Dissertation Report

On

"Analysis of Aluminium Alloy (AA6061) Matrix Composite Reinforced by Boron Carbide and Molybdenum Disulfide"

Submitted in partial fulfillment of the requirements for the obtainment of degree of

Master of Technology

In

Production Engineering

By

Yogesh Kumar
2013PPE5170

Under the Supervision of

Mr. Mukesh Kumar

DEPARTMENT OF MECHANICAL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR-302017

June 2015

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

DEPARTMENT OF MECHANICAL ENGINEERING

Jawahar Lal Nehru Marg, Jaipur-302017(Rajasthan)

CERTIFICATE

This is to certify that the Dissertation titled **"Analysis of Aluminium Alloy (AA6061) matrix composite reinforced by Boron carbide and Molybdenum disulfide"** that is being submitted by YOGESH KUMAR**,** M. Tech (2013PPE5170) requirement for partial fulfillment of award of the degree of **Master of Technology, Production Engineering,** Malaviya National Institute of Technology Jaipur is found to be satisfactory and is hereby approved for submission.

Place: **Mr. Mukesh Kumar**

Date: Asst. Professor Mechanical Engineering Department

MNIT Jaipur

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY

JAIPUR

DEPARTMENT OF MECHANICAL ENGINEERING

Jawahar Lal Nehru Marg, Jaipur-302017(Rajasthan)

CANDIDATE'S DECLARATION

I hereby certify that following work which is being presented in the dissertation entitled **"Analysis of Aluminium Alloy (AA6061) Matrix Composite Reinforced by Boron Carbide and Molybdenum Disulfide**" in the partial fulfillment of requirement for award of the degree of Master of technology (M. Tech.) and submitted in **Department of Mechanical Engineering** of Malaviya National Institute of Technology Jaipur is an authentic record of my own work carried out by me during a period from July 2014 to June 2015 under the supervision of **Mr. Mukesh Kumar,** Assistant Professor, Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur.

The matter presented in this dissertation embodies the result my own work and studies carried out and has not been submitted anywhere else.

Date: **Yogesh Kumar**

2013PPE5170

ACKNOWLEDGEMENT

It gives me immense pleasure to express my deep sense of gratitude and indebtedness to my supervisor **Mr. Mukesh Kumar** for his constant encouragement and guidance from inception to completion of this dissertation work by taking interest and giving personal attention to the same. His valuable feedback and moral support have been a great source of inspiration for broadening my horizons in this area of research.

I am grateful to **Professor G.S. Dangayach, H.O.D. Mechanical Engineering Department** for providing me a healthy and supportive environment for my research work.

I would like to extend my sincere thanks to **Dr. Amar Patnaik** for his invaluable support throughout the research work and **Professor Upendra Patel, H.O.D. Metallurgical & Material Engineering Department** for his help and cooperation

I would also like to thanks all Technical and Non-Technical Staff of the office of Mechanical Engineering department, MNIT-Jaipur and staff of Material Research Center for his support.

I sincerely thanking to my family members and friends for encouraging me and giving me support through all my works.

Yogesh Kumar

(2013PPE5170)

List of tables

List of figures

*****

ABSTRACT

The Aluminum alloy composite materials have of high strength, high stiffness, more thermal stability, more corrosion and wear resistance, and more fatigue life. Aluminum alloy materials found to be the best alternative with its unique capacity of designing the materials to give required properties.

An attempt has been made to fabricate a metal matrix composite through Stir casting technique by taking matrix material as Aluminium Alloy AA6061 and reinforcement as Boron carbide and Molybdenum disulfide. Boron carbide powder of mesh size 220 and Molybdenum disulfide powder of particle size approximately 6 µm is taken as reinforcement in composite material. Molybdenum disulfide is a self lubricating material and used mainly in automobile industries. Boron carbide is one of the hardest materials ranking third after diamond and cubic boron nitride. The experiments have been conducted on four compositions. The compositions are AA6061/0% B_4C/4% MoS_2, AA6061/3% B_4C/4% MoS_2, AA6061/6% B_4C/4% MoS_2 and AA6061/9% B_4C/4% MoS_2.

The experiment evaluate the density, hardness, tensile strength, impact strength and flexural strength and result reveals that the density of composite decreases as boron carbide particulate increasing. The % Void content on the all four samples is less than 1.5. Hence casting done for all four samples is fair enough. Hardness increases by adding wt % reinforcement of B_4C in the composite material. Impact strength is increases rapidly from 2 J for specimen of composition 0% B_4C to 8.2 J for specimen of composition 3% B_4C and then there is slow increment of impact strength. Wear rate is calculated on the pin on disc type of sliding wear tester in varying parameters which is sliding distance, load, and sliding speed. In all cases the value of wear rate decreases due to the presence of the particulate material B_4C and MoS_2.

*****

Content

1.1Composite:

Composites are materials which made of two or more chemically distinct constituents, on a macro-scale, having a distinct interface separating them. One or more discontinuous phases therefore, are embedded in a continuous phase to form a composite. [1]

Generally, most of the composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This reinforcement is usually in fiber or particulate form. [2]

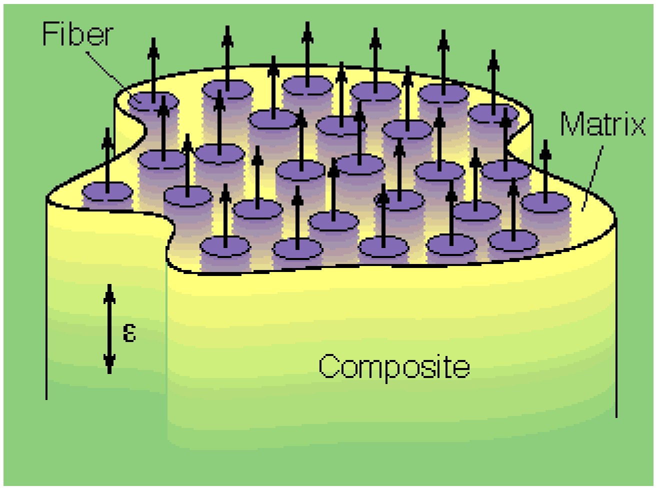


Fig.1 Composite Material

1.2 Why Composites?

In the recent decades application of composite materials in aerospace sector as well as in the other sectors increases drastically.

The use of composites in various sectors because: [2]

a) Composites can be very strong and stiff, light in weight, so strength-to-weight and stiffness-to-weight ratios are several times greater than steel or aluminum.
b) Fatigue properties are generally better than for common engineering metals.
c) Toughness is often greater too.
d) Composites can be designed that do not corrode like steel.
e) Composites can withstand in high temperature.

1.3 Classification of Composite:

On the basis of reinforcing phase and matrix phase composites are classified as:

1.4 Based on Reinforcement

Reinforcement in the composite material is used to improve mechanical as well as thermal properties. Metal matrix composite is classified according to the reinforcement used as:

1.5 Particle Reinforced Composites

Particle reinforced composites are also classified in two subdivisions as: (a) large particle and (b) dispersion- strengthened composites. The distinction between these relies upon reinforcement or strengthening mechanism.

1.6 Large-Particle Composites

The term large demonstrate that particle- matrix associations can't be dealt with on the molecular or atomic level. Properties are a blend of those of the segments. The guideline of blends predicts that a upper bound of elastic modulus of the composite is given as far as the elastic moduli of the matrix (E_m) and the particulate (E_p) given by: [5]

$$E_c = E_m V_m + E_p V_p$$

Where V_m and V_p are the volume fraction of the two phases.

A lower bound is given by:

$$E_c = \frac{E_p E_m}{E_p V_m + E_m V_p}$$

Where E and V represents the elastic modulus and volume fraction, respectively and the subscript c, m, and p represents composite, matrix and particulate phases respectively.

1.7 Dispersion-Strengthened Composites:

These composites contain particulates or dispersions, which helps to increase the strength of the composite by resisting the movement of dislocations. The dispersoid is typically a stable oxide of the original material. Particle-matrix interactions occur on the atomic or molecular level and lead to strengthening. Particles like oxides do not react so the strengthening action is retained at high temperatures. A common example is sintered aluminium powder (SAP).Particles for dispersion-strengthened composites are normally much smaller (diameter between 0.01 micrometer and 0.1 micrometer). [5]

1.8 Fiber-Reinforces Composites:

These are solid strands imbedded in a gentler framework to deliver items with high strength to weight proportions. The matrix material transmits the load to fibers, which ingest the anxiety. The length to diameter, or aspect ratio of the fibers utilized as support impacts the properties of the composite. Higher the aspect ratio, more grounded is the composite. In this way, long, persistent fibers are superior to anything short ones for composite development. Nonetheless, continuous fibers are harder to deliver and place in the matrix. Shorter fibers are simpler to place in the matrix however offer poor support. There are two conceivable extremes as for introduction: (i) a parallel arrangement of the longitudinal axis of the fibers in the single direction, and (ii) an absolutely arbitrary arrangement. [4]

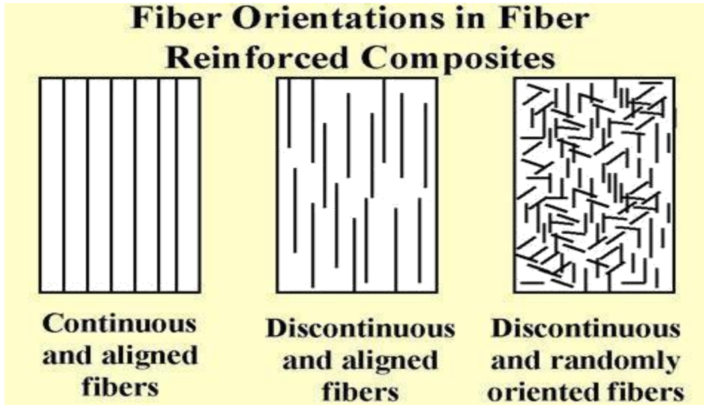


Fig.2 Fiber Reinforced Composites

1.9 Structural Composite:

The most generally utilized structural composites are laminar composites and sandwich boards. Laminar composites are comprised of sheets or boards which are two-dimensional and the layers are orchestrated such that in each progressive layer the introduction of the bearing of high strength changes. Subsequently, high strength can be found in different headings in the 2-D plane. In a sandwich board, a thicker center isolates two slender sheets. The sheets or faces are reinforced adhesively to the center. The center is for the most part light in weight and gives backing to the external appearances. It should be able to prevent buckling of the sandwich panel. The sheets show in outward heading ought to be produced using an in number and hardened material like steel, titanium, Al combinations, and so forth to support different anxieties because of stacking.

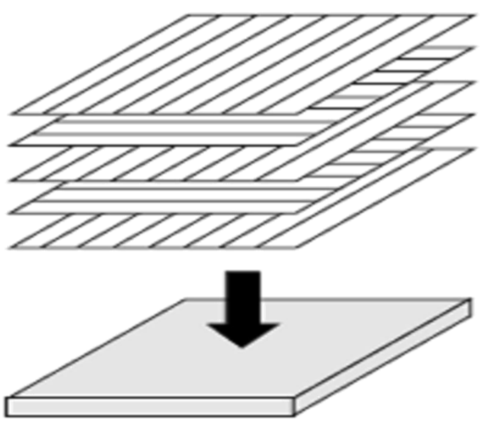


Fig.3 Laminar composite

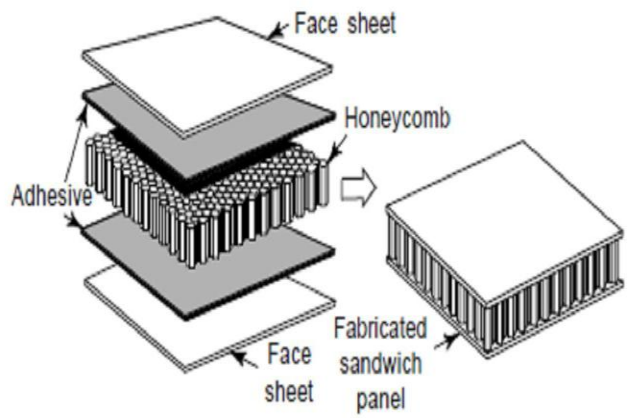


Fig.4 Honeycomb structure [1]

1.10 Based on Matrix

1.11 Polymer Matrix Composite

In polymer matrix composite matrix material choose as polymer and fiber like E-glass, carbon or aramid as the reinforcing phase. Glass Fiber-Reinforced Polymer (GFRP) composites, Carbon Fiber-Reinforced Polymer (CFRP) composites and Aramid Fiber-Reinforced Polymer Composites are most widely used Polymer Matrix Composites (PMC). The most commonly used polymers as matrix are vinyl esters and polyesters. PMCs are widely used because they are easily fabricated and their properties are comparable to metals on the specific range of loads.

1.12 Ceramic Matrix Composite

This class of composites contains ceramic materials as matrix. CMCs are created basically to enhance the fracture toughness of ceramic materials. This makes the CMCs to be utilized as a part of compelling situations of high temperature and anxiety state. The dispersed phase plays a major role in preventing the propagation of cracks. This dispersed phase can be fibers, particles or whiskers. Different components like transformation toughening crack bridging, crack deflection, etc help in obstructing the development of a split [4].

1.13 Metal Matrix Composite

The matrix phase for a MMC is a metal regularly which is ductile. With plans to have high strength to weight ratio, high resistance to abrasion and corrosion, resistance to creep, good dimensional stability, and high temperature operability the MMCs are fabricated. The fundamental points of interest that MMCs have over CMCs are the convenience at high temperatures, and imperviousness to consumption by natural liquids. MMCs are used in industries like automobile and aerospace. Primarily Aluminum and Copper are utilized as the metal matrix. Composite degradation may be a problem while utilizing MMC at raised temperatures. To avoid that the reinforcement is given a protective surface coating or the composition of the matrix alloy is modified. [4]

There are three types of metal matrix composites:

a) Particle reinforced MMCs
b) Short fiber or whisker reinforced MMCs
c) Continuous fiber or sheet reinforced MMCs

Particle or discontinuously reinforced MMCs ,the term discontinuously reinforced MMCs is generally used to demonstrate metal matrix composites having reinforcements in the form of short fibers, whiskers, or particles.

The particulate reinforced metal matrix composites consists of particulates of enhanced modulus and strength embedded in a metal matrix with distinct interface between them

Characteristics of Particulate filled MMCs

a) Inexpensive
b) Conventional metallurgical processing techniques can be used for fabrication
c) Enhanced modulus and strength
d) Increased thermal stability
e) Better wear resistance

1.14 Hybrid Composite

Hybrid composite are typically two or more fibers which are not quite same as each other in a single matrix phase. The most commonly utilized hybrid composite as the one in which polymeric resin as the matrix and both glass and carbon fibers as reinforcing phase. We get anisotropic properties in majority of the hybrid composites. The overall properties of a hybrid composite are superior to the composites having only one fiber as reinforcing phase.

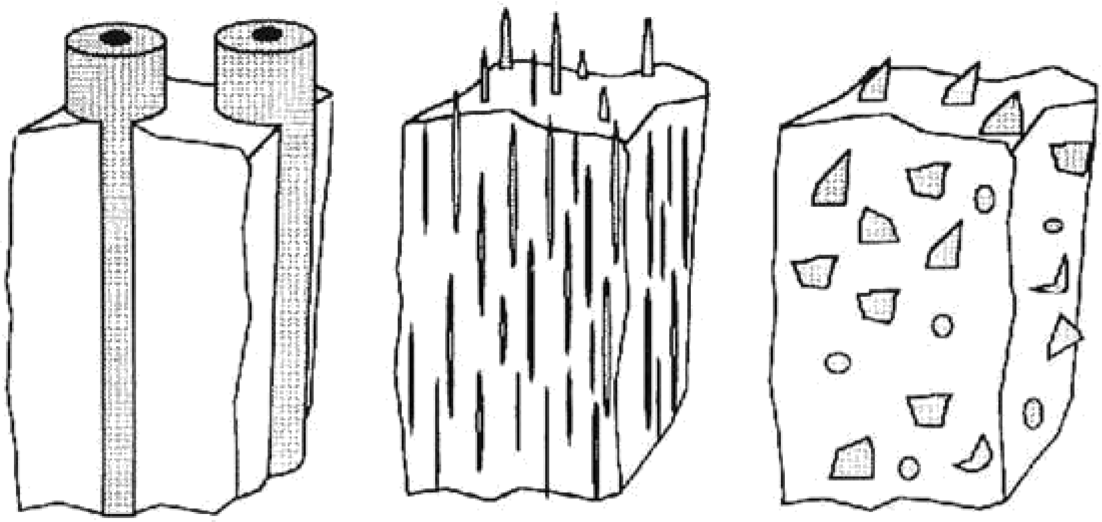


Fig.5 Schematic presentation of shapes of metal matrix composite materials [9]

1.15 Processing Of Metal Matrix Composites

It is obvious now that in metal matrix composites the matrix phase contain a metal or an alloy. There are so many MMCs that we come across more often such as Al-SiC or Cu-SiC composites. Mostly the reinforcement phases incorporated are fibers, particulates or whiskers.

The reinforcement can serve several purposes like improve the strength to weight ratio, improve the creep and thermal shock resistance, improve the wear resistance, increase the fatigue strength, improvement in resistance to corrosive environments, etc [1]. The reinforcement materials used should be able to fulfill certain conditions [2] like having low density, good chemical and mechanical compatibility, high strength (both compressive and tensile), high temperature stability and economical cost of production and processing. These requests can be basically fulfilled by non-metallic reinforcement. Contingent on the reinforcement phases MMCs can be characterized into dispersion hardened and particle composites, layer composites or laminates, fiber composites and invasion composites. A few inquires about are going ahead in the field of MMCs on the grounds that metals absolutely have some unmistakable points of interest over polymers and ceramics.

There are different methods by which a metal-matrix composite can be manufactured:

A. Solid-phase fabrication methods [5]
    a) Diffusion-bonding method
    b) Powder Metallurgy Technique

B. Liquid-phase fabrication methods
    a) Liquid-metal infiltration
    b) Squeeze casting
    c) Spray co-deposition
    d) Compocasting

C. Vapor state method
    a) Physical vapor deposition (PVD)

1.16 Liquid-Phase Fabrication

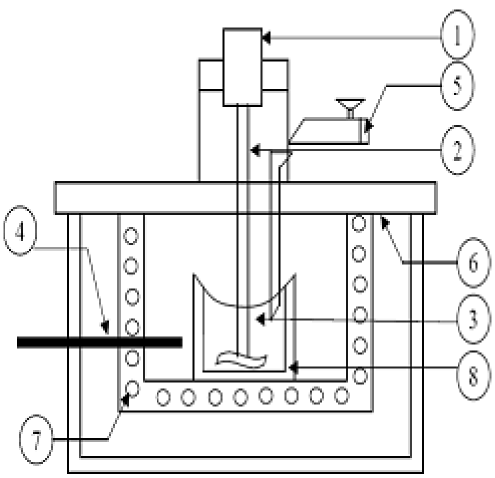
Fluid state creation of Metal Matrix Composites includes expansion of scattered stage into a liquid framework metal, trailed by its Solidification. To give better mechanical properties of the composite, great interfacial holding (wetting) between the scattered stage and the fluid grid ought to be gotten. Wetting change may be acquired by covering the scattered stage particles (strands). Legitimate covering decreases interfacial vitality, as well as opposes concoction association between the scattered stage and the network. The simplest and the most cost effective method of liquid state fabrication is Stir Casting.

Stir Casting

Stir Casting is a liquid state method to fabricate composite materials, in which a dispersed phase (Boron carbide and molybdenum disulfide particles) is mixed with a molten matrix metal with the help of mechanical stirring. The liquid composite material is then pouring into the mould.

Stir Casting have by the following features:

a) Content of dispersed phase is limited (usually not more than 30 vol. %).
b) Dispersed phase of reinforcement added in the composite is not throughout the matrix and not perfectly homogeneous.
c) Distribution of dispersed phase may be improved if the matrix is in semi-solid condition. The method using stirring metal composite materials in semi-solid state is called Rheocasting.
d) High viscosity of the semi-solid matrix material enables better mixing of the dispersed phase.



1. Motor
2. Shaft
3. Molten Aluminum
4. Thermocouple
5. Particle injection chamber
6. Insulation hard board
7. Furnace
8. Graphite crucible

Fig.6 Schematic set up for Stir casting

Thesis outline

This thesis is outlined as

Chapter 2: Incorporates literature survey intended to give a synopsis of the essential information accessible including the issues of present exploration interest. This chapter shows the various researches on the composite materials. Physical, mechanical, wear properties and surface morphology is discussed by researchers.

Chapter 3: Shows description of raw materials and test done step by step on the composite materials. It also describes the fabrication technique and investigation of various characteristics of composite material. This chapter also deals with the Taguchi experimental technique.

Chapter 4: This chapter presents the physical, mechanical, wear analysis of composite material.

Chapter 5: presents the conclusions of this work.

This research exploration work is attempted to study the physical, mechanical, wear analysis of particulate filled aluminium alloy matrix composite. The various objectives are outlined in the next chapter.

****

CHAPTER 2 LITERATURE REVIEW

The purpose of this literature review is to give foundation data on the issues to be considered in this thesis and to accentuate the relevance of the present study. The different parts of the metal matrix composites as found in the writing in connection to the under said subjects are thoroughly investigated.

B. Vijaya Ramnath et al. 2014 [6] investigated the mechanical properties of aluminium alloy (LM25) matrix composite reinforced by boron carbide (B_4C) and alumina (Al_2O_3) fabricated through stir casting. He take three samples as sample 1 contains alumina-3% and boron carbide-2%, sample 2 contains alumina-2% and boron carbide-3% and sample 3 contains aluminium alloy only. It has been found that the tensile strength of sample 3 is quite higher than other two samples due to the presence of its aluminium content. But, the sample 1 has larger tensile strength (54.60 MPa) than sample 2 (51.75 Pa). It has been obtained that the flexural strength of sample 3 is better than other two samples. The results of the impact test shows the impact value of sample 1 (2.18 J) is less than the impact value of sample 2 (2.42 J), but greater than that of sample 3 (2 J). Also, the brinell hardness of sample 1 (48.53) is marginally lower than that of sample 2 (52.80) but higher than that of sample 3 (37.83).

S.A. Sajjadi et al. 2012 [8] takes Aluminium Alloy AA356 as matrix and Al_2O_3 as reinforcement. Samples are prepared by taking Micro Alumina Al_2O_3 as 1, 3, 5, and 7.5 and Nano Alumina is taken as 1, 2, 3 and 4 in wt% through stir casting and Compo Casting. Different tests show that yield strength and tensile strength increases while fracture strain decreases with increasing Nano-particle content.

H.R. Ezatpour et al. 2014 [9] investigated an experiment in which Aluminium Alloy AA6061 taken as matrix phase and Nano Alumina Al_2O_3 as reinforcement. The mesh sizes are as 50 µm and 40 nm and fabrication is done through Stir Casting and Extrusion process. Result shows that there is fine microstructure with high porosity and the porosity %vol. increased with increasing alumina weight fraction and decrease with extrusion process. Also found that for both as-cast and extruded samples, with increasing amount of Al_2O_3 nanoparticles, yield strength and tensile strength increased but elongation decreased.

B. Vijaya Ramnath et al. 2014 [10] have fabricated the Aluminium Alumina and Boron Carbide composite by Stir Casting. He has taken three samples in which sample 1 contains Alumina 3% and Boron Carbide 2% sample 2 contains 2% Alumina and 3% Boron Carbide and sample 3 contains only Aluminium Alloy. Tensile strength higher for sample 1 than sample 2 but less than sample 3, Flexural strength is Maximum in sample 3, Impact load is less in sample 1 than sample 2 but greater than sample 3 and Brinell Hardness is less in sample 1 than sample 2 but more than sample 3

F.Chen et al. 2015 [12] have taken Aluminium as matrix material and TiB_2 as reinforcement prepared composite by using Stir Casting. The fabricated composites have much higher improvements in mechanical properties when compared with the Aluminum matrix and the Al–TiB_2 in situ composites fabricated by conventional process. The enhanced mechanical properties mainly due to $\Delta\sigma_{CTE}$, followed by Orowan strengthening, grain refinement strengthening and load transferring effect.

L.J. Zhang et al. 2015 [13] have produced a composite material by taking Aluminium Alloy AA2014 as a matrix material and nano SiC particles as reinforcement and consolidated through Stir Casting and Extrusion process. Result shows that there is improvement in stress strain without sacrificing ductility, uniform distribution of nano SiC particle in the composite. $\sigma_{0.2}$, σ_{UTS} and ε_f at 493K of 0.5vol% nano - SiCp/Al2014 composites are 8.5%, 18.9% and 57.3% higher than those of the 4vol% micron SiCp/Al2014 composites respectively.

S. Amirkhanlou et al. 2010 [14] have opted Aluminium Alloy AA356 as matrix and SiC particle as reinforcement to produce composite by Stir Casting and Compocasting. Samples are taken in different variation. Addition of SiC particles in the form of Al-SiCp composite powder and casting in semisolid state increases the hardness of the composites by 10% and decreases the porosity by 68% approximately also Impact energy is influenced by the form of the reinforcement addition.

H. R. Ezatpour et al. 2013 [15] have prepared a composite material by Stir Casting and Hot Extrusion process. The mass fraction of Al_2O_3 particle in composite is taken as 3%, 5% and 7%. Porosity is increases with increasing alumina and decrease in the extruded ones by approximately 50%, Hardness, yield and ultimate tensile strengths of composites increases with increasing stirring speed up to 300 r/min., Compression strength increases with Al_2O_3 content increasing and extrusion.

B. **ASHOK KUMAR et al. 2014 [16]** investigated the wear properties by using Aluminium Alloy AA6061 and Aluminium nitride AlN Composite. The fabrication is done by using Stir Casting. Result shows that the Accuracy of prediction of wear rate of AA6061/AlN particle composites is in range of ±6% of their experimental values, Wear rate of the composite linearly increases with increase in sliding velocity, sliding distance and normal load; wear rate of the composite decreases with increase in AlN reinforcement in the matrix; Adhesive wear mechanism is dominant in AA6061 alloy, whereas abrasive wear is predominant in AA6061/AlN particle composites.

S. Gopalakrishnan, N. Murugan 2012 [17] done an experiment in which Aluminium Alloy AA6061 is taken as matrix material and TiC particle as reinforcement. They prepared composite by Stir Casting in which Magnesium Mg is taken as filler material. They have found that Specific strength increases by the addition of TiC particle in the composite, Wear rate increases with the addition of TiC particle.

David Raja Selvam et al. 2013 [18] uses Aluminium Alloy as matrix and SiC and Fly Ash as reinforcement. They prepared a composite material by taking 1% of magnesium particle and SiC particle 7.5 to 10% and 7.5% fly ash by %wt. and fabricated through Stir Casting. Various mechanical testing shows that there is Enhancement in the tensile strength of aluminum matrix and composites, the micro and macro-hardness of the composites also increase.

S. Suresh and N. Shenbaga Vinayaga Moorthi 2013 [19] have uses Aluminium Alloy AA6061 and Titanium diboride TiB_2 as matrix phase and reinforcement respectively. The composite is prepared by taking TiB_2 particle in 0, 4, 8, and 12% by weight through Stir Casting. The result shows that there is Increase in the hardness, micro-hardness value also

Improve, Improvement in the wear resistance characteristics, by increasing load the weight loss too increases.

V. Bharath et al. 2014 [20] have fabricated a composite material by Stir Casting in which Aluminium Alloy AA6061 as matrix and Alumina Al_2O_3 as reinforcement. The amount of Al_2O_3 in composite is as 6%, 9% and 12% by weight. The various mechanical and wear test shows that there is increase in the hardness with increasing wt% of alumina, ductility is less, tensile strength is more than Aluminium Alloy.

P.B. Pawar and Abhay A. Utpat 2014 [21] conducted an experiment in which pure Aluminium is taken as matrix and Silicon Carbide particulate taken as reinforcement. Metal matrix is prepared by stir casting. He prepare four samples in which SiC particle taken as 2.5, 5, 7.5, and 10 in wt%. Different mechanical tests are done and result shows that there is enhancement in Hardness, material toughness. The maximum enhancement is shown in 10 % of SiC particulate sample.

Bhargavi Rebba and N. Ramanaiah 2014 [22] investigated on Aluminium matrix composite in which he takes Aluminium alloy AA2024 as matrix material and molybdenum disulfide powder of approximately 40μm particle size as reinforcement. Fabrication is done by stir casting. Weight ratio of MoS_2 in composite is taken as 1%, 2%, 3%, 4% and 5%. With increase in the weight % reinforcement up to 4% of MoS_2 particles in the composite the hardness and tensile strength increases and for 5% of MoS_2 particle in the composite there is decrease in the hardness and tensile strength.

J. Jebeen Moses et al. 2014 [23] done an experiment in which he takes Aluminium alloy AA6061 as matrix material and silicon carbide SiC in different composition as reinforcement. Fabrication is done through stir casting. The periphery of vortex of the composite is added by silicon carbide and then solidified in permanent mould. It is found that fairly homogeneous distribution of silicon carbide particle in the Aluminium matrix. There is enhanced microhardness and ultimate tensile strength of the composite

N.G. Siddesh Kumar 2014 [24] have produced Aluminium Alloy AA2219, Boron Carbide B_4C, Molybdenum Disulfide MoS_2 metal matrix composite using Stir Casting. The wt% of the B_4C is fixed to 3% and varying the composition of MoS_2 as 3, 4, and 5 wt% in the composite. It has been observed that the density & micro hardness of Al2219 alloy is relatively low as compared to prepared hybrid composites, Tensile strength is minimum for Al2219+3% B_4C+5% MoS_2 and maximum for Al 2219 alloy, addition of B_4C and MoS_2 reinforcement decreases the wear rate of hybrid composites and increases the wear resistance of the composites.

Kumar A et al. 2012 [26] have fabricated a composite material in which Aluminium Alloy AA359 as matrix and alumina Al2O3 as reinforcement by using Electromagnetic Stir Casting. The composition of Alumina of mesh size 30 µm in the composite material is 2, 4, 6 and 8 in wt%. Hardness of the MMCs is more than the unreinforced matrix metal and the hardness of the cast composites increases linearly with increasing the weight fraction of Al_2O_3, The tensile strength of the as cast composites also increases.

Rama Rao et al. 2010 [27] investigated mechanical properties like density compressive strength etc. They have taken Aluminium as matrix material and Boron Carbide B_4C as reinforcement. The fabrication is done by Stir casting and composition of Boron Carbide B_4C as 2.5%, 5%, and 7.5% by weight in Aluminium matrix composite. They have found that there is decrease in density; Hardness of the composite increases with increase in the amount of B_4C, Compressive strength is also increase with increase in the weight % of B_4C.

Lokesh GN et al. 2013 [29] have investigated the tensile, compressive, hardness and impact properties of the base alloy as well as the composite by stir, squeeze and gravity casting. In this the weight fraction of fly ash is varied from 3% to12% which increases the above properties. The base alloy prepared by squeeze casting has lower porosity when compared to the base alloy prepared by gravity casting.

Boopathi MM et al 2013 [30] Mentioned a increase in hardness was observed with increase in weight fraction of SiC & fly ash. Maximum hardness is observed at Al/ (10%SiC+10%fly ash). Incorporation of fly ash particles improves the hardness and also the deformation of the

Al matrix. It is observed that the fact that the combination of SiC with fly ash particles possess higher hardness than the aluminum alloy.

Prasanna M et al. 2014 [31] have taken Aluminium Alloy LM25 as matrix material and Silicon Carbide SiC, E Glass and Red Mud as reinforcement. The composition of reinforcement in the composite material as sample 1 contains SiC 3%, E Glass 1% and Red Mud 3, 6, 9%; sample 2 contains SiC 3%, E Glass 1, 2, 3% and Red Mud 3%; sample 3 contains SiC 3, 6, 9%, E Glass 1% and Red Mud 3%. The tests shows that there is Improvement in Tensile Strength, Impact Strength and reduce in the % Elongation. Addition of E Glass minimizes the Hardness and there is nearly uniform distribution of reinforcement in the composite.

Research gap:

On the basis of the literature review of particulate reinforced MMCs tells the following research gap, which helps to set objective of this research work.

a) Almost all possible MMCs is fabricated by the researchers but the effect of the boron carbide and molybdenum disulfide as reinforcement in the MMCs has hardly been discussed.
b) Taguchi method, regardless of being a straightforward, productive and deliberate methodology to improve outlines for execution, quality and expense, is utilized just as a part of a constrained number of utilizations around the world. Its execution in parametric evaluation of wear procedures has hardly been reported.

Objective:

a) Fabrication of particulate filled Aluminium Alloy AA6061 composite through stir casting technique.
b) Distribution of particulate in the composite is homogeneous.
c) Determination of mechanical properties of particulate filled Aluminium Alloy composite.

d) Wear behavior of the composites.
e) Surface topology of the composites.
f) Use of Taguchi method to optimize the parameter of sliding wears (pin on disc) process of all particulate filled AA6061 alloy composites systematically.

Chapter summary:

This chapter gives

a) A thorough survey of exploration takes a shot at different parts of metal and metal alloy
b) composites reported by previous researchers
c) The research gap in earlier investigations
d) The objectives of the present work

The next chapter deals with the materials and methods used for the fabrication of the composites, physical, mechanical and wear properties of the composite material. The next chapter also deals with the use of Taguchi analysis.

****

This section depicts the materials and systems utilized for the handling of composites. It presents the details of physical, mechanical, wear analysis of the proposed composite materials under numerous impact conditions. The methodology used for sliding wear analysis is based on Taguchi experimental technique.

3.1 Material Selection

3.2 Matrix Material

Aluminum alloy AA6061 is a standout amongst the most widely utilized of the 6000 series Aluminum Alloys. It is a flexible heat treatable expelled composite with medium to high quality capacities. [37]

Physical Properties of AA6061 [37]

Material	Density	Melting Point	Modulus of Elasticity	Poissons Ratio
AA6061	2.7 g/cm^3	580 °C	70 to 80 GPa	0.33

Table 3.1. Typical composition of aluminium alloy AA6061 [37]

Component	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Others
Amount (Wt %)	Balance	0.8 - 1.2	0.4 - 0.8	Max. 0.7	0.15- 0.40	Max. 0.25	Max. 0.15	Max. 0.15	0.04 - 035	0.05

Table 3.2. Mechanical properties of AA6061 [37]

Ultimate tensile strength (MPa)	**Brinell Hardness (300 Kg load, 10mm ball)**	**Elongation 50mm dia (%)**
110-152	30-33	14-16

3.3 Particulate Materials

One of the important functions of reinforcement in a composite material is to improve the mechanical property. The cost of the particulate composites (B_4C and MoS_2) is less than the fiber reinforced composites, owing to the lower cost of particles. In addition the mechanical and the physical properties of particulates are generally isotropic. In this study we are using two different particulate filler materials as Boron Carbide B_4C and Molybdenum Disulfide MoS_2.

Fig.7 Boron Carbide Powder

Fig.8 Molybdenum Disulfide Powder (MoS_2)

The B_4C and MoS_2 both are black in color and mesh size of 220 and approximately 6 µm particle size. Boron Carbide is one of the hardest materials known; positioning third behind Diamond and cubic boron nitride. Boron carbide powder is mainly manufactured by reacting carbon with B_2O_3 in an electric arc furnace, through carbothermal reduction or by gas phase reactions. For commercial use B_4C powders normally need to be processed and purified to remove metallic impurities [38].

Boron carbide is characterized by its: [38]

a) High hardness.
b) Difficult to sinter to high relative densities without the utilization of sintering guides.
c) Good chemical resistance
d) Low density

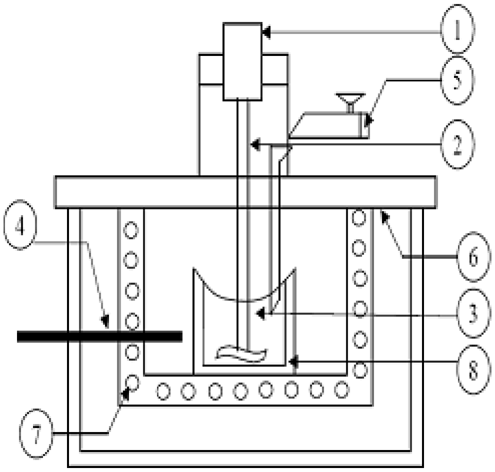
Molybdenum disulfide is the inorganic compound with the formula MoS_2 [25]. Molybdenum disulfide is similar to graphite. It is widely used as a lubricant in solid form because it has low friction properties and robustness. It has density of 5.06 g/cm^3 [25].

Table 3.3 Properties of Boron Carbide Powder B_4C [38]

Density (g/cm^3)	**Melting point (°C)**	**Young's modulus (GPa)**	**Thermal conductivity (W/m.K)**	**Thermal expansion co-eff. x10^{-6} (°C)**	**Hardness (knoop 100g) (Kg/mm^2)**
2.52	2445	450 – 470	30 – 42	5	2900 - 3580

3.4 Fabrication used for Composite Materials

The equipments used in this experimental arrangement consist of main furnace, graphite crucible, etc. The first process in the experiment is to preheat the materials used to fabricate composite. Here, the empty crucible and the reinforcement powders, namely boron carbide and Molybdenum disulfide powders are heated separately to a temperature close to that of the main process temperature. The melting of the aluminium alloy AA6061 ingot is carried out in the graphite crucible inside the furnace. Initially, the ingot was preheated for 3‑4 h at 500 °C. At the same time boron carbide and Molybdenum disulfide powders are also preheated to 350 °C in the respective containers. Then, the crucible with aluminium alloy AA6061 is heated to 820°C while the preheated powders are mixed with each other below their melting points. The furnace completely melts the pieces of aluminium alloy AA6061 and the powders of Molybdenum disulfide and boron carbide. The stirrer is then lowered into the crucible. The stirrer is carried out for some time, then uniformly dispersing the reinforcing powders in the aluminium alloy matrix. The temperature rate of the furnace should be controlled at 820 ± 10 °C in final mixing process.



1. Motor 5. Particle injection chamber

2. Shaft 6. Insulation hard board

3. Molten Aluminum 7. Furnace

4. Thermocouple 8. Graphite crucible

Fig.9 Stir Casting [11]

This experiment is repeatedly done by taking different compositions of the composite powder. In this study the different compositions taken are as given below.

3.5 Composition of Samples

In this experiment, the fabrication is done by Stir casting. For fabrication matrix material is taken as aluminium alloy AA6061 and reinforcement as boron carbide B_4C and molybdenum disulfide MoS_2. These materials are taken in different composition which are listed below

Table 3.4 Compositions of Samples in wt%

Designation of sample	AA6061	B_4C	MoS_2
B0	96	0	4
B3	93	3	4
B6	90	6	4
B9	87	9	4

3.6 Physical and Mechanical Characteristics

3.7 Density and Void Content

The theoretical density of the composites in terms of weight fraction is obtained by rule of mixture as proposed by Aggarwal and Broutman [39]. The actual density of the composites was measured by the Archimedes principle of weighing the sample first in air and then in water.

$$\rho_c = \frac{1}{\frac{W_p}{\rho_p}+\frac{W_m}{\rho_m}} \qquad (1)$$

Where, w and ρ represents the weight fraction and density respectively. The suffix c, p and m stand for composite, particulate and matrix material respectively.

The actual density of the composite can be calculated experimentally by Archimedes's principle. The void content of composites is calculated by Eq. 2 given by Aggarwal and Broutman [39].

$$\text{Void Content} = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \times 100 \qquad (2)$$

Where, suffix ct and ce represents theoretical and experimental values of density.

3.8 Rockwell Hardness

Hardness tester is used to measure the hardness of the material. This tester consists of diamond or steel hemisphere-conical penetrator is pressed against the Aluminium matrix composite and measures the resulting indentation depth on the specimen. Firstly the Minor load of 10 kgf was applied and then the test dial is reset to zero. Now the major load of 100 kgf was applied for full indentation. The major load is now reduced back to the minor load, and the depth measurement was taken. The reading is taken 3 to 5 times for better accuracy and plotted a graph showing the hardness reading. The hardness plotted in the graph is taken as average of all readings.

Fig. 10 Rockwell Hardness Tester

Brinell hardness test is carried out in this work to find out the deformation of the composite under constant compressive load from an object which is sharp.

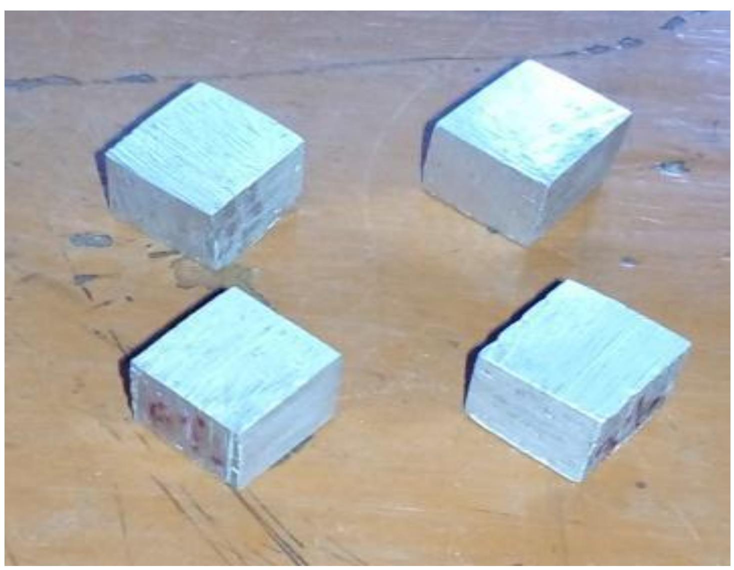


Fig.11 hardness test specimen

To Test the Hardness on the machine, the specimen is prepared as $10 \times 10 \times 10\ mm^3$. The specimen is as above.

3.9 Tensile Strength

The Tensile strength is determined by using Universal Testing Machine (UTM) as well as Electronic Tensometer. UTM machine is little heavy as compared Electronic Tensometer. In this experiment Electronic tensometer is used for measuring tensile strength. Round shape of specimen is used in this study. The specimen has the dimensions as per ASTM: B-557M.

Fig.12 Tensometer and different types of chucks

The specimen is prepared for the tensile testing with the help of lathe machine in the dimensions given below

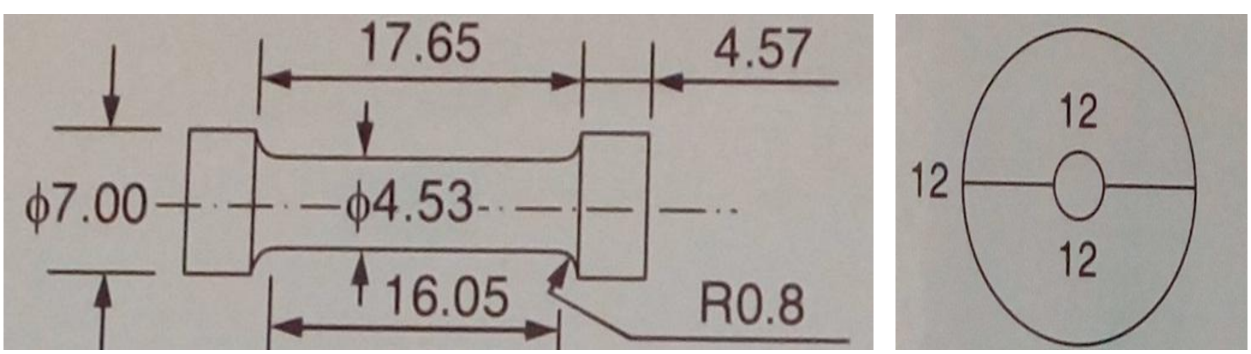


Fig.13 Tensile test specimen dimensions and chuck dimension

The final shape of the specimen for testing is given below

Fig.14 Tensile test specimen

3.10 Impact Test

In impact testing a sudden and dynamic application of the load on the composite specimen is applied. The amount of energy absorbed in joule by the specimen is taken for the rupture. The standard dimension of the specimen is as per IS: 1757

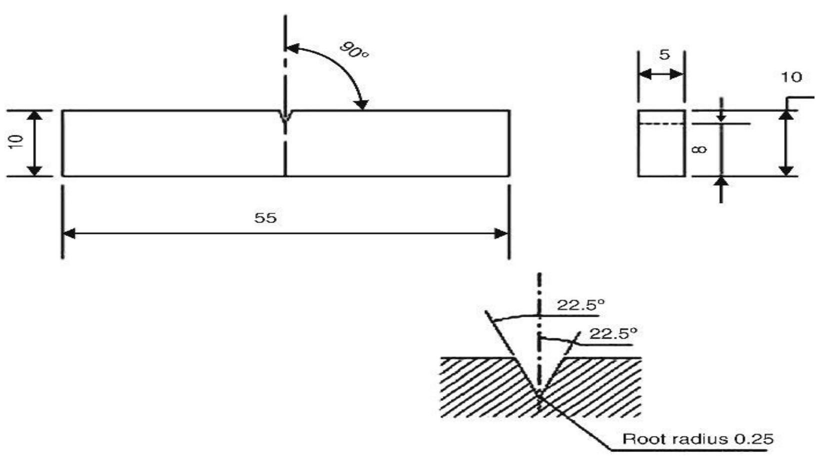


Fig.15 Impact test specimen [10]

The specimen is cut into 10 mm × 10 mm cross section area and a length of 55 mm and a notch of 2 mm from top in the center of the specimen.

Fig.16 Impact specimen **Fig.17 Impact tester**

The specimen of size 55×10×10 mm^3 is clamped in a support at the bottom of the machine. The notch is situated in bottom facing apposite to hammer of the arm. The notch is placed in center to the square support. For testing first the pendulum hammer hold by safety lock in the upper position. Dial indicator is set to the maximum load and then pendulum hammer is released to impact the specimen. When hammer hit the specimen the reading is noted directly from the dial indicator.

3.11 Flexural Test

The use of flexural test is to determine the flexural property of composite. This test measures the behavior of materials subjected to simple bending loads. The specimen is prepared as per ASTM: A-370 standard.

Fig.18 Flexural test on Universal Testing Machine

The standard specimen size is 10 mm × 10 mm of cross-sectional area and 50 mm in length and a span length of 40 mm. The flexural strength is given by:

$$FS = \frac{3PL}{2bt^2} \tag{3}$$

Where, P is the maximum load, b the width of the specimen, t the thickness of specimen and L is the span length of the sample.

3.12 Sliding wear test

Wear testing of all the samples were carried out on the pin on disc type of sliding wear tester having hardened steel bar indenter. This test technique includes a ball shaped upper specimen that slides against a rotating disk as a lower specimen under an endorsed arrangement of conditions. The load is given in downward direction with a motor driven carriage that uses the load sensor for feedback to maintain a constant load. The specimen is taken in this experiment is of 25x8x8 mm^3 size in square shape. The specimen used for the experiment is also of round shape. First weight of the specimen is taken before wear. After weighing the specimen is mounted on the machine and after that the machine is run by changing the parameters like sliding speed, sliding distance and load.

Fig.19 Pin on disk sliding wear

In this experiment we take 16 specimens of different compositions. The study on first 4 specimens is carried out by varying speed and keeping load and sliding distance constant. Second study is carried out by varying load and keeping sliding distance and sliding speed constant, third is by varying sliding distance and keeping sliding speed and load constant. Weight of the specimen noted after the wear test.

3.13 Scanning Electron Microscopy (SEM)

The scanning electron microscope (SEM) is a sort of electron magnifying instrument that pictures the example surface by examining it with high-energy beams of electron emission in a raster sweep design. The electrons connect with the atoms that make up the example delivering signals that contain data about the specimen's surface geology, compositions and different properties, for example, electrical conductivity. An extensive variety of amplifications is conceivable, from around 10 times (about proportionate to that of an intense hand-lens) to more than 500,000 times, around 250 times the amplification furthest reaches of the best light magnifying lens.

Fig.20 Scanning Electron Microscopy

The sample for the SEM test is used by taking wear test samples. The surface topology of the sample is discussed thoroughly in the next chapter.

Taguchi Analysis

Statistical methods are commonly used to improve the quality of a product or process. Such methods enable the user to define and study the effect of every single condition possible in an experiment where numerous factors are involved. The goal in any experimentation process is to characterize the relationship between response and a set of factors that influence the response. This can be achieved by conducting experiments and analyzing the data. Solid particle erosion is one such process in which a number of control factors collectively determine the performance output i.e., the erosion rate. Hence, in the present work a statistical technique called Taguchi method is used to optimize the process parameters leading to minimum erosion of the metal matrix composites under study. This part of the chapter presents the Taguchi experimental design methodology in detail. In any experimental research, since test procedures are generally expensive and time consuming, the need to satisfy the design objectives with the least number of tests is clearly an important requirement. In this context, Taguchi method provides the designer with a systematic and efficient approach for experimentation to determine near optimum settings of design parameters for performance and cost. This method involves laying out the experimental conditions using specially constructed tables known as 'orthogonal arrays'. Use of orthogonal arrays significantly reduces the number of experimental configurations to be studied. The conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, initially a large number of factors are included so that non-significant variables can be excluded at the earliest opportunity. However, the author has not come across any report on the influence of a factor like erodent temperature on wear performance of metal matrix composites. Therefore, in this work, to explore the possible effect of erodent temperature, it is also considered as a control factor in addition to impact velocity, impingement angle, filler content, and erodent size. Thus, the impact of five parameters is studied using L_{16} orthogonal design.

Chapter Summary

This chapter has provided:

a) The descriptions of materials utilizes in this study
b) The details of fabrication and characterization of the composites
c) The description of sliding wear test and Taguchi experimental design approach

The next chapter deals with the physical and mechanical analysis of particulate filled aluminium alloy composites.

*****

4.1 Void content in composite material

Density and Void content of boron carbide and molybdenum disulfide reinforced aluminium matrix composite have been examined at room temperature to figure out the measure of void development in the matrix, the broadening of prior voids with a specific end goal to get great physical and mechanical properties in the composites. The density is measured by simple water immersion technique. The densities, obtained from the recorded weights, were then compared to the theoretical Rule of Mixtures densities from which the volume content of porosity was calculated.

Table 4.1. Density of Composite Experimentally and Theoretically

Sample	Experimental density (g/cm^3)	Theoretical density (g/cm^3)	Void content (%) $V_f = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \times 100$
B0	2.712	2.751	1.42946
B3	2.706	2.745	1.4327
B6	2.704	2.739	1.2910
B9	2.696	2.733	1.369

The graph is plotted in originlab software by taking multi curve. This graph is plotted by taking multi Y- axes.

The graph below shows lower density than Aluminium alloy and goes on decreasing as composition of boron carbide increases. The void content in the sample is sometime increases and sometime decreases. The void content is lowest for the sample 3 which contains 6% of boron carbide and 4% of molybdenum disulfide. Higher void content in composites are undesirable and represents poor quality. High void content composite material affects various properties and performance when in use.

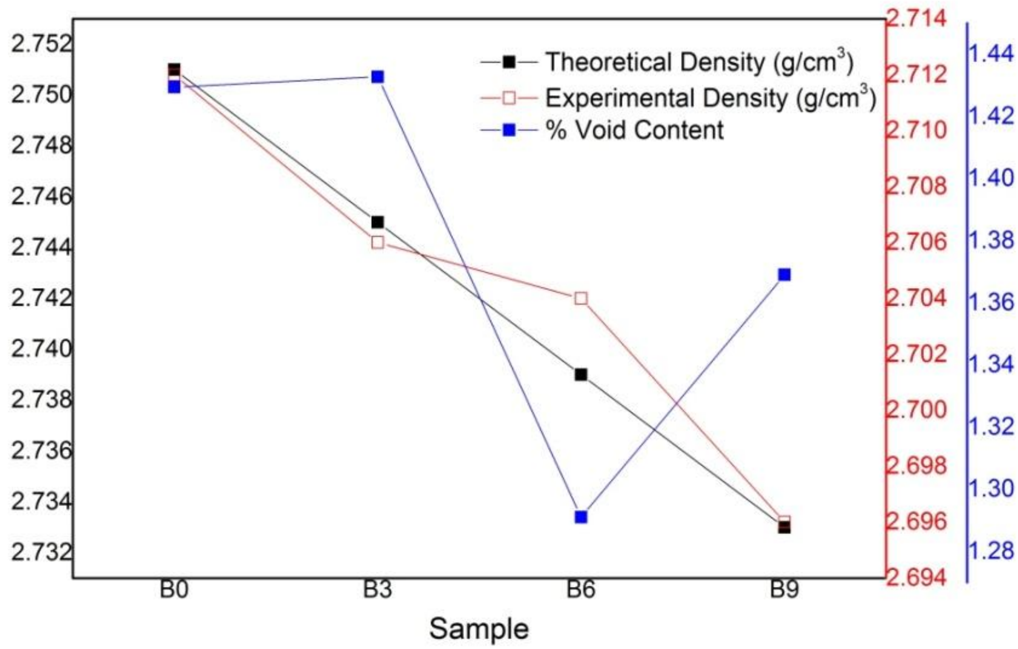


Fig. 21 effect of void content in the composite

Therefore, it can be said that a basic criterion with which to evaluate their quality is the density of composites. The above graph shows the variation of experimental density, theoretical density and % void content with the different composition of the specimen.

4.2 Hardness of composite material

The test performed in this study is Rockwell hardness of B scale. The hardness is measured with the help of hardness tester. There are 3 readings are taken for each sample and finally the average of all 3 readings is taken for the analysis. The table is summarized by the value obtained from the hardness tester. Since Rockwell hardness tests are relatively easy to perform, since limited sample preparation is required.

Table 4.2 Rockwell Hardness of composite material

Sample	Average Hardness(HRB)
B0	45.7
B3	51.1
B6	54.8
B9	62.7

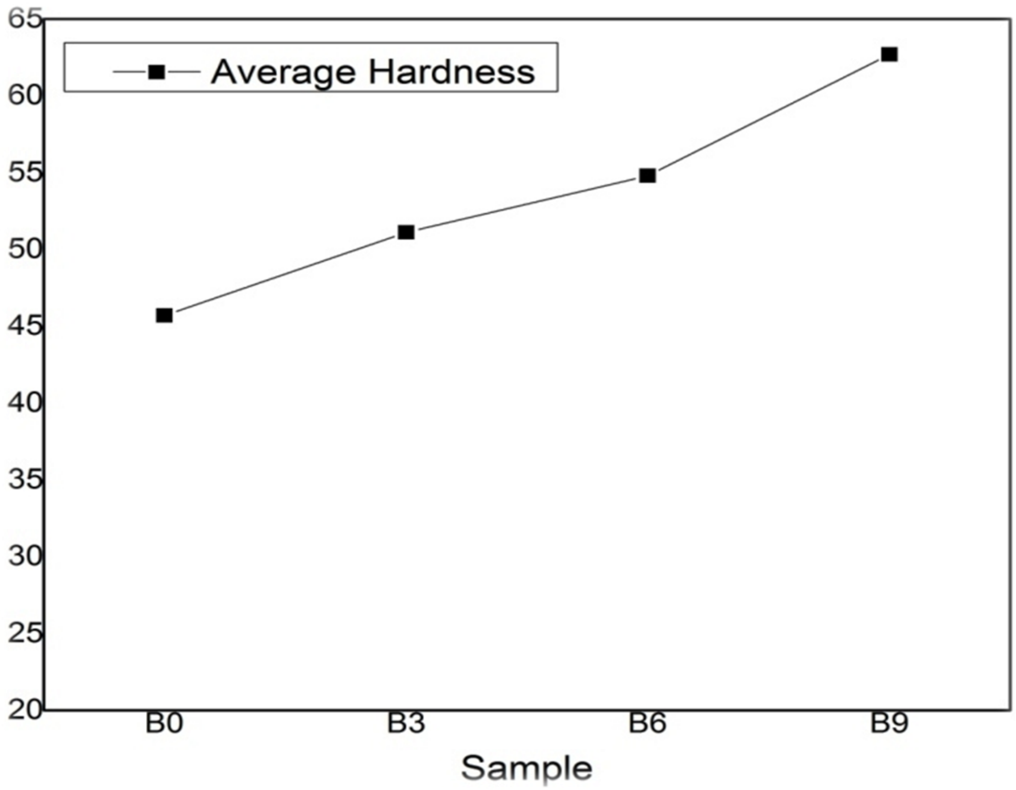


Fig.22 Effect of hardness on composite

The increase in hardness is quite obvious and expected since Boron Carbide is third hardest material which helps effectively to improve the hardness of the composites.

4.3 Tensile Strength of composite material

The capacity of a material to withstand a static load can be dictated by testing the material in tension or compression. Mechanical testing assumes an essential part in assessing the central properties of building materials and also in growing new composite materials and to control the nature of materials utilized as a part of outline and development.

Table 4.3 tensile strength of composite material

Sample	Maximum Load (KN)	Cross - Sectional Area (mm^2)	Tensile Stength (MPa)
B0	2544	16.11	157.924
B3	2839	16.11	176.238
B6	3018	16.11	187.349
B9	3520	16.11	218.511

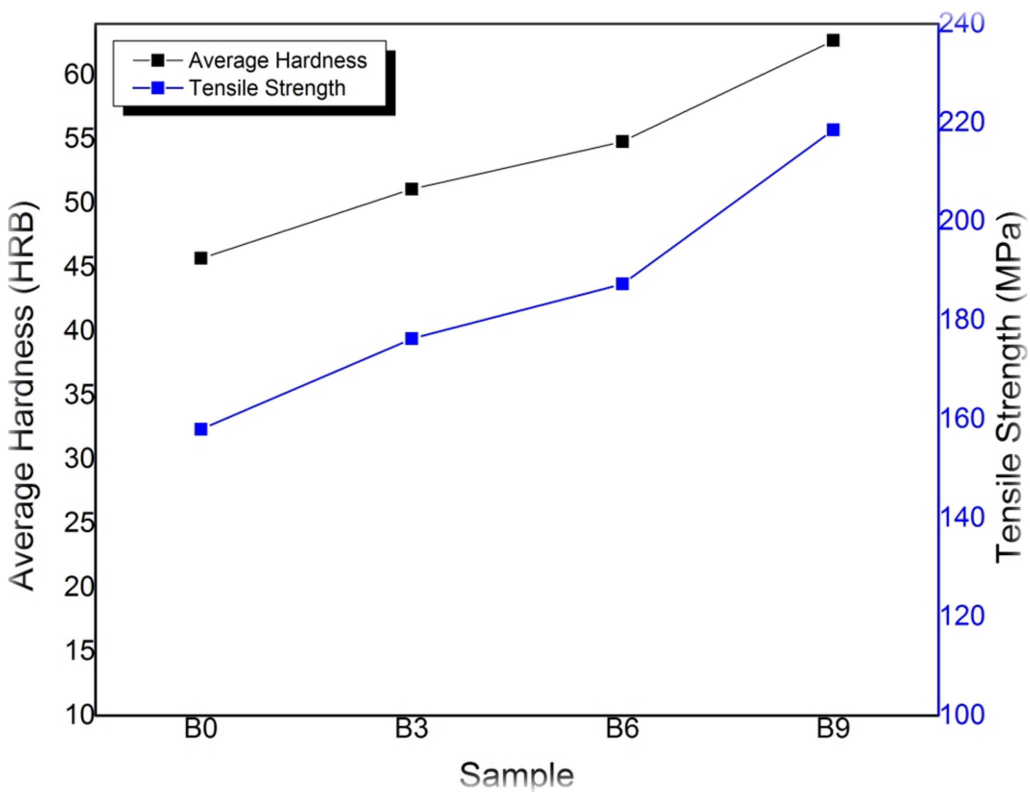


Fig.23 Effect of tensile strength on composite

The value of tensile strength is increases by the addition of the particulate material in the matrix. The value of tensile strength is larger for B9 sample which is approximately 218 MPa. The graph shown here is multi Y-axis graph which shows the comparison of tensile strength and average hardness. Both hardness and tensile strength has maximum value for the B9 sample. When more 9 wt% amount of particulate material added in matrix then bonding between the base material and reinforcement looses strength to withstand the tensile load.

4.4 Impact Strength of composite material

Impact testing includes the sudden and dynamic application of the load on the composite specimen. This test measures the measure of energy absorbed by the specimen for the rupture in joules. Charpy impact test is carried out in this work.

Table 4.4 Impact strength

Sample	Impact Strength (J)
B0	2
B3	8.2
B6	9.6
B9	10.1

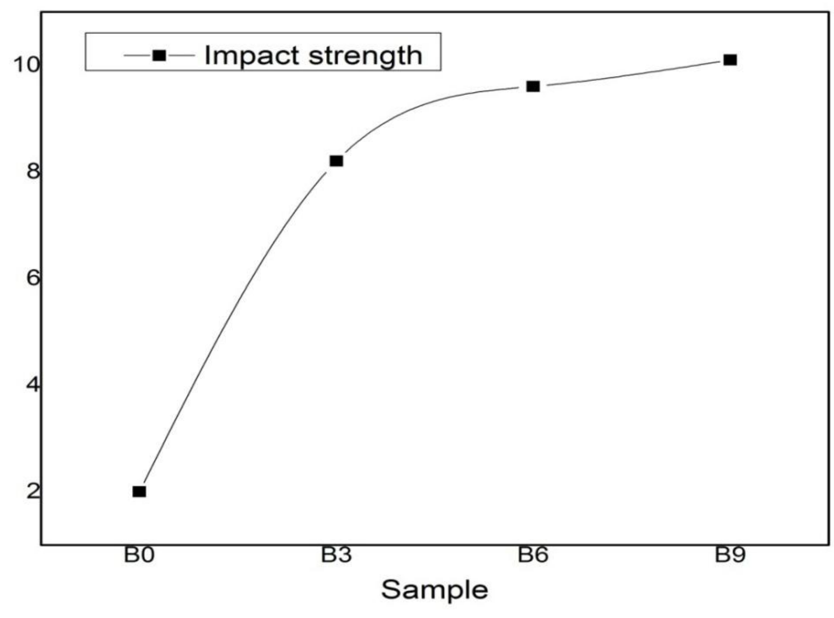


Fig.24 Effect of impact strength on composite

The impact strength of the composite material goes on increasing as adding particulate material. The value of the impact strength for sample B0 is approximately 2 J and for sample B3 the value of impact strength increases drastically. The reason behind this sudden increment is because of the presence of boron carbide and molybdenum disulfide material. The highest value of the impact strength is for B9 sample which is approximately 10.1 J.

4.5 Flexural strength

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. When the flexural force is applied to the specimen, the upper and lower surface of the specimen under three point bending load is subjected to compression and tension, whereas the axis-symmetric plane is subjected to shear stress.

Table 4.5 Flexural strength

Sample	Break load (KN)	Flexural Strength (MPa)
B0	1710	102.6
B3	1825	109.5
B6	1895	113.7
B9	1790	107.4

The flexural strength of the composite is determined using Universal Testing Machine (UTM). The specimen was cut as per ASTM: A-370 standard. The value of flexural strength of the composite material is shown in the graph below. The maximum value of the flexural strength is approximately 113 MPa which is for sample B6.

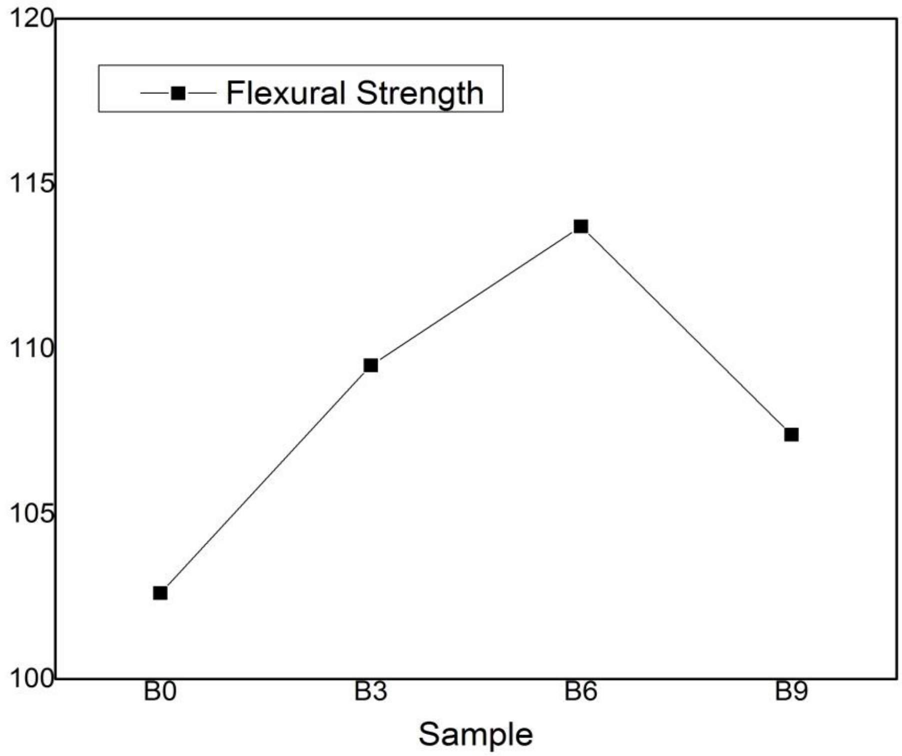


Fig.25 Effect of Flexural strength on composite

After sample B6 the value of flexural strength decreases. This decrement may be attributed for the maximum void fraction present.

4.6 Wear analysis

The dry sliding wear characteristics of the composite specimen pin size of 8 mm and height 25 mm and 60 mm track radius is determined using a pin on disc apparatus as per ASTM G99-95 standards. The test is conducted by taking the parameters like load, sliding distances, and sliding velocities. The initial weight of the specimen is measured by using electronic weighing machine. The specimen is fixed on the steel disc. The test is performed at varying sliding distance, sliding velocity and loads. The specimen is again noted down. The wear rate is calculated by using the formula.

Table 4.6 wear rate at varying sliding distance

Sample	**Wear rate (g/cm) x 10^{-4}**			
	500 m	1000 m	1500 m	2000 m
B0	1.0034	1.1394	1.1933	1.4645
B3	0.9742	1.0553	1.1636	1.2989
B6	0.9329	1.0275	1.0816	1.1238
B9	0.674	0.8897	0.9436	0.97056

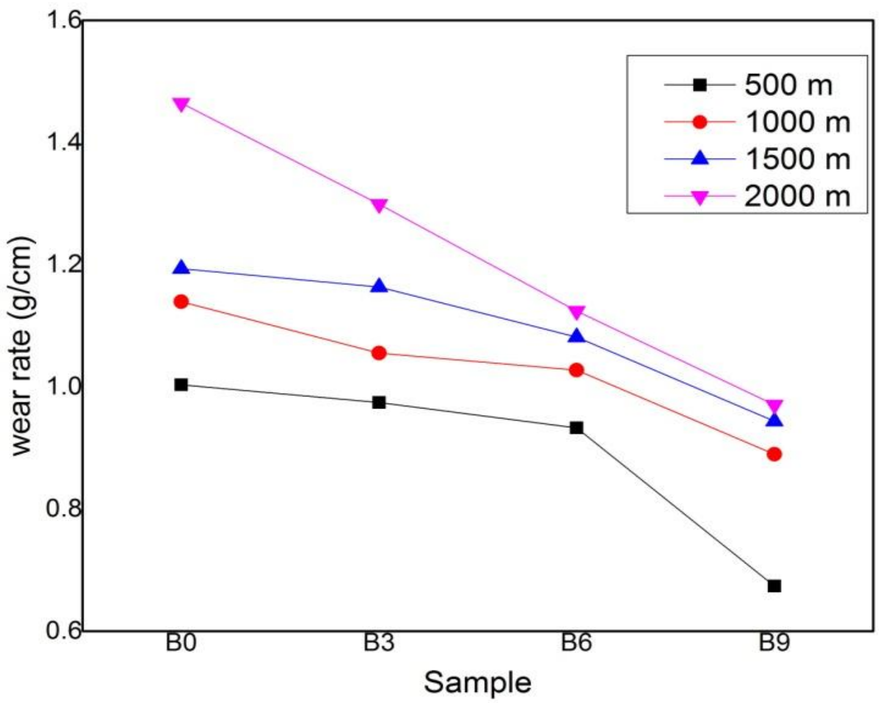


Fig.26 Variation of wear rate with sample for different sliding distance at a constant sliding velocity of 3.77 m/s

Figure 22 shows clearly that the variation of wear rate with addition of wt % reinforcement to Aluminium alloy for different sliding distances 500 m, 1000 m, 1500 m, and 2000 m. in this work clearly identified that by addition of wt % of reinforcement material i.e., B_4C and MoS_2 to

AA6061 the wear rate reduces in all different sliding distances. Initially the wear rate is more in the absence of asperities projection of B_4C.

Table 4.7 Wear rate at varying load

Sample	Wear Rate (g/cm) x 10^{-4}			
	10 N	20 N	30 N	40 N
B0	0.75936	0.8678	1.0848	1.2204
B3	0.5412	0.8118	1.0553	1.1906
B6	0.4326	0.676	0.9464	1.0275
B9	0.674	0.8897	1.0275	0.9436

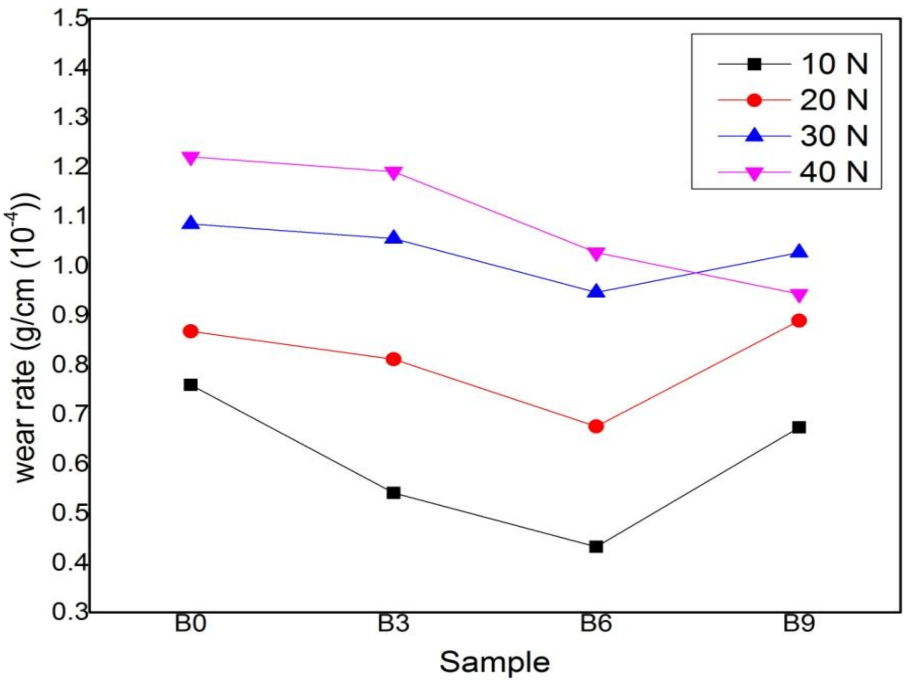


Fig.27 Variation of wear rate with sample for different loads at a constant sliding velocity of 3.77 m/s

Figure 23 clearly shows that variation of wear rate with addition of wt % reinforcement to AA6061 for different loads 10 N, 20 N, 30 N, and 40 N. wear rate reduces in all different loads, as the load increases the wear rate is also increases in all cases.

Table 4.8 wear rate at varying sliding speed

Sample	Wear rate		
	1.256 m/s	**2.513 m/s**	**3.77 m/s**
B0	0.65088	0.678	0.92208
B3	0.59532	0.56826	0.6765
B6	0.5408	0.51376	0.62192
B9	0.43264	0.4056	0.5408

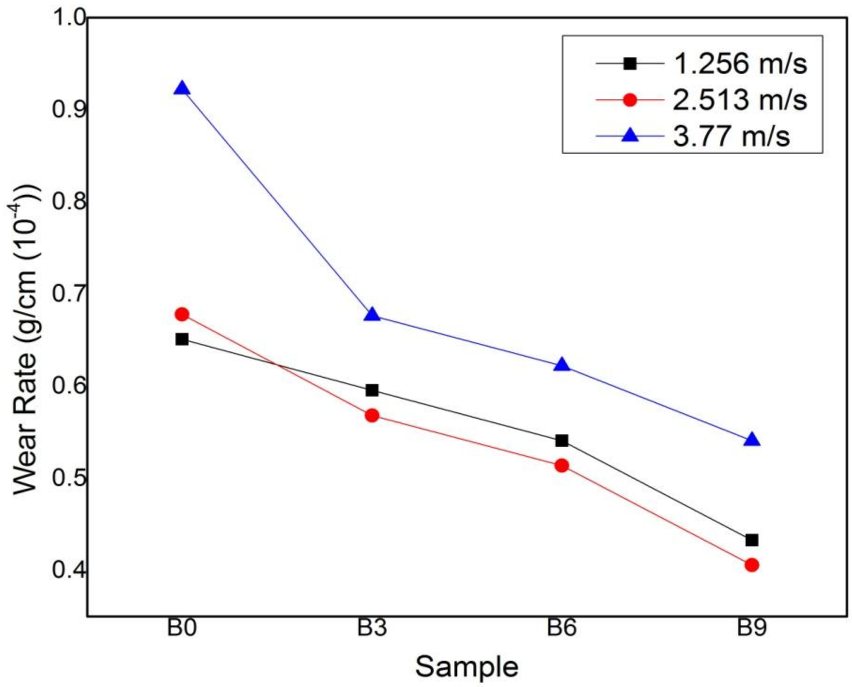


Fig.28 Variation of wear rate with sample for different sliding distance at a constant sliding velocity of 3.77 m/s

Figure shows that the variation of wear rate with addition of wt % reinforcement to AA6061 for different sliding speed 1.256 m/s, 2.513 m/s, and 3.77 m/s. clearly identified from graph by addition of wt % of reinforcement the wear rate reduces in all different sliding speeds.

4.7 Surface morphology

The scanning electron microscope (SEM) is a sort of electron magnifying instrument that pictures the example surface by examining it with high-energy beams of electron emission in a raster sweep design.

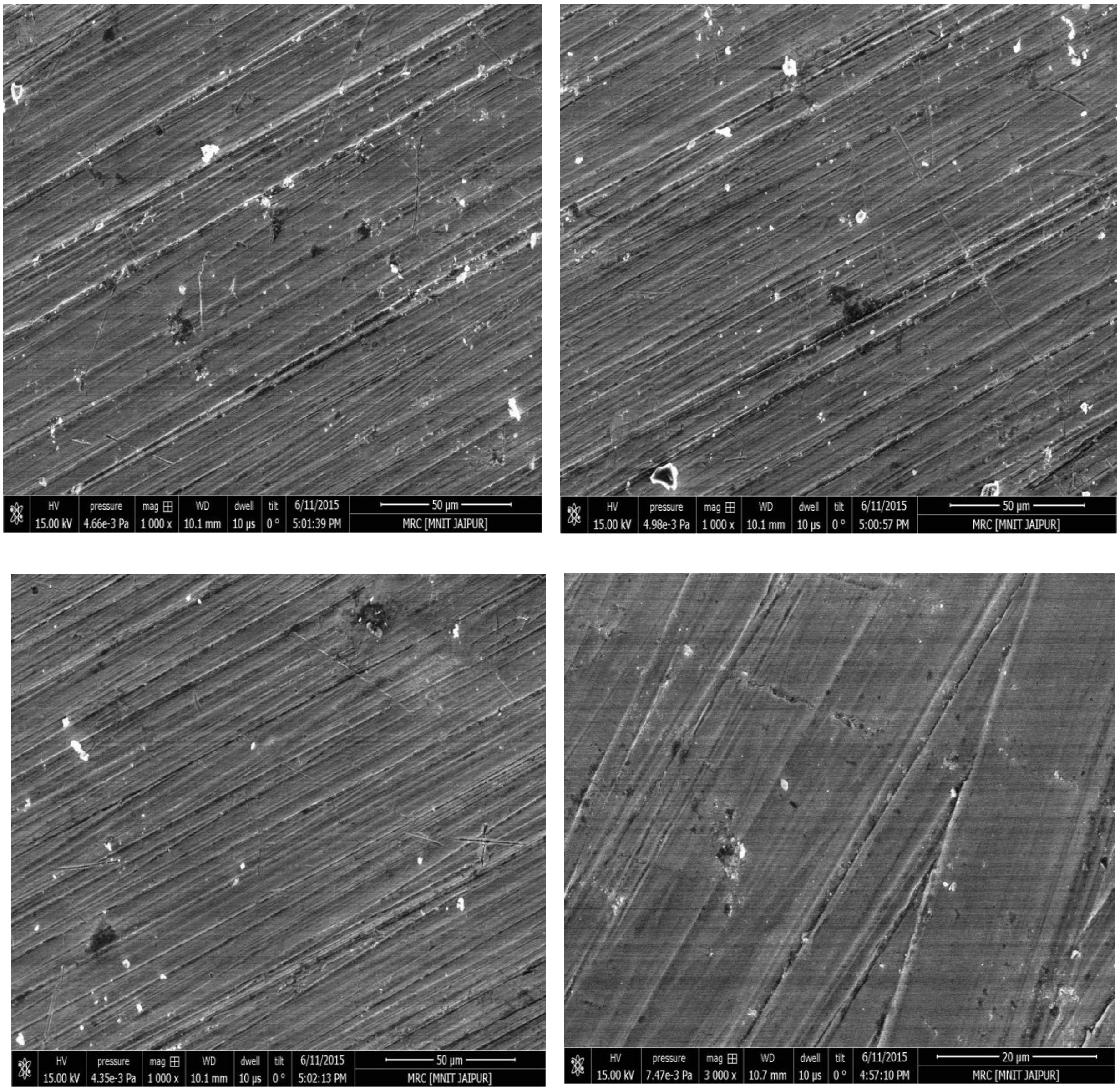


Fig 29 SEM of wear specimens

After wear testing surface of the samples see through Scanning Electron Microscopy (SEM) in MRC lab, MNIT Jaipur. Fig clearly shows the wear surface of the particulate filled AA6061 composites.

Chapter Summary

This chapter has provided:

a) The relative effects of type and content of different particulate fillers on various properties of these composites.
b) The mechanical characterization of the particulates filled alloy composites in experimentally and compared with finite element simulated results.
c) The wear and surface morphology of the particulate filled AA6061 matrix composites.

The next chapter presents the conclusions drawn from this investigation along with recommendations for potential applications and future work.

*****

CHAPTER 5 CONCLUSIONS

The experiment investigated on particulate filled metal matrix composites has led to the following specific conclusions:

a) Aluminium Alloy AA6061 Metal Matrix composite reinforced by Boron Carbide and Molybdenum Disulfide has been successfully fabricated through Stir Casting
b) Density of composite material decreases with the addition of the reinforcement. The values of Experimental density and theoretical density are close to each other. Hence void content is not much higher that means casting of composite material is fair enough.
c) Hardness of the composite material increases as adding wt% of Boron Carbide because Boron Carbide is third hardest material after diamond and cubic boron nitride.
d) Impact strength increases rapidly when boron carbide particulate increase and after that there is slow increment of impact strength.
e) Tensile strength also increases by the addition of particulate material but after 9 wt% the bonding between particulate and matrix losses its strength.
f) Wear test with various parameters shows that the wear rate decreases with the addition of the wt % of particulate filled in AA6061 material in all cases which is varying sliding distance, varying sliding length, varying load.

REFERENCES

[1]. W. D. Callister, Jr., “Materials Science and Engineering”, (2008), John Wiley & Sons, page 400-736.

[2]. Karl Ulrich Kainer, “Basics of Metal Matrix Composites”, (2006), WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

[3]. T. W. Clyne, P. J. Withers, An Introduction to Metal Matrix Composites, Cambridge University Press, Cambridge (1993).

[4]. Daniel B. Miracle and Steven L. Donaldson;” Introduction to Composites” ASM Hand Book of Composite Materials, volume-21.

[5]. S.L.Kakani, Amit Kakani, “Material science”; New Delhi, New age international publishers, 2004, page-593-613

[6]. PB Pawar, AA Utpat - Procedia Materials Science, 2014 – Elsevier

[7]. A Matin, FF Saniee, HR Abedi - Materials Science and Engineering: A, 2015 – Elsevier

[8]. SA Sajjadi, HR Ezatpour, MT Parizi - Materials & Design, 2012 – Elsevier

[9]. HR Ezatpour, SA Sajjadi, MH Sabzevar, Y Huang - Materials & Design, 2014 – Elsevier

[10]. BV Ramnath, C Elanchezhian, M Jaivignesh - Materials & Design, 2014 – Elsevier

[11]. XJ Wang, KB Nie, XJ Sa, XS Hu, K Wu, MY Zheng - Materials Science and Engineering, 2012 – Elsevier

[12]. F Chen, Z Chen, F Mao, T Wang, Z Cao - Materials Science and Engineering, 2015 - Elsevier

[13]. LJ Zhang, F Qiu, JG Wang, QC Jiang - Materials Science and Engineering, 2015 - Elsevier

[14]. S Amirkhanlou, B Niroumand - Transaction of Nonferrous Metals Society of China, 2010 – Elsevier

[15]. HR Ezatpour, M Torabi-Parizi, SA Sajjadi - Transactions of Nonferrous Metals Society of China, 2013 – Elsevier

[16]. BA Kumar, N Murugan, I Dinaharan - Transactions of Nonferrous Metals Society of China, 2014 – Elsevier

[17]. S Gopalakrishnan, N Murugan - Composites Part B: Engineering, 2012 – Elsevier

[18]. JDR Selvam, DSR Smart, I Dinaharan - Energy Procedia, 2013 – Elsevier

[19]. S Suresh, NSV Moorthi - Procedia Engineering, 2013 – Elsevier

[20]. V Bharath, M Nagaral, V Auradi, SA Kori - Procedia Materials Science, 2014 – Elsevier

[21]. PB Pawar, AA Utpat - Procedia Materials Science, 2014 – Elsevier

[22]. B Rebba, N Ramanaiah - Procedia Materials Science, 2014 – Elsevier

[23]. JJ Moses, I Dinaharan, SJ Sekhar - Procedia Materials Science, 2014 – Elsevier

[24]. NGS Kumar, VM Ravindranath, GSS Shankar - Procedia Materials Science, 2014 – Elsevier

[25]. A Viswanath, H Dieringa, KKA Kumar, UTS Pillai, BC Pa - Journal of Magnesium alloys, 2015 – Elsevier

[26]. A Kumar, S Lal, S Kumar - Journal of Materials Research and Technology, 2013 – Elsevier

[27]. SR Rao, G Padmanabhan, International Journal of Materials and Biomaterials Applications, 2012 - urpjournals.com

[28]. KK Alaneme, PA Olubambi - Journal of Materials Research and Technology, 2013 – Elsevier

[29]. GN Lokesh, M Ramachandra, KV Mahendra, T.Sreenith - International Journal of Engineering, Science and Technology, 2013 - ajol.info

[30]. MM Boopathi, KP Arulshri, N Iyandurai - American Journal of Applied Sciences, 2013 - search.proquest.com

[31]. M Prasanna, M Devraj, M Rakeshkumar, M Mahadevappa, Sharanabasappa RP - IOSR Journal of Mechanical and Civil Engineering - iosrjournals.org

[32]. G IACOB, G POPESCU, M BUZATU - scientificbulletin.pub.ro

[33]. K.Hemalatha, V. S. K.Venkatachalapathy, N.Alagumurthy, Int. Journal of Engineering Research and Applications, 2013

[34]. M Kumar, AK Mishra, International Journal of Scientific and Research Publications - ijsrp.org

[35]. N Radhika, R Subramanian, SV Prasat - Journal of Minerals and Materials Characterization & Engineering,, 2011 - file.scirp.org

[36]. PV Krupakara - Portugaliae Electrochimica Acta, 2013 - scielo.mec.pt

[37]. http://www.azom.com/article.aspx?ArticleID=3328

[38]. http://www.azom.com/article.aspx?ArticleID=75

[39]. B.D. Agarwal, L.J. Broutman. Analysis and performance of fiber composites, 2nd edition, Jhon wieley and Sons, New York, 1990.