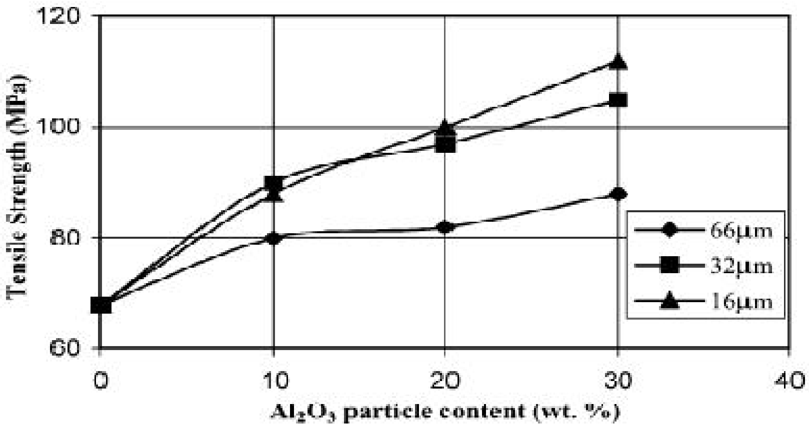


Figure 2.2: Variation of tensile strength with Al_2O_3 particle content and size

It was concluded that the hardness and tensile strength of the composite were improved with decrease in size and increase in weight percentage of the Al_2O_3 particles in Al 2024 alloy metal matrix composite. It was found from the microstructure that the finer particles lead to agglomeration and porosity while coarse particles are dispersed more uniformly in the material.

Ahlatic *et al.* [23] investigated the metal abrasive and dry sliding wear resistance of aluminium matrix hybrid composites manufactured by the pressure infiltration process. The reinforcement content were 25 vol.% SiC, 37 vol.% Al_2O_3 and 8 wt. % magnesium. The test was conducted under a load of 28 N with 1200 m sliding distance at velocity of 0.5 m/s.

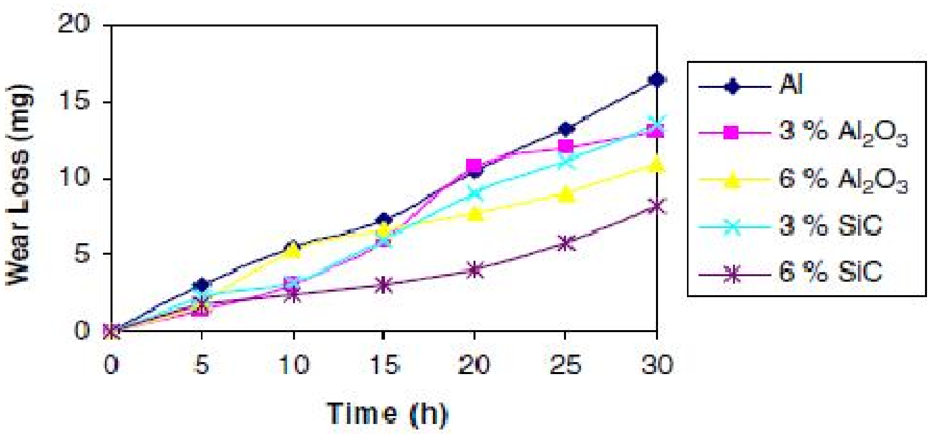
It was concluded that the addition of Mg content in aluminium matrix facilitated the increased wear resistance of metal due to the formation of Fe rich transfer layer. It was also stated that the addition of Mg content resulted in increase in hardness and decrease in porosity of reinforced composite.

Zhang *et al.* [24] observed the tensile properties of the Al_2O_3 and Al_3Zr reinforced metal matrix composite. The composite was fabricated by magneto chemistry in situ reaction at 1173 K with 5, 10, 15, 20 and 25 wt.% of reinforced materials. The tensile test was performed in the ultimate tensile machine to determine the yield strength and ultimate tensile strength of the composites.

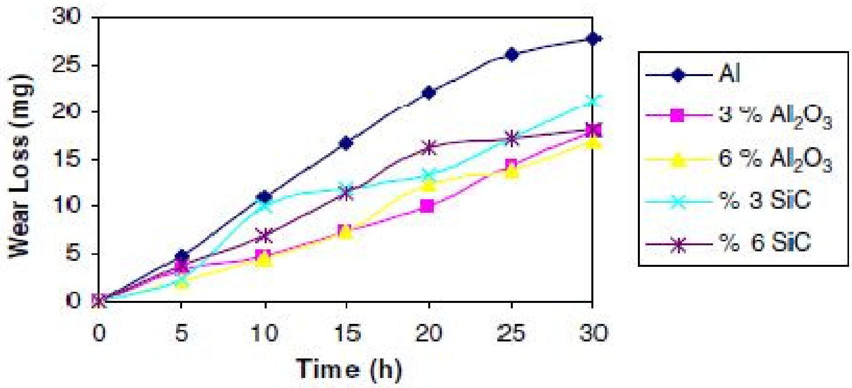
It was concluded that the tensile and yield strength of Al_2O_3 and Al_3Zr reinforced aluminium matrix composites are much higher than the pure aluminium due to homogeneous distribution of the reinforced particle in the matrix material. The Al composite with 20 % reinforcement of Zr material exhibits the higher yield and ultimate strength as compared to the other composition of the composites.

Unlu [25] noticed the wear behaviour of Al_20_3 alloy and silicon carbide reinforced composite. It was produced using powder metallurgy and casting route. The wear lose of the composites were observed at 10 N loads, 0.628 m/s sliding speed and sliding distance of 1130 m. The test was run on the pin and disk type machine under dry conditions. The size of the aluminium powder was 10μm (99% pure), Aluminium oxide was 15-20μm and the reinforced material size was 55-60μm. Figure 2.3 shows the wear loss of Al composite materials for casting and powder metallurgy.

It was concluded that the wear properties of Al based Al_2O_3 and SiC reinforced casting specimen were improved around 1.5 to 2 times than powder metallurgy specimen because pure aluminium specimen were rough than the reinforced aluminium specimen.



(a)



(b)

Figure 2.3: Wear loss of Al composite material (a) Casting (b) Powder Metallurgy

Kumar *et al.* [26] found the mechanical properties such as hardness, tensile strength and wear resistance of the Al-7Si/TiB_2 composite. The Al-7Si alloy was reinforced by 0, 5 and 10wt.% of TiB_2 and prepared by the route of salt reaction method. The mechanical properties of the Al-7Si/TiB_2 composite were compared with the Al-Si alloy. The hardness test was carried out at load 5 kN on Vickers hardness tester. The tensile test was performed by the Shimadzu AGIS 250 kN unit. Sliding wear test was conducted on the pin and disk type machine under the dry conditions with load of 40 to 120 N, sliding distance 800 m at velocity 1 m/s.

It was concluded that the mechanical properties such as hardness, tensile strength and wear resistance were improved in Al-7Si/TiB_2 composite as compared to Al-Si composite. TiB_2 in Al-7Si alloy was not only acting as grain refiner for aluminium but also as modifier of Si in the eutectic mixture. It was also found from the analysis of the worn surfaces that ploughing and adhesion were predominant at lower load whereas delamination was more at higher load.

Kalkanli and Yilmaz [27] investigated the tensile properties of the 7075 aluminium alloy reinforced with the SiC particle size of 29 µm. The composite was prepared using the pressure casting process with four different weight fractions (10, 15, 20 and 30 %) of the silicon carbide particulates. The heat treatment and as-cast was done on the composites to enhance their properties. Figure 2.4 shows ultimate tensile with varying percentage of SiC particles.

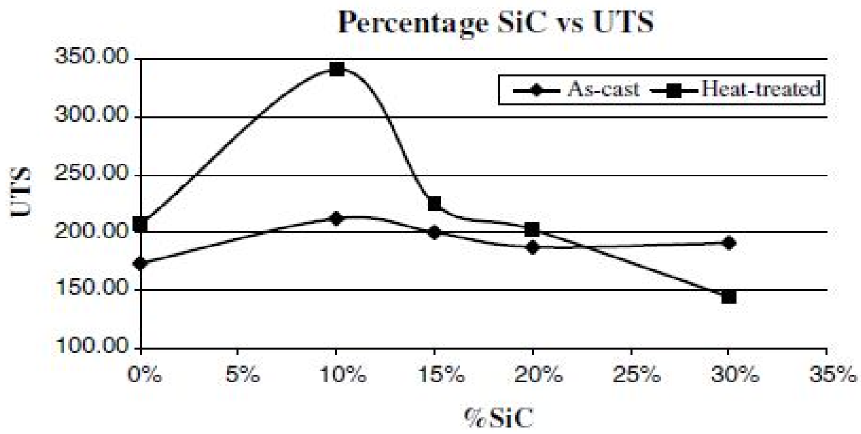


Figure 2.4: Ultimate tensile strength with varying percentage of SiC particles

It was concluded that the tensile and flexural strength of the silicon carbide reinforced 7075 aluminium alloy was improved for both heat treated and as-cast sample. The tensile and flexural strength improved up to 10 wt% of SiCp, beyond which the strength decreased due to agglomeration of SiCp particulates.

Suresha and Sridhara [28] observed the wear characteristics of the Al-Si and Al-Si-Gr composite which was prepared by using stir casting process. The wear test was performed under the sliding velocity of 0.4, 0.8, 1.2, 1.6 m/s and sliding distance of 400, 800, 1200, 1600 m at load of 15, 30, 45, 60 , 75 N. The hybrid composite was combined with the equal weight percentage (2.5, 5, 7.5 and 10 %) of the reinforced material.

It was concluded that the tribolayer plays an important role on the wear resistance of Al-Gr and Al-Si-Gr composite. It was also found that the Al-Si-Gr composite had better wear resistance as compared to the graphite composite. The SEM images of the worm surfaces revealed that the resistance to wear improved with increase in speed due to the presence of the supporting tribolayer in between the worm surface and the disc. It decreases with increase in load and sliding distance due to the reduction in tribolayer.

Sahin [29] noticed the effect on wear behaviour of 15 wt.% SiC particle reinforced composite. The specimen were fabricated using powder metallurgy method with varying particles sizes of SiCp/Al 9/61, 14/70 and 33/55 µm. The test was performed on the pin and disc type of machine under 10, 20, 30 N load and sliding distance of 18, 36, 54 m at velocity 1 m/s.

It was concluded that the particle size had more effect on the wear resistance. It was found from the worm surface that the small particle size of composites exhibits less wear as compared to large particle size of composites.

Kaur and Pandey [30] investigated the wear behaviour of LM35 alloy with SiC alloy and high purity zircon sand reinforcement. The composite was developed by using spray forming technique. The wear test was conducted under the temperature range of 30 to 35 ºC and relative humidity range of 25 to 35% on pin and disc type of machine. The test was performed under different loads of 1, 2, 3, 4 and 5 kg and sliding distance of 2880 m at constant velocity of 1 m/s. Wear loss of the performed specimen was measured in term of volume loss. Table 2.3 shows the varying percentage of reinforcement materials.

Table 2.3: Reinforcement combination of composite

Composite	Total 15 wt% reinforcement	
	$ZrSiO_2$	SiC
A	15	-
B	3.75	11.25
C	7.5	7.5
D	11.25	3.75
E	-	15

It was concluded that the Zn reinforced composite exhibit less wear as compared to Al-SiC composite under different load condition due to abrasive, adhesive and oxidative wear mechanism. The combination of 3.75% zircon sand and 11.25% SiC reinforced composite exhibit better wear resistance as compared to the other combinations.

Rajaram *et al.* [31] studied the behaviour of aluminium silicon carbide alloy with reinforcement of 3% wt. of graphite which was prepared using stir casting process. The graphite was pulverised with 1% wt. of Ni, Cu and added in molten Al-Si alloy. The wear test was conducted at 100, 150, 200, 250, 300, 350ºC and room temperature on pin and disc tribo testing machine. The sliding distance and load were constant at 20 m and 2 N respectively. The sliding velocity during the test was 1.2 m/s.

It was concluded that the wear rate of the reinforced composite decreased with increase in temperature due to the formation of glazing layer and oxide layer at high temperature.

Shin and Huang [32] observed the tensile properties of the 6061 Al alloy reinforced with SiC particles. The silicon carbide was added in 0, 10 and 20 vol.%. with the average diameter of the SiC particles as 37 µm with sharp edge corners. The diameter of the aluminium powder was 122 µm with irregular shape. The composite was fabricated using the permanent casting process. The tensile test was carried out in MTS 810 servo hydraulic testing machine at room temperature.

It was concluded that the strength of the Al6061alloy reinforced with SiC depends on the temperature. The beneficial effect on strength was till temperature of 200 ºC, beyond which there was no effect on strength. It was also seen that the strength, young modulus and strain hardening increased with increase in vol. % of the SiC particles but the percentage elongation decreased with increase in vol. % of the SiC particles.

Nemati *et al.* [33] studied the mechanical properties of Al-4.5 wt.% cu alloy with different fraction (0 to 10%) of nano and micro particle of TiC. The composite was prepared using powder metallurgy process of milled mixing in a high energy attritor with a blend press sinter. The wear test were conducted at sliding speed 2000 rpm, sliding distance 1500 m, load 10 and 20 N and ambient temperature 25 ºC.

It was concluded that the resistance to wear of nano size TiC reinforcement composite was more than the micro size TiC reinforcement composite. The wear loss of TiC reinforced composite increased with increase in TiC content up to 5 wt.%. It was also found that the worn surfaces of composites were smoother, grooves were finer and total depths of deformation were smaller than the unreinforced aluminium alloy composites.

Kumar *et al.* [34] investigated the mechanical properties of the Al6061-SiC composite. The composite was prepared using liquid casting technique via stir casting process with 2 to 6wt.% of SiC. The cast specimens were machined to prepare the sample as per ASTM standards. The hardness test was performed on Brinell hardness testing machine with 10 mm steel ball at a load of 500 kg for 30 seconds. The wear test was performed on computerized pin and disc machine and tensile test was performed on the universal tensile test machine at room temperature.

It was concluded that the hardness of the composite was improved with addition of the filler material. The tensile strength and wear resistance of Al-SiC material was higher than the Al material. It was also found that the uniform distribution of the particulates in the matrix material is important to improve the mechanical properties.

Zhu *et al.* [35] studied the wear behaviour of in situ composite (Al_3Zr+α-Al_2O_3)/Al on pin and disc type machine at a temperate of 373 and 473 K. The composite was prepared using powder metallurgy technique with 20 and 30 vol.% of reinforced material. The sliding velocity and applied load for the wear test were 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 m/s and 20, 30, 40, 50, 60, 70 and 80 N respectively. The sliding distance for each run of the test was 2000 m.

It was concluded that the wear rate of reinforcement composite (Al_3Zr+α-Al_2O_3)/Al increases with increase in sliding speed. The wear rate increased up to 0.6 m/s, beyond which the wear rate decrease gradually. But with the increase in test temperature, the increase in sliding velocity decreases the wear rate.

Baradeswaran and Perumal [36] observed the wear and mechanical behaviour of the Al7075 graphite composite under the sliding condition. The composite was prepared using conventional liquid casting method followed by the T6 heat treatment conditions. The Al7075 alloy was combined with 5, 10, 15 and 20 wt.% of the SiC reinforced material. The hardness test was conducted on the Rockwell hardness tester using a load of 100 kg. Wear test was carried out on the computerized pin and disc machine at 100 m sliding distance and 10, 20 and 30 N applied load with 0.8 and 1.0 m/s sliding distance.

It was concluded that the hardness and resistance to wear of Al-SiC composite increased with increase in SiC particles due to uniform distribution of the SiC particles along the cross section and longitudinal direction of specimen. It was also found that the wear resistance increased with increase in sliding distance and load.

Farahani *et al.* [37] studied the mechanical characterises and wear properties of the sc grain refined Al 70742 alloys. The 0.03 wt.% of Ti and 0.3 wt.% Zr were added to refine the grain of the aluminium alloy. The hardness test was performed in Brinell hardness testing machine by applying the force of 187.5 kg with a spherical indentor. The tensile test was conducted in SANTAM-STM20 tensile test machine at room temperature with a cross head velocity of

1mm/min. The sliding wear test was performed in pin and disc type of machine at load of 20, 30, 50 N and sliding distance of 1000 m for a sliding velocity of 1 m/s.
It was concluded that there was mixed type of wear mechanism *i.e.*, delamination, adhesive and abrasive at higher applied load for Al-5Ti-1B and Al-15Zr alloy. It was also found that the wear resistance of SC free 7042 alloy increased with applied pressure due to friction heat which softened the composite during sliding. The mechanical properties of the Ti refined composite was superior as compare to Zr refined composite as Ti reduce the grain size of the composite to a larger extend.

Prabu *et al.* [38] investigated the effect of silicon carbide size and volume fraction on sliding wear of Fe/SiC/Gr reinforced hybrid composites. The two particle ranges; 1-30 µm and 150-180 µm and three different volume fractions; 10, 15 and 20 % of silicon carbide were used to prepare the hybrid composite. The wear test was carried out under the load of 15, 20, and 20 N at a sliding velocity of 2 m/s for 1500 m sliding distance.
It was concluded that the wear resistance of Fe/SiC/Gr reinforced hybrid composites were improved with increasing volume fraction of SiC for all particle sizes (1-30µm and 150-180µm). The controlling wear was more effective at lower sliding speed and higher fraction volume with large particle size (100-150 µm). On the hand the controlling wear was more effective at higher speed and higher fraction volume for all particle sizes.

It can be seen from the literature review that number of researchers has worked on the mechanical and wear properties of various aluminium alloys reinforced with different materials. Very less amount of work is reported on enhancement of mechanical and wear properties of Al359 alloy. It can also be seen from the literature review that SiC is commonly used as reinforcement of aluminium alloys. But SiC being hard material can adversely affect the mechanical properties of the base alloy. So the present work is to study the mechanical and wear behaviour of Al359 alloy with the addition of Silicon Carbide (SiC) and Graphite (Gr) particles.

2.2 Problem formulation

The following objectives are defined for the present work:

i. To prepare the aluminium composite using stir casting (liquid state casting) process with different percentages of SiC and Gr reinforcement particles.

ii. To perform hardness test on Vickers hardness test machine to evaluate the hardness of the prepared composites.
iii. To perform the tensile test on universal testing machine to evaluate the stress-strain properties of the prepared aluminium composites.
iv. To perform the wear test on pin and disc type machine to evaluate the wear resistance of the prepared composite.
v. To compare the results for the different prepared composites.

Figure. 2.5 represent the different steps involved in the present work.

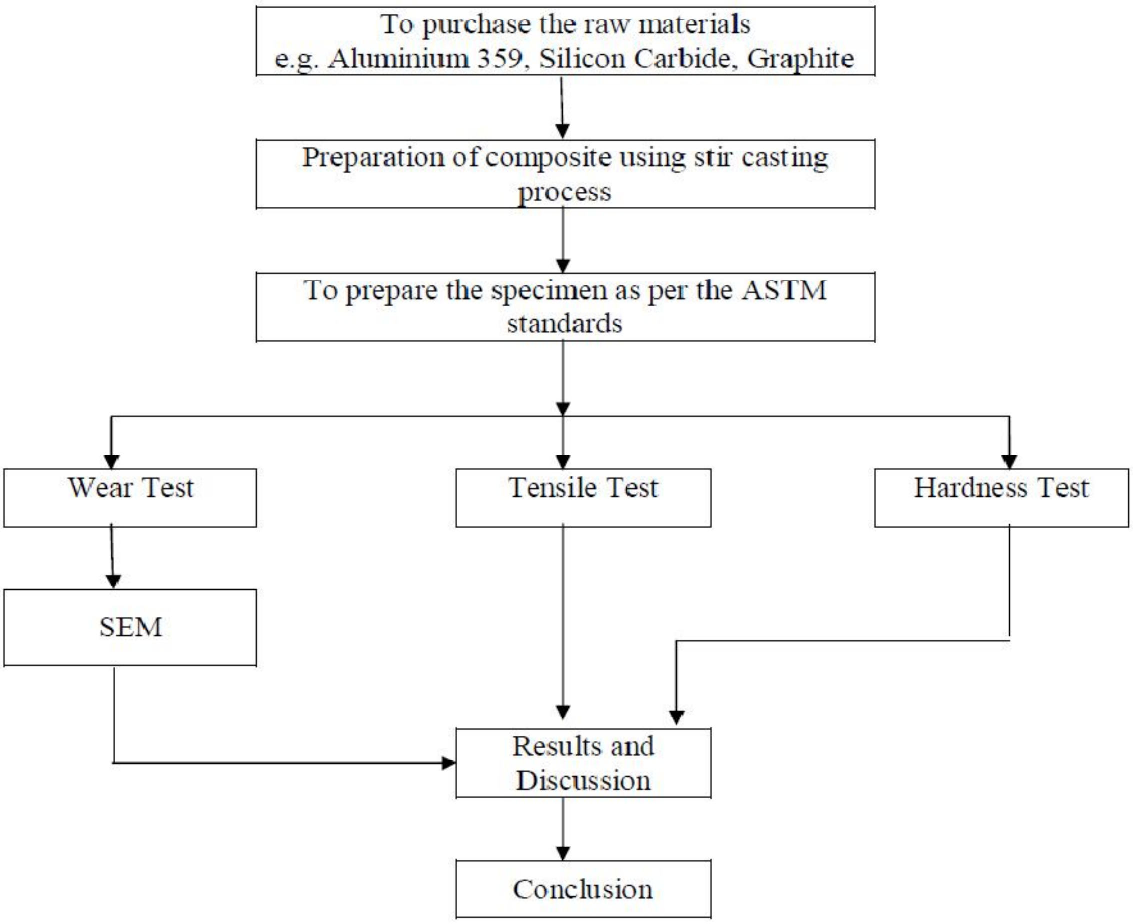


Figure 2.5: Flow chart giving the steps followed in the present work

Chapter 3

Experimentation

3.1 Preparation of Composite Material

The test specimen for investigation of different mechanical properties and wear properties were prepared as per the ASTM standards. The description of the material and experimental procedure used in the present work is given in the following sections.

3.1.1 Materials

Aluminium and its alloys, when reinforced with hard ceramic particulates impart a combination of properties that are not achievable in either of the constituents individually. Al359 is one such alloy that has number of application in automobiles, aerospace, electronics industries [18], which require both strength and wear characteristics. In the present work Al359 alloy was used as a metal matrix composite with SiC and Gr as the reinforced materials. Silicon Carbide is used as it improves thermal extension resistance, wear resistance and strength of the matrix material. The addition of appropriate graphite content improves the machinability and wear properties of Al as it acts as the lubricant in the material which reduces the wear. The Al359 alloy was purchased from Sankar & Company, Delhi. Al359 was analysed for it chemical composition. The detailed chemical composition is given in Table 3.1. The Silicon Carbide and Graphite were purchased from Haazi Steels, Patiala.

Table 3.1: Chemical composition of Al359 alloy (in wt.%)

Al	Si	Fe	Mn	Zn	Cu	Ti	Mg
86.97	10.22	1.39	0.47	0.38	0.30	0.17	0.11

The composite material was prepared with Al359 as a matrix and SiC and Gr as the reinforcement particles. As per the literature survey atleast 10 wt.% SiC of reinforced particle was found to improve the properties of the Al alloy. In the present work 10 wt.% of SiC and SiC/Gr were added in Al359 to improve its properties. The weight percentage variation of Al alloy, SiC and Gr for the preparation of the specimen are given in Table 3.2. The composite material was prepared by using liquid casting process.

Table 3.2: Wt. % variation of Al alloy, SiC and graphite

S. No.	Al	SiC	Gr
1.	100%	0%	0%
2.	90%	10%	0%
3.	90%	7.5%	2.5%

3.1.2 Liquid casting process

Among the variety of processing techniques available for particulate-or-discontinuous reinforced metal matrix composites, stir casting is one of the methods adopted for preparing the aluminium composites. It is attractive because of simplicity, near net shaping, flexibility and economical for large size components to be fabricated. Al359 alloy was heated in a furnace at about 830 ºC, which is above the melting point temperature of aluminium. The calculated quantity of SiC or SiC/Gr powder was preheated at temperature of 300 ºC in a separate furnace. After melting the Al359 alloy in the furnace, the preheat reinforcement powder was fed at a constant rate. To achieve the desired mechanical properties, mixture was stirred at a constant speed of 600 rpm for 10 minutes to disperse the reinforced particles into molten metal. Figures 3.1 and 3.2 shows the setup of stir casting machine and process involved during the casting of composite materials. Thereafter the molten metal was poured into moulds to prepare the specimen. The cast were prepared of the size 520 mm x 140 mm x 8 mm for the tensile test and 30 mm diameter, 100 mm length for wear test. SEM images, shown in Fig. 3.3, were taken to ensure the uniform dispersion of the reinforced particles in Al359 alloy.

Figure 3.1: Stir Casting Machine **Figure3.2: Casting Process**

(a) **(b)**

Figure 3.3: SEM Images of (a) Al359 with 10 wt. % of SiC (b) Al359 with 7.5 wt. % of SiC and 2.5wt. % of Gr

3.2. Mechanical Properties of Prepared composites

Different mechanical properties such as hardness, tensile and wear were conducted on the prepared composite.

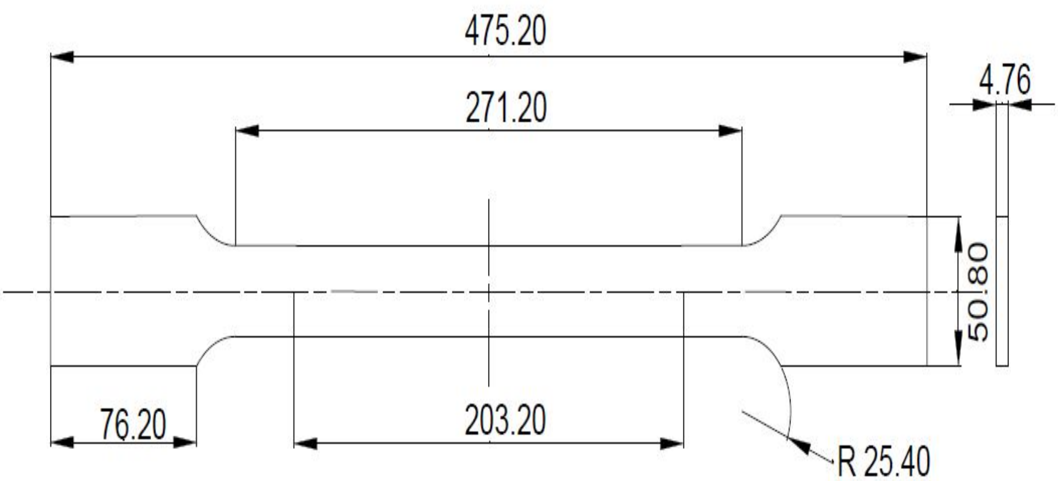
3.2.1 Hardness Test

The Vickers indentation tester, shown in Fig. 3.4 was used for measuring the Micro indentation hardness of the specimens. The hardness of prepared samples was measured at different location using a load of 100 gm for 10 seconds. The Vickers hardness test was carried out in Material Science laboratory Thapar university, Patiala.

Figure 3.4: Vickers Hardness Tester

3.2.2 Tensile Test

The tensile samples were prepared as per ASTM E8-04 standards. The dimensions of the prepared specimen are shows in Fig 3.5(a). The tensile test was conducted on Universal Testing Machine (H-1000A) supplied by Hung Ta Instrument Company Ltd., Taiwan. The machine is shown in Fig 3.5(b). The test was performed at room temperature with a cross head velocity of 1mm/min. The tensile test was performed at Structures Engineering Lab in Civil Engineering Department at Thapar University, Patiala.



(a)

(b)

Figure 3.5: (a) Tensile Test Specimen (all dimensions in mm); (b) Testing on UTM

3.2.3 Wear Test

The wear characteristics of prepared composite material were investigates using pin and disc type of apparatus, shown in Fig. 3.6. The tests were conducted as per the ASTM G99 standard. The test specimens in the form of pin of diameter 10 mm were prepared. The end faces of the specimen were polished with abrasive paper of 800 grit. The specimen were cleaned with acetone before and after each run of the wear test. The wear test was conducted at the loading of 1, 3 and 5 N; with the velocity of 1, 1.5, 2 and 2.5 m/s; and with the sliding distance of 2000 and 2500 m. The weight loss was measured using electronic weighting machine with resolution of ± 0.1 mg. Scanning Electron Microscope were used to study the behaviour of the worm surface of pin and debris. The SEM machine is shows in Fig. 3.7.

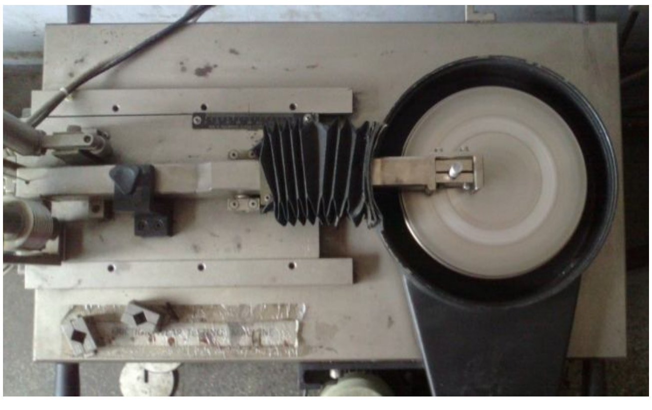


Figure 3.6: Wear Test Machine

The wear test and SEM images were conducted in Mechanical Engg. Department and SAI lab, Thapar University, Patiala respectively.

Figure 3.7: Scanning Electron Microscope Machine

Chapter 4

Result and discussion

4.1 Hardness

The Vickers indentation tester was used for measuring the Micro indentation hardness. Figure 4.1 shows the variation of micro-hardness with change in the weight percentage of reinforcement materials. It can be seen from the Fig. 4.1 that the hardness of reinforced composites was higher than the base material alloy. It can also be seen from the figure that the micro hardness of SiC reinforced composite is higher than the SiC/Gr hybrid composite. It is due to the fact that the addition of graphite softens the material along with acting as a lubricant.

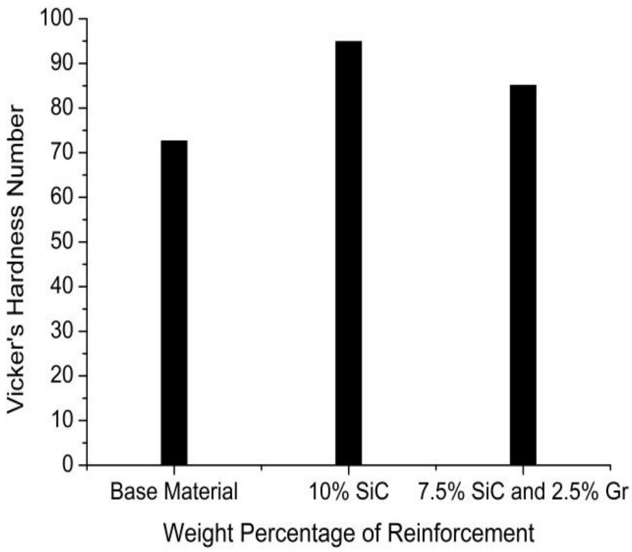
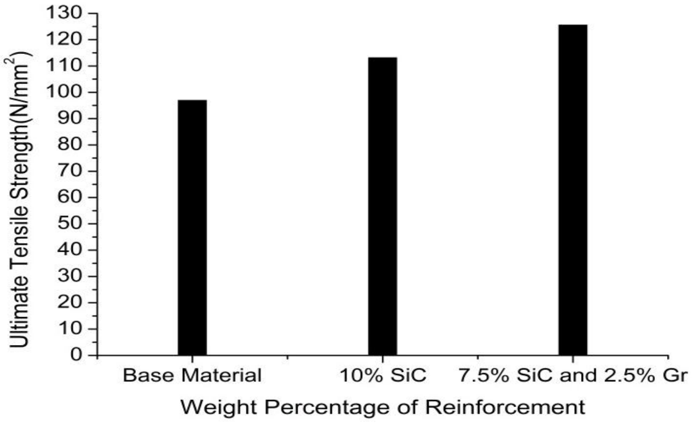


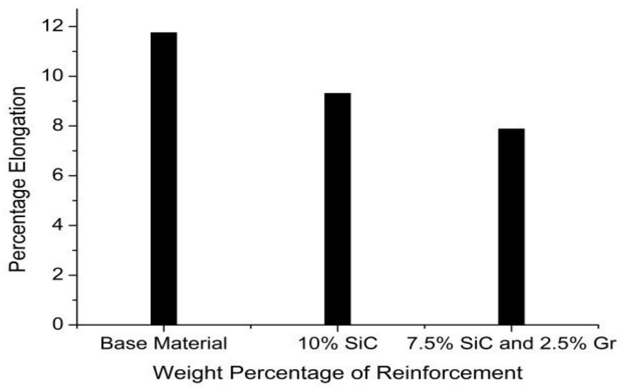
Figure 4.1: Variation of micro hardness with respect to change in reinforcement composition

4.2 Tensile Strength

Figures 4.2 (a) and (b) shows the variation of ultimate tensile strength and percentage elongation with respect to reinforcement composition in Al359 alloy. It can be seen from Fig. 4.2(a) that the ultimate tensile strength of the SiC or SiC/Gr reinforcement is more as compared to the base material alloy. The tensile strength of SiC/Gr hybrid reinforced composite is more as compared to SiC reinforcement. It is due to the fact that SiC and Gr reinforcement exhibits a good bonding with Al359 alloy and also with each other which helps in withstanding more load as compared to Al359 alloy. It can be seen from the Fig. 4.2(b), that the ductility of the composite decreases continuous and significantly with the addition of the SiC or SiC/Gr reinforcement in matrix material. The reduction in ductility is due to the presence of hard phase of ceramics that is responsible for the localized crack initiation and increased embrittlement effect on the composite due to local stress concentration at the interface of reinforcement and matrix material.



(a)



(b)

Figure 4.2: (a) Ultimate tensile strength with respect to change in reinforcement; (b) Percentage elongation with respect to change in reinforcement

4.3 Wear Rate

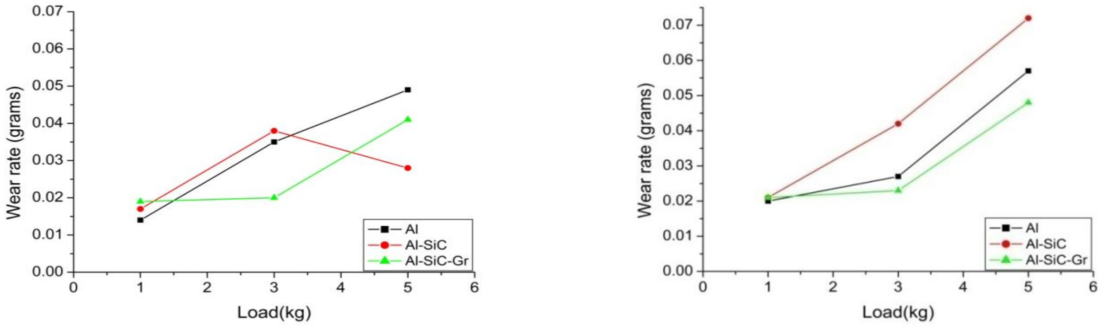
Figures 4.3 to 4.6 represents the variation of wear rate with different sliding distances ant different loads. The sliding velocity of the wear test varies from 1 m/s to 2.5 m/s.

Figure 4.3 shows the wear rate at sliding distance of 2000 m and 2500 m with velocity of 1m/s. It can be seen from the Fig. 4.3 that the wear rate of base material and composite are almost similar at low load condition but at higher load the wear rate of Al-359-SiC composite is less as compared to Al-359-SiC-Gr and matrix alloy. But with the increase in sliding distance Al359-SiC-Gr exhibit the minimum wear.

Figure 4.4 shows the comparison of wear rate at sliding distance of 2000 m and 2500 m with the velocity of 1.5 m/s. The load varies from 1 to 5 kg. It can be seen from Fig. 4.4 (a) that at lower load the wear rate of Al359-SiC-Gr exhibits the minimum wear. At higher load, the wear rate of Al359-SiC is minimum. With the increase in sliding distance, again Al359-SiC-Gr exhibits better wear properties for higher loading conditions, shown in Fig. 4.4 (b).

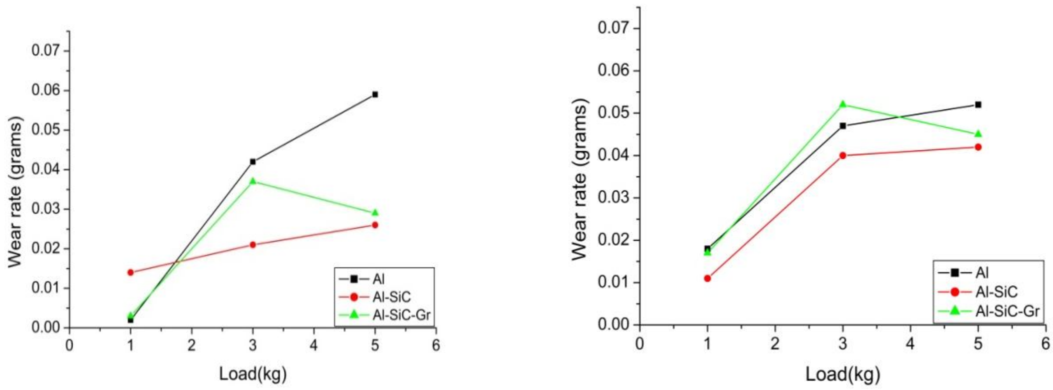
Figure 4.5 shows the comparison of wear rate at sliding distance of 2000 m and 2500 m with the velocity of 2 m/s. It can be seen from Fig. 4.5 (a) that the wear rate of Al-359-SiC-Gr composite is minimum at higher load as compared to other composites. Figure 4.5 (b) shows that the wear rate of all the composites increased with increase in load while the minimum wear rate was observed for Al-359-SiC-Gr composite at higher load as compared to matrix alloy and Al-359-SiC Composite.

Figure 4.6 shows the comparison of wear rate at sliding distance of 2000 m and 2500 m with velocity of 2.5 m/s. The wear is minimum for Al-SiC-Gr composite for both the sliding distance at higher load.



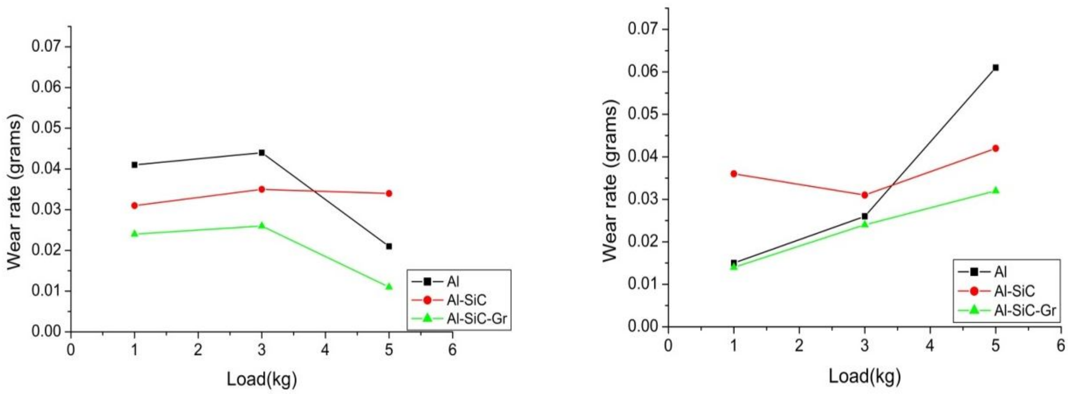
(a) (b)

Figure 4.3: Variation of wear rate of different composites at sliding velocity of 1 m/s with different sliding distances: (a) 2000 m (b) 2500 m



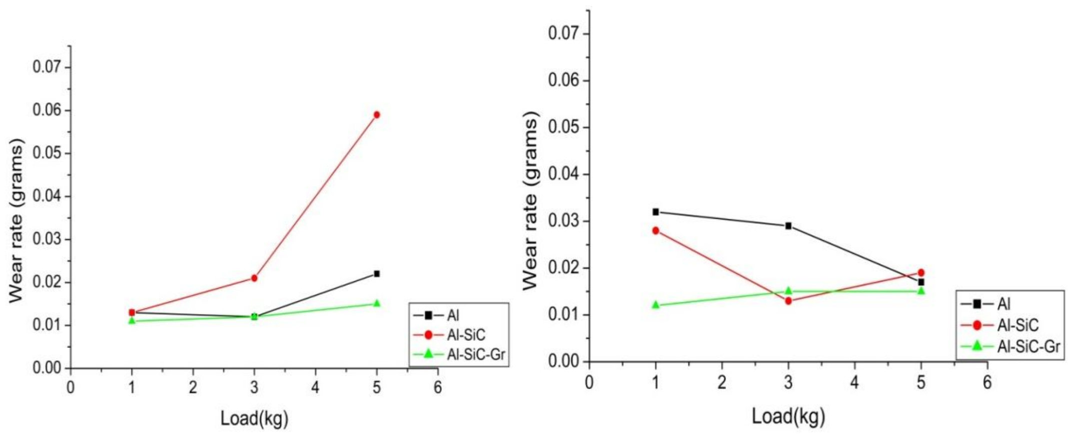
(a) (b)

Figure 4.4: Variation of wear rate of different composites at sliding velocity of 1.5 m/s with different sliding distances: (a) 2000 m (b) 2500 m



(a) (b)

Figure 4.5: Variation of wear rate of different composites at sliding velocity of 2 m/s with different sliding distances: (a) 2000 m (b) 2500 m



(a) (b)

Figure 4.6: Variation of wear rate of different composites at sliding velocity of 2.5 m/s with different sliding distances: (a) 2000 m (b) 2500 m

It can be concluded that the addition of the Silicon Carbide and graphite to the Al-359 alloy improve the properties of the composite which exhibits the lesser wear as compared to the Al-359 alloy. The addition of appropriate graphite content improves the wear properties of Al as it acts as the lubricant in the material which reduces the wear even at higher loads.

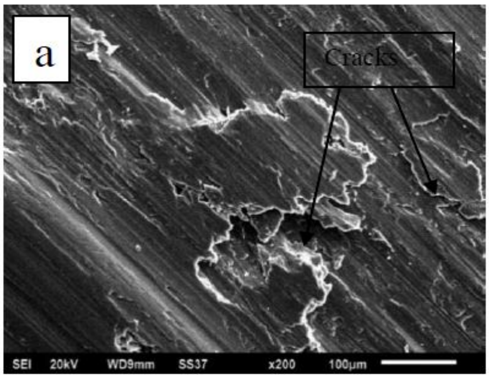
4.3.1 Morphological analysis of worm surfaces

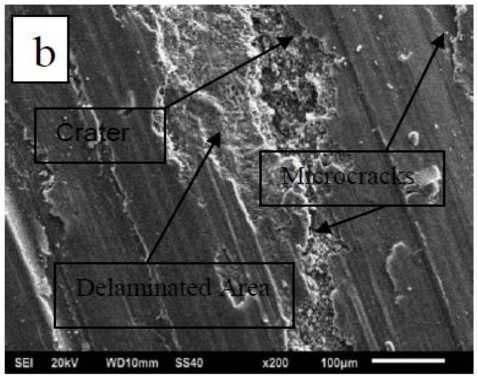
The morphologies of worm out surface of pin offer the clues to wear mechanism involved during sliding of the sample with a given load. SEM images were taken which helped to understand the mechanism.

Figures 4.7 and 4.8 show the SEM images of Al359-SiC and Al359-SiC-Gr materials at different sliding distance, velocity and load. It can be seen from Fig. 4.7 (a) that there is plastic deformation of asperities during the wear test which forms the abrasive and adhesive wear. The images also suggest the excessive material removal and cracks on the worm surface of the composite.

As the sliding distance increases, the material loss is in the form of craters which grows in the sliding direction, shown in Fig. 4.7 (b).The material loss due to delimitation and several micro cracks are also observed.

With the increase in speed some plowing marks with speckle are formed on the worn pin surface. This is shown in Fig. 4.7 (c). Some small grooves and cracks are also seen in the images. With further increase in velocity, the plowing marks grow deeper, shown in Fig. 4.7 (d).





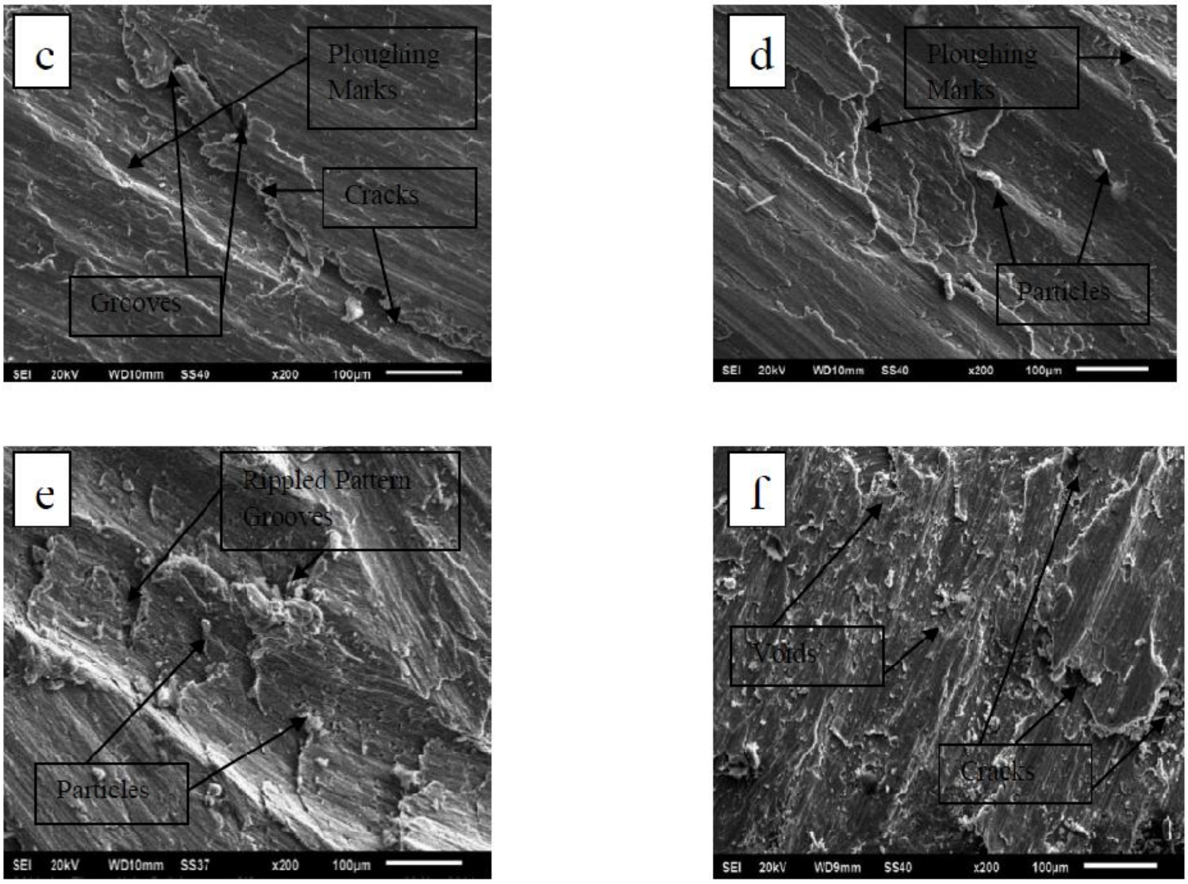


Figure 4.7: SEM Image of worm pin surface of composite Al-359-SiC at load 3kg for different velocities and sliding distances: (a) velocity 1 m/s and sliding distance 2000 m ; (b) velocity 1 m/s and sliding distance 2500 m ; (c) velocity 1.5 m/s and sliding distance 2500 m ; (d) velocity 2 m/s and sliding distance 2500m ; (e) velocity 2.5 m/s and sliding distance 2000 m ; (f) velocity 2.5 m/s and sliding distance 2500 m

With the velocity of 2.5 m/s, the images in Fig. 4.7 (e) shows the rippled pattern of grooves which are formed due to plastic deformation followed by the plowing action of particles.

Figure 4.7 (f) shows the generation of cracks in the form of plowing marks due to delamination of matrix material. This occurs at high velocity and high sliding distances.

Figure 4.8 shows the SEM image of Al359-SiC-Gr composite for 3 kg load at different velocities and sliding distance. Images in Fig. 4.8 (a) shows the wider and longer cracks along the sliding direction at the velocity of 1 m/s. With the increase in sliding distance there are grooves and debris formed on the surface, shown in Fig. 4.8 (b). With an increase in velocity to 2.5 m/s, images in Fig. 4.8 (c) shows the cavities and microcracks along the sliding direction due to earing and delamination of surface material. With an increase in sliding distance at velocity of 2.5 m/s, images in Fig. 4.8 (d) shows the finer grooves and abrasive zones, which take place due to increase in temperature at the interface of pin and disc.

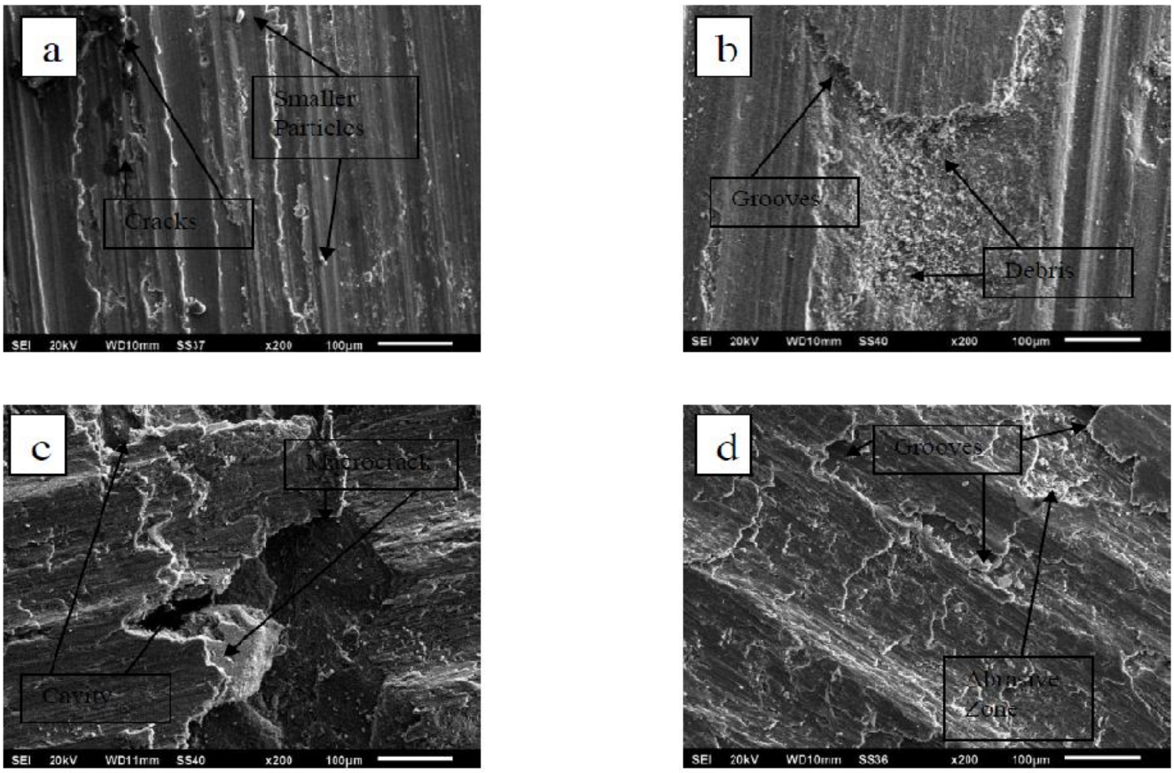


Figure 4.8: SEM Image of worm pin surface of composite Al-359-SiC-Gr at load 3kg: (a) velocity 1 m/s and sliding distance 2000 m ; (b) velocity 1 m/s and sliding distance 2500 m ; (c) velocity 2.5 m/s and sliding distance 2000 m ; (d) velocity 2.5 m/s and sliding distance 2500 m

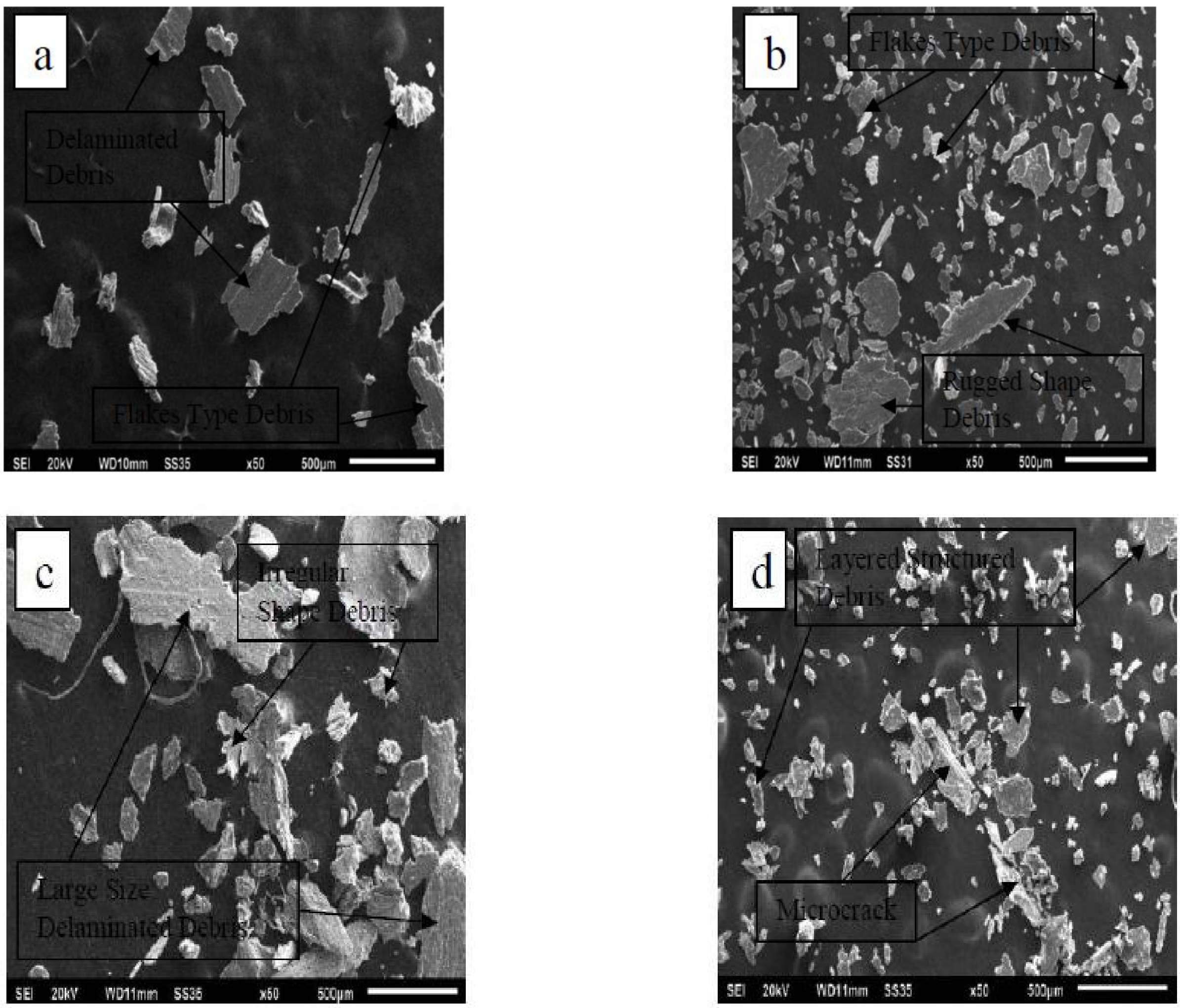
4.3.2 Morphological analysis of debris

The morphologies of debris offer the clues to wear mechanism involved during sliding of the component at a given load. The SEM images of the wear debris tested at sliding distance of 2000 and 2500 m under different velocities and loading conditions are given in Figs. 4.9 and 4.10.

Figure 4.9 shows the SEM images of debris generated after testing of Al359-SiC composite at different load, velocity and sliding conditions. The images in Fig. 4.9 (a) shows the crack on large size delaminated debris. The wear rate is higher when the crack is present in the debris. The thin wear sheets and flakes are formed along the sliding direction.

Figure 4.9 (b) shows the debris in the form of flakes with debounded reinforced particles. The formation of such type of debris is due to delamination of the matrix material. Some rugged shape debris is also formed due to microcutting actions.

Figure 4.9 (c) shows the SEM image of Al359-SiC debris at load 3kg and velocity 1.5 m/s with sliding distance of 2500 m. The large size delaminating debris are formed due to increase in velocity. SEM image shows the irregular shaped oxide debris and oxide layer which helps to reduce wear at high load.



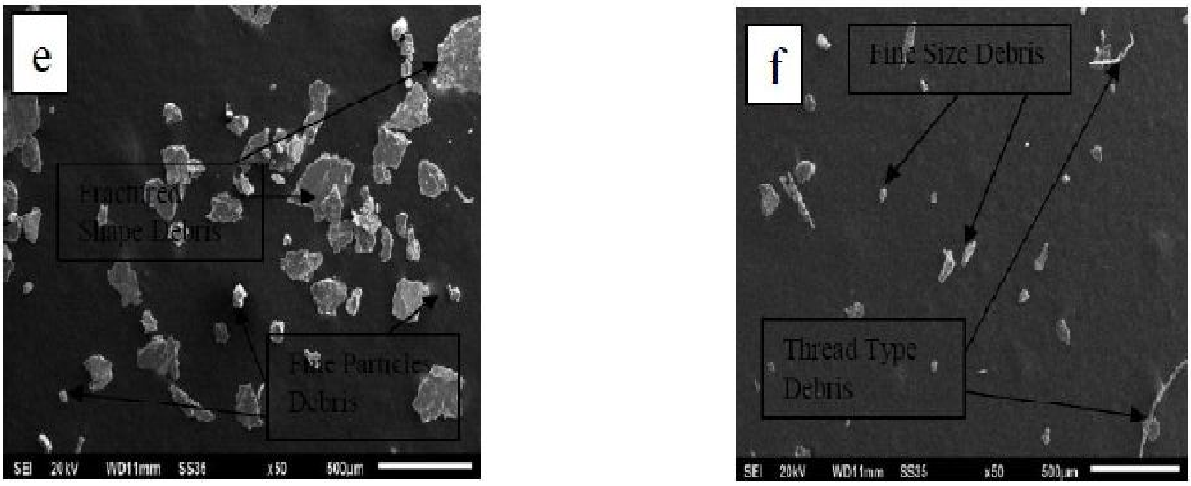


Figure 4.9: SEM Image of wear debris of composite Al-359-SiC at load 3kg : (a) velocity 1 m/s and sliding distance 2000 m ; (b) velocity 1 m/s and sliding distance 2500 m ; (c) velocity 1.5 m/s and sliding distance 2500 m ; (d) velocity 2 m/s and sliding distance 2500 m ; (e) velocity 2.5 m/s and sliding distance 2000 m ; (f) velocity 2.5 m/s and sliding distance 2500 m

Figure 4.9 (d) shows the debris in the form of microcracks. These are due to delamination and crack propagation. The flakes are generated by cutting action and removal of material due to continuous sliding of the components. It is also responsible for formation of layered structured debris.

Figure 4.9 (e) shows the debris in the form of very fine particles. These types of debris are formed due to delamination of matrix material. Increase in velocity will further reduce the size of debris, shown in Fig. 4.9 (f).

Figure 4.10 shows the SEM images of debris generated after testing of Al359-SiC-Gr composite at different load, velocity and sliding conditions.

Figures 4.10 (a) and (b) shows the SEM images of Al359-SiC-Gr composite at load 3kg and velocity 1 m/s with sliding distance 2000 m and 2500 m, respectively. Figure 4.10 (a) shows the removal of material in the form of crack due to delamination. The SEM image shows the crushed debris and flakes which are formed due to micro cutting. Figure 4.10 (b) shows the small flakes and layered debris with the increase in sliding distance.

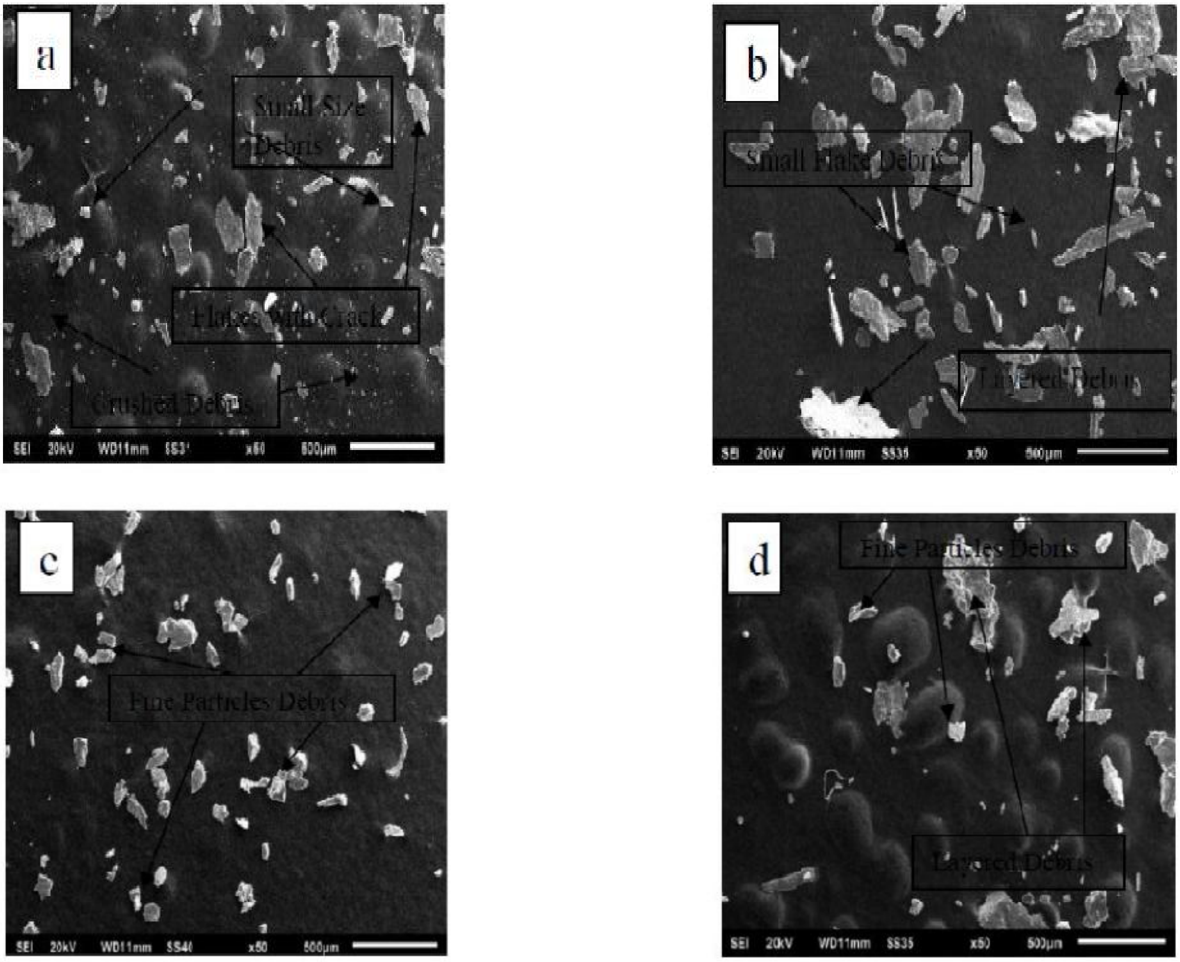


Figure 4.10: SEM Image of wear debris of composite Al-359-SiC-Gr at load 3kg : (a) Velocity 1 m/s and sliding distance 2000 m ; (b) velocity 1 m/s and sliding distance 500 m ; (c) velocity 2.5 m/s and sliding distance 2000 m ; (d) velocity 2.5 m/s and sliding distance 2500 m

Figs. 4.10 (c) and (d) shows the SEM image of Al359-SiC-Gr composite at load 3kg and velocity 2.5 m/s with sliding distance 2000 and 2500 m, respectively. The SEM image in Fig. 4.10 (c) shows the debris in the form of fine particles which are caused due to delamination of the matrix material. With the increase in sliding distance, the layered debris are formed, shown in Fig. 4.10 (d).

Chapter 5

Conclusion

5.1 Conclusions

The effect of silicon carbide and graphite reinforcements on the mechanical and wear properties of Al359 alloy were investigated in the present work. The following conclusions can be drawn:

i. The hardness of the Al359 metal matrix composite was improved with the addition of silicon carbide and graphite particles. The hardness of the Al-359-SiC composite is better than Al359-SiC-Gr composite as the addition of graphite material softens the composite.

ii. The ultimate tensile strength of the reinforced composite is better as compared to the base alloy. The silicon carbide / graphite reinforced composite exhibits a superior ultimate tensile strength against silicon carbide reinforced composite, because of good bonding of silicon carbide / graphite with Al359 alloy which helps to withstand the higher load. The percentage elongation decreases continuously with the addition of the SiC or SiC/Gr reinforcement in matrix material. The reduction in ductility in SiC/Gr composite is due to the localized crack initiation and increased embrittlement effect on the composite due to local stress concentration.

iii. The addition of the silicon carbide and graphite to the Al359 alloy improved the wear properties of the alloy. The wear of the Al-SiC composite considerably decrease with increase in load and speed upto 1.5 m/s at 2000 m sliding distance. Beyond the speed of 1.5 m/s, the wear of Al-SiC composite increases. However, for higher loadings, sliding distances and velocities the wear rate of Al-SiC-Gr composites is lesser as compared to Al-SiC composites. It is due to the fact that the addition of graphite in the metal matrix acts as lubricant which reduces the wear rate at higher values.

iv. The SEM images of Al-SiC and Al-SiC-Gr composites found that there are larger size cracks, ploughing marks, grooves and voids present on the worn surfaces of component prepared from Al-SiC composite material as compared to Al-SiC-Gr material. The cavities, grooves and micro cracks are very fine in components prepared from Al-SiC-Gr material.

v. The SEM image of the debris of Al-SiC and Al-SiC-Gr material suggests that the debris from Al-SiC material is larger in size as compared to Al-SiC-Gr material.

5.2 Future Scope

The present work can be extended in the following directions:

i. Composite can be prepared by using other manufacturing techniques *i.e,* powder metallurgy, pressure die casting etc. and the result pertaining to mechanical properties can be compared with the specimen prepared using stir casting process.

ii. Weight percentage of the reinforced particles can be varied and the change in the different mechanical properties can be studied.

iii. Heat treatment of the metal matrix composite can be done to study the behaviour of the different mechanical properties.

Publication

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References

[1] http://en.wikipedia.org/wiki/Composite_material

[2] http://www.mech.utah.edu/~rusmeeha/labNotes/composites.html

[3] http://www.virginia.edu/bohr/mse209/chapter17.htm

[4] http://composite.about.com/od/glossaries/g/Matrix.htm

[5] http://en.wikipedia.org/wiki/Aluminium_alloy

[6] http://www.aalco.co.uk/datasheets/Aluminium-Alloy_Introduction-to-Aluminium-and-its-alloys_9.ashx

[7] http://www.morgantechnicalceramics.com/materials/silicon-carbide-sic

[8] http://www.azom.com/article.aspx?ArticleID=1630

[9] http://www.corrosionpedia.com/definition/1072/tensile-strengthA

[10] http://www.calce.umd.edu/TSFA/Hardness_ad_.htm

[11] http://www.corrosionpedia.com/definition/1072/tensile-strength

[12] Koji Kato, Koshi Adachi Modern tribology hand book, Vol 1, CRD Press London, 2001.

[13] Apachitei, J. Duszczyk, Autocatalytic nickel coating on aluminium with improved abrasive wear resistance, Surface and Coating Technology 132 (2000) 89-98

[14] L.M. Tham, M. Gupta, L. Cheng, Effect of limited matrix-reinforcement interfacial reaction on enhancing the mechanical properties of aluminium-silicon carbide composites, Acta Materialia 49 (2001) 3243-3253.

[15] Joel Hemanth, Fracture toughness and wear resistance of aluminium-boron particulate composites cast using metallic and non-mettalic chills, Materials and Design 23 (2002) 41-50.

[16] B. Torres, M. Lieblich, J. Ibanez, A. Garcia-Escorial, Mechanical properties of some PM aluminide and silicide reinforced 2124 aluminium matrix composites, Scripta Materialia 47 (2002) 45-79.

[17] K.H.W. Seah, J. Hemanth, S.C. Sharma, Mechanical properties of aluminium / quartz particulate composites cast using metallic and non metallic chills, Materials and Design 24 (2003) 87-93.

[18] John Gilbert Kaufman, Elcoin L. Rooy, Aluminium Alloy Casting: Properties, Processes and Applications, First Ed., ASM International, USA, 2004.

[19] D.S. Metha, S.H. Masood, W.Q. Song, Investigation of wear properties of magnesium and aluminium alloys for automotive applications, Journal of Material Processing Technology 155-156 (2004) 1526-1531.

[20] M. Ramachandra, K. Radhakrishna, Study of abrasive wear behaviour of Al-Si (12%)-SiC Metal Matrix Composite synthesised using vortex method, International Symposium of Research Students on Materials Science and Engineering, IIT Madras, Dec, 20-22, 2004.

[21] Yung-Chang Kang, Sammy Lap-Ip Chan, Tensile properties of nanometric Al_2O_3 particulate-reinforced aluminium matrix composites, Materials Chemistry and Physics 85 (2004) 438-443.

[22] M. Kok, Production and mechanical properties of Al_2O_3 particle-reinforced 2024 aluminium alloy composites, Journal of Materials Processing Technology 161 (2005) 381-387.

[23] Hayerttin Ahlatic, Tolga Kocer, Ercan Candan, Hyseyin Cimenoglu, Wear behaviour of Al/(Al_2O_{3P} + SiC_P) hybrid Composites, Tribology International 39 (2006) 213-220.

[24] Song-Li Zhang, Yu-Tao Zhao, Gang Chen, Xiao-Nong Cheng, Qi-Xun Dai, Microstructures and mechanical properties of aluminium matrix composites fabricated from Al-x wt. % $Zr(CO_3)_2$(x=5, 10, 15, 20, 25) system, Alloys and Compounds 429 (2007) 198-203.

[25] Bekir Sadik Unlu, Investigation of tribological and mechanical properties Al_2O_3-SiC reinforced Al composites manufactured by Casting or P/M Method, Materials and Design 29 (2008) 2002-2008.

[26] S. Kumar, M. Chakraborty, V. Subramanya Sarma, B.S. Murty, Tensile and wear behaviour of in situ Al-7Si/TiB_2 particulate composites, Wear 265 (2008) 134-142.

[27] Ali Kalkanli, Sencer Yilmaz, Synthesis and characterization of aluminium alloy 7075 reinforced with silicon carbide particulates, Materials and Design 29 (2008) 775-780.

[28] S. Suresh, B.K. Sridhara, Effect of silicon carbide particulates on wear resistance of graphitic aluminium matrix composite, Materials and Design 31 (2010) 4470-4477.

[29] Yusuf Sahin, Abrasive wear behaviour of SiC/2014 Aluminium Composite, Tribology International 43 (2010) 939-943.

[30] Kamalpreet Kaur, O. P. Pandey, Dry Sliding Wear Behaviour of Zircon Sand Reinforced Al–Si Alloy, Springer Science 38 (2010) 377-387.

[31] G. Rajaram, S. Kumar, T. Srinivas Rao, M. Kamaraj, Studies on high temperature wear and its mechanism of Al-Si/graphite conditions under dry sliding conditions, Tribology International 43 (2010) 2152-2158.

[32] C.S. Shin, J.C. Huang, Effect of temper, Specimen orientation and test temperature on the tensile and fatigue properties of SiC particles reinforced PM 6061 Al Alloy, Fatigue 32 (2010) 1573-1581.

[33] N. Nemati, R. Khosroshahi, M. Emamy, A. Zolriasatein, Investigation of microstructure, hardness and wear properties of Al-4.5 wt% Cu-TiC nanocomposites by mechanical milling, Materials and Design 32 (2011) 3718-3729.

[34] G.B. Veeresh Kumar, C.S.P. Rao, N. Selvaraj, Studies on mechanical and dry sliding wear of Al 6061-SiC Composites, Composite: Part B 43 (2012) 1185-1191.

[35] Heguo Zhu, Cuicui Jar, Jinzhu Song, Jun Zhao, Jianliang Li, ZonghanXie, High temperature dry sliding friction and wear behaviour of aluminium matrix composites (Al_3Zr + α-Al_2O_3), Tribology International 48 (2012) 78-86.

[36] A. Baradeswaran, A. Elaya Perumal, Wear and Mechanical Characteristics of Al 7075/graphite composites, Composites: Part B 56 (2013) 472-476.

[37] M. Vasheghani Farahani, E. Emadoddin, M. Emamy, A. Honarbakhsh Raouf, Effect of grain refinement on mechanical properties and sliding wear resistance of extruded Sc-free 7042 aluminium alloy, Materials and design 54 (2014) 361-367.

[38] T. Ram Prabhu, V.K. Varma, Srikanth Vedantam, Effect of SiC volume fraction and size on dry sliding wear of Fe/SiC/graphite hybrid composites for high sliding speed applications, Wear 309 (2014) 1-10.