Synthesis, Mechanical Testing and Characterization of AlMg-Matrix SiC Reinforced Composite Via Powder Metallurgy and Optimization of Process Parameters

By

Dessalegn Bayu Zegeye

(PGR/18177/11)

A Thesis Submitted to Department of Mechanical Design and Manufacturing Engineering

School of Mechanical, Chemical and Materials Engineering

Office of Graduate Studies

Adama Science and Technology University

January-2021

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APPROVAL SHEET

We, the undersigned, members of the board of examiners of the final open defense by **Dessalegn Bayu Zegeye** have read and evaluated his thesis entitled **"Synthesis, Mechanical Testing and Characterization of AlMg-matrix SiC Reinforced Composite via Powder Metallurgy and Optimization of Process Parameters"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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DECLARATION

I hereby declare that the research work which is being presented in this thesis entitled "Synthesis of AlMg-matrix SiC reinforced composite via Powder Metallurgy and Optimization of process parameters" in partial fulfillment of requirements for the award of the degree of Masters of Science in Manufacturing Engineering is an authentic record of my own work carried out starting from November, 2019 under the supervision of Dr. Devendra Kumar Sinha (PhD) and Dr. Ch. Venkatesh (PhD), department of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University (ASTU), Ethiopia.

Any portion embodied in this thesis work has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duty acknowledged.

Name

Dessalegn Bayu Zegeye ________________ ________________

Candidate signature date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This has been submitted for examination with our approval.

Name

Dr. Devendra Kumar Sinha (PhD) ________________ ________________

Advisor signature date

Dr. Ch. Venkatesh (PhD) ________________ ________________

Co-Advisor signature date

ACKNOWLEDGMENT

First of all, I would like to express my deep gratitude to the almighty **God** for giving me the strength and healthy timelessly to complete my study by His assistance with an integration of my best ability.

Secondly, I would like to express my sincere gratitude to my academic advisor Dr. Devendra Kumar Sinha and co- advisor Dr. Ch. Venkatesh for their best functional-guidance and sharing their knowledge, (during work with them as my academic advisor made me to realize that a thesis is an interesting work while I worked under their supervision)

Thirdly, I would also like to thank Mr. Mengistu Gelaw (MSc) Program chair of Mechanical Design and Manufacturing program for his continuous constructive support and permission to use the argon-gas to finish my thesis work.

Fourthly, I have a great acknowledgment to Dr. Moera Gutu, Dr. Habtamu Beri, Dr. Guteta k., Dr. Devendra and Dr. P.J. Ramulu under Program of Mechanical Design and Manufacturing Engineering for their best teaching and sharing their academic knowledge and life experiences.

ABSTRACT

Aluminum-Magnesium (AlMg) alloys possess many uses in the current scenario for universal use specially in, automotive, aerospace and computer industries; due to the lightweights, good identified strength, high recyclability and low-density properties, the primary AlMg-alloys are the vital reason for their versatility. The objectives of this thesis work were to fabricate and provide the light weight, high strength materials of AlMg-matrix and AlMg/SiC composite for vital use in automotive application. The Powder metallurgy (PM) technique with the basic processing variables (such as, compaction pressure, sintering temperature and sintering time) has been considered to produce the high-performance lightweight AlMg-matrix reinforced with different weight percentages (wt%) of SiCp reinforcement using Taguchi L9 orthogonal array experimental design. The AlMg alloy and AlMg/SiC composite fabricated materials were tested with different material testing machines and analysis of the effects of the PM process parameters and the SiC particle addition of 5 and 10 weight percentages on the composite hardness, compression strength, wear performance, porosity and actual density have been investigated. In addition to that, evolutions of microstructure and wear morphological characterization of the wear surfaces for the developed AlMg/SiC composites have been also investigated by optical microstructure (OM) and Scanning Electron Microscope (SEM).

The actual density and porosity results obtained by Archimedes principles for the AlMg-matrix has been found to be less compared to the AlMg-SiC composite due to higher density of the SiCp addition into the matrix. Whereas, when the wt% addition of SiC increases, the hardness and compression strength of the composites were increased. The higher hardness (132.633HV) and compression strength (350.37MPa) for the composite was obtained with the addition of 10% of SiC into the matrix. The wear resistance of the AlMg-5%SiC and AlMg-10SiC composites were improved from 26.3% to 78.9% as compare to the AlMg-matrix.

Keywords: *AlMg-alloy, SiCp, PM, sintering, Taguchi-method, Minitab, "ImageJ"*

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ACRONYMS AND ABBREVIATIONS

Al	Aluminium
Al_2O_3	Aluminium oxide
AlMg	Aluminium-Magnesium alloy
AMMC	Aluminium metal matrix composite
B_4C	Boron carbide
COF	Coefficient of friction
DoE	Design of experiments
HEBMS	High-energy ball milling and sintering process
HEMA	High energy mechanical alloying
HV	Vickers hardness
Mg	Magnesium
MMCs	Metal matrix composites
MPa	Mega pascal
OP	Optical microscopy
PM	Powder metallurgy
RPM	Revolution per minuet
SEM	Scanning electron microscope
SiC	Silicon carbide
TiB_2	Titanium bromide
TiC	Titanium carbide
UTS	Ultimate tensile stress
VHN	Vickers hardness number
Wt%	Weight percentage
µm	micro meter
XRD	X-ray diffraction microscope
YS	Yield strength

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

It is a natural phenomenon that human beings keep on flying from one country to other country and moving here and there in the country to perform their daily activities within a given time range; so, an airplane and vehicles are the dominant way of transportation system. Thus, researching on these areas to provide a well improved, fast, economic and aesthetically attractive airplane and vehicles is a crucial idea for the development of the world countries by providing fast, effective and sufficient way of transportation. Recent efforts by the transportation industry for reducing the fuel consumption and avoiding the environmental problems due to the exhaust emissions, scientists are always looking for lightweight structural materials that show high performance during both processing and application. As a result, Aluminum (Al) and magnesium (Mg) alloys have received considerable attention over the past decades as a potential material of choice to achieve significant weight savings. Among the various metal candidates, magnesium (Mg) seems to be the most promising to achieve this target, where it is ~33, 60, and 75% lighter than aluminium (Al), titanium (Ti) and steel respectively, as shown in figure1.1(a) ***Miller et al. (***2016). However, the poor mechanical properties of Mg, such as low ductility and strength, limit its potentiality in several fields ***Luo et al.*** (2016).

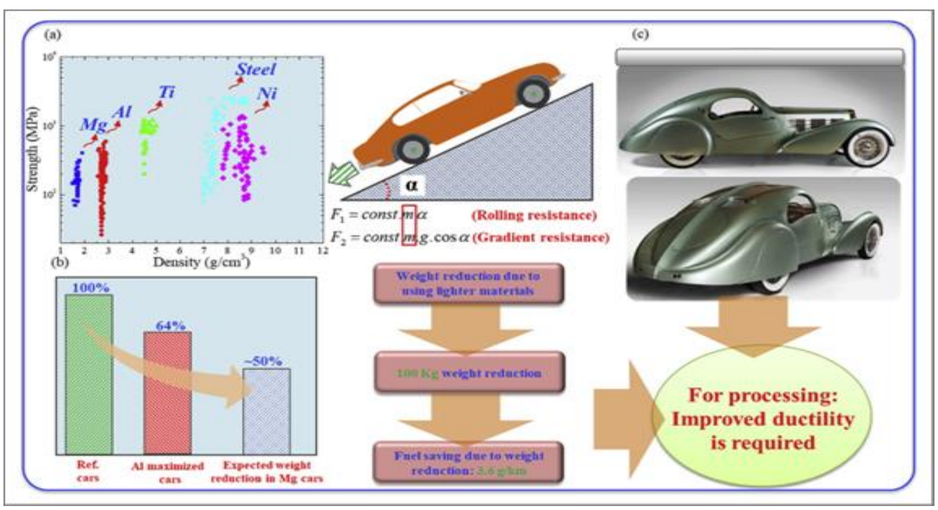


Figure 1.1 (a). Strength of several structure as function to their densities, (b) expected weight reductions in Al and Mg cars, (c) Bugatti Aerolithe car made from Electron Mg alloy.

One of the most beautiful and amazing cars ever built, was designed in Volkswagen Beetle by Jean Bugatti as shown in figure1.1(c). In this design, Al alloys, which were used to build the car bodies before the world war (II), were totally replaced by a Mg alloy (Elektron Mg alloy). This alloy had high strength-to weight ratios which can be comparable to those of other materials used in the car bodies industry. However, the Bugatti Aerolithe was more expensive as compared to the other cars. Accordingly, it is worth noting that “All-in-One” Mg materials (lightweight, high strength and improved ductility) can be a main component for manufacturing green vehicles. In this regard, a lot of works have been carried out to overcome these limits and to reach the full potential of Mg ***Cerri et al.*** (2007), ***Fogagnolo et al.*** (2006) and ***Yazdian et al.*** (2010).

However, recently the automotive and aerospace markets have given light metals powder metallurgy a large boost, and also the Al and Mg PM part is expected to experience a large growth in the next decade ***Burke et al.*** (2011). Although the market for Al and Mg products continues to grow, many opportunities remain untapped because of the low stiffness and strength of Al and Mg alloys in comparison with ferrous alloys and some other structural materials. On the other hand, grain refinement is considered an effective way to increase the strength of materials as expressed by the Hall–Petch relation ***Li et al.*** (2012). The powders produced by PM techniques, such as mechanical grinding, atomization, and high-energy milling, possess a very fine grain structure, which can result in superior mechanical properties for the bulk alloys consolidated from fine-grained PM powders.

To address the aim of scientists’ looking for lightweight structural materials for reducing the fuel consumption and avoiding the environmental problems, a wise composite material improvement is crucial mechanism. From the literature study revealed that among all reinforcements SiC was chemically compatible with aluminum alloy and forms an adequate bond with the matrix without developing inter-metallic phase, have good mechanical properties and other advantages such as excellent thermal conductivity and good workability ***Venkatesan. et al.*** (2014). Materials, such as aluminium based matrix composite reinforced with ceramics, which are difficult to process through casting because of their high melting point temperatures, could be processed through the PM technique without difficulty ***Groover*** (2007).

The PM process greatly reduce the need to use metal removal processes. It is used to make unique materials, impossible to get from melting in other ways. In this metallurgy, Al alloy powder is blended with reinforcement particles to obtain a homogenous mixture. The appropriate size ratio of alloy and reinforcement particles will help to obtain uniform distribution in the composites**.** The cost of current MMCs compared to aluminium alloys was inhibited production on a large industrial scale, for example, in the automotive industry ***Alaneme*** *et al.* (2013). To overcome this, several research and development programs were focused on Al-based matrix composites using low-cost suitable manufacturing technique for investigation of mechanical behaviour of aluminium alloy reinforced by nano and micro hard particles such as Al2O3 and SiC is an interesting area of research ***Sajjdi et al.*** (2012). Generally, powder metallurgy has a number of benefits, one of that is any type of alloy and reinforcement can be done for the fabrication of the composite, but it also has many defects, that is long mixing time is required for the uniform distribution of the particles ***Velikokhatnyi et al.*** (2010)**.** The addition of ceramic particles in the Al, Mg and AlMg alloy increases the hardness of the developed MMCs product and also the product has; light weight, low density, good strength and stiffness, high wear and corrosion resistance ***Muni et al.*** (2016).

The aim of this research work is to investigate the effect of compaction pressure, sintering temperature, sintering time and the various weight percentage (wt%) of silicon-carbide particle reinforcement on the fabricated AlMg-Matrix and AlMg-SiC composite by PM method through process parameters optimization to provide light weight material that have good mechanical properties (such as; good strength and hardness), high wear resistance, less density and porosity. In addition, the PM method is advantages to produce net- or near-net-shaped part, that reduces or eliminates the capital and operating costs associated with intricate machining operations. The present work also investigates the effect of normal loads, sliding speed and time on the volumetric wear rate of AlMg-matrix and AlMg-SiC composites during dry sliding condition on pin on disc apparatus and identifies the most effective control parameter from the reference variables by using the Taguchi method.

1.2 Challenges associated in AlMg alloy matrix composite

The addition of ceramic particles in the AlMg alloy increases the hardness of the developed composite. It is difficult to minimize the tool wear rate, during machining of AlMg-SiC composite. One of the methods to prevent the machining process or to minimize the machinability, the PM method is the most economical process for fabricating the net or near net particulate reinforced MMC ***Han et al.*** (1995).

1.3 Statement of the problem

Aluminum- magnesium alloys possess many uses in the current scenario for universal use, due to their light weight, high specific strength, stiffness, high recyclability; reduced prices for primary AlMg-matrix are the vital reason for their versatility. Despite these merits, the application of AlMg alloys remains limited because of undesirable properties, such as agglomeration or clustering, porosity and poor wear resistance. Due to the overwhelming uses in automotive and aerospace industries; reviewing and compiling data for AlMg alloy type, knowing the effect of addition of different reinforcement particles on AlMg-matrix to fabricate lightweight AlMg-based composite is the most beneficial. Although, stir-Casting is the most widely used method for preparing AlMg-matrix reinforced with ceramics particle, it is difficult to get good uniform distribution of reinforcement particles within the matrix and the AlMg-SiC composite cast part may need machining process, that increases the cost of the cast part and fabrication. To overcome this problem, PM technique is the most economical method for fabricating the near net particulate reinforced composite. PM greatly reduce the need to use metal removal processes and can be used to ease the formability problem in AlMg-matrix alloy that reinforced with ceramics materials; which are difficult to process through casting because of their high melting point. Therefore, in this study, the effect of different weight percentage of SiC_p reinforcement added on AlMg-matrix was investigated and the AlMg-SiC composite materials possesses good mechanical property. Under this study, optimization of mechanical properties correlated with process variables (compaction pressure, sintering temperature, sintering time) have been investigated and identifies the most effective control parameter from the reference variables using Taguchi method. In addition to that, the effect of normal loads, sliding speed and time on the volumetric wear rate of AlMg-matrix and AlMg-SiC composites during dry sliding condition on pin on disc apparatus was investigated.

1.4 Objectives of the study

In line the above justification, the study addresses the following general and specific objectives.

1.4.1 General Objective

Fabrication, characterization and testing of the mechanical properties of the light weight AlMg-matrix and (AlMg/SiC) composite developed by PM process and optimization of its parameters for vital use in automotive application.

1.4.2 Specific Objectives

- Developing light weight, high strength of AlMg matrix composite materials reinforced with various wt% of silicon carbide.
- Investigation of microstructure of developed composite and distribution of reinforced particles over the AlMg matrix and composites.
- Investigation of the mechanical and physical properties of the developed (AlMg/SiC) composite materials.
- Optimization of the PM process parameters (compaction pressure, sintering temperature and time) and various weight percentage (wt%) of SiC reinforced with base matrix (AlMg) alloy.
- Investigation of the effect of normal loads, sliding speed and time on volumetric wear rate of AlMg matrix and composites during dry sliding condition on pin on disc.

1.5 Significance of the study

This research work has both academicals and practical importance. From the academic aspect, it adds more knowledge to the pre-existing researches on AlMg alloys and their specific application on aerospace and automotive. In practical aspect, this study helps in determining the suitability of light weight, high strength of magnesium composite materials especially for aerospace applications. The research gives important to reduction of fuel consumption of vehicles by reduce weight of automotive components. By learning and understanding how to prevent porosity occurrence in the samples, the performance to enhance the mechanical and physical properties in the developed materials can be improved to prolong its life.

1.6 Scope of the study

This research work mainly concentrates on the development of lightweight aluminum-magnesium matrix (AlMg) and (AlMg/SiC) composite material through optimization of the process parameters, mathematical modeling and enhancing the mechanical properties and physical properties for the developed materials have been done.

1.7 Limitation of the work

The challenges which faced on work were:

- Lack of PM set up challenges to conduct production of the MMCs sample.
- The more challenging work was lack of vacuum furnace, (to minimize or prevent formation of reaction) during sintering of the green compacted AlMg/SiC samples.
- Budget scarcity for all process and to conduct a greater number of experiments.

1.8 Output

At the end of the work, different experimental outputs are achieved such as:

- The light weight product (AlMg/SiC) which used for automotive components.
- The mechanical properties improved of the AlMg matrix and AlMg/SiC composite product obtained through PM process parameters optimization.
- The weight percentage effect of SiC-reinforcement has been investigated on improvement of the AlMg/SiC composite wear and mechanical properties.

1.9 Thesis organization

This thesis consists of five chapters and essence of each chapter is detailed below.

The **1st chapter** is about the introduction and background of study, problem statement, objectives, research significance and scope, limitation of the work, output of work and the organization of the thesis. **The 2nd chapter** is organized for the literature review of some other researchers which have done about the mechanical and w testing on the developed reinforced metal matrix composites, In addition microstructure characterization of metal matrix composites. Literature gap of the present work also discussed. In the **3rd chapter**, it is described about materials and methodology of the work, mean that it explains about the AlMg-matrix and weight percentage (wt.%) of SiC reinforcements used and the process of fabrication method that used in this research to fabricate both the AlMg-matrix and AlMg/SiC composite. In the **4th chapter,** a detail discussion and analysis has been performed based on the experimental result of mechanical and wear properties, OM and SEM morphology of the AlMg matrix and AlMg/SiC composite. Finally, the **5th chapter** presents the conclusion and recommendation of the future works.

CHAPTER TWO

LITERATURE REVIEW

This chapter provides a review of the published literature on introduction to composite materials manufacturing processes, reinforcement effects on mechanical properties, wear performance, the microstructures characterization and optimization of process parameters of metal matrix composites have been reviewed to place the research problem in perspective. From the summery of this literature review, the gap areas are identified and also discussed for further investigations and studies.

2.1 Introduction to composite materials

A composite material is a material system composed of a suitably mixture or combination of two or more macro, micro or nano constituents with an interface separating them that differ in form and chemical composition. Composite is a multiphase material that exhibits a significant proportion of the properties of both the reinforcement (with discrete constituent) and matrix (continuous phase) constituent phases such that a better combination of properties is realized. The composite materials have high strength to weight ratio and modulus to weight ratio, excellent fatigue properties, good wear and corrosion resistance behaviors.

The basic aim of developing new materials for automotive application is as mentioned in chapter one to enhance vehicle efficiency and fuel economy by reducing the dead weight of the vehicle. In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile designers and manufacturers in the present scenario. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and particle distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites, but also an easily controllable manufacturing variable used to alter its properties ***Chandramohan*** and ***Marimuthu*** (2011), ***Banga*** (2015).

2.2 Classification of composite materials

The main categories of composite materials can be classified;

- Based on chemical nature of the matrix phase (matrix material).
- Based on dispersed phase (geometry of reinforcements).

Based on the chemical nature of the matrix phase measurement, composite materials are classified as metal matrix (MMC), polymer matrix (PMC) and ceramic matrix composites (CMC), composite materials are also classified as particle reinforced composite, fiber reinforced composite and structural composites, based on geometry of the reinforcements (dispersed phase) ***Kalaa et al.*** (2014).

2.2.1 Metal matrix composites

MMCs are interfusion of two or more materials, which expose properties that are hard to obtain from a single material with high strength and stiffness with less density. MMCs are engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties. MMCs combine metallic properties of matrix alloys (ductility and toughness) with ceramic properties of reinforcements (high strength and high modulus), leading to greater strength in shear and compression and higher service temperature capabilities, ***Kok*** (2005). MMCs are also advantages in some of physical attributes such as; no significance moisture absorption properties, non-inflammability, high electrical and thermal conductivities, and resistance to most radiations ***Russo*** (2006). ***Toptan et al.*** (2010) have been developed the MMCs to respond to the demand for materials with superior mechanical properties, namely high stiffness, wear resistance, greater shear and compressive strengths and better high temperature capabilities. Aluminum and magnesium matrix alloy are used to produce the light weight MMCs reinforced with ceramics that used in several industrial sectors due to their desirable properties like high strength-to-weight ratio, high modulus, and low ductility, high wear resistance, high thermal conductivity and low thermal expansion ***Chawla et al.*** (2006) and ***Hussain et al.*** (2017).

2.2.1.1 Aluminum based matrix composite

Aluminum based matrix composites have significant properties than other metal matrix composites in terms of its high strength to weight ratio. Particulate ceramics such as; SiC, Al_2O_3, TiB_2, TiC and B_4C are used as reinforcement to produce, improve mechanical and wear resistance properties of the Al based alloys, ***Suresh*** and ***Ravikumar*** (2018) and ***Bharath et al.*** (2014).

2.3 Introduction of effectible variables on the metal matrix composite properties

The variable such as manufacturing methods, composition of matrix, distribution and weight percentage of reinforcement particle were affect the mechanical properties (like; hardness, wear resistance, compression and tensile strength) of the composite material, ***Singh.et al.*** (2015).

2.4 Manufacturing methods and processing of metal matrix composites

MMCs are manufactured by various techniques. Manufacturing process play a vital role in determining the final properties of the MMCs. Selection of a suitable method depends on the properties needed by MMC, the amount of production, the cost, alloy matrix, distribution reinforcement members (particles or fibers) and the product areas of application. The processing methods utilized to manufacture particulate reinforced MMCs can be grouped depending on the temperature of the metallic matrix during processing. Accordingly, the processes can be classified into three categories:

- Solid state processes
- Liquid state processes and
- In-situ (two phase; solid-liquid) processes.

Liquid state process includes; stir casting, squeeze casting, liquid infiltration, spray disposition. Solid metallurgical process includes; the powder blending and consolidation, diffusion bonding and physical vapour deposition.

2.4.1 Solid state processing technique.

Solid state fabrication of MMC is the process, in which MMCs are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure. Many techniques were developed for producing particulate reinforced MMCs, from those methods, PM route is one the most economical process for fabricating the near net particulate reinforced MMCs. Powder metallurgy serves as one of the best methods and to achieve the desired properties such as reduced porosity, more uniform distribution of the reinforcement. It also offers versatility and flexibility in the selection of process parameters such as compaction pressure, holding time, sintering temperature, sintering time, heating rate, etc. Since powder metallurgy fabrication method offers more uniformity in the distribution of the reinforcement material it eliminates clustering problem and porosity to some extent thereby increasing the mechanical properties ***Kumar et al.*** (2016), ***Kanthavel et al.*** (2016) and ***Nassar et al.*** (2017). The process parameters such as milling, sintering parameters and heat treatment conditions contribute to the significant effect on hardness, tensile and compressive properties of the composite and with low processing temperatures of the matrix and reinforcement phases is prevented from interaction ***Wang et al.*** (2011), ***Ghasali et al.*** (2015) and ***Mendoza et al.*** (2015).

Powder metallurgy is defined as mixing of different metal powders to form finished and semi-finished components by compressing it. After compressing subsequent heating at elevated temperature in the furnace, under a progressive atmosphere is done so as to obtain satisfactory strength and density.

- Powder metallurgy utilizes metal or alloy powders as raw materials in order to obtain finished parts of high precision and accuracy, at competitive costs.
- Considerable saving in raw material could be achieved in PM process, as very little after-machining is required for the formed powder metal components.
- PM is a net-shape/near net-shape forming operation which is capable of producing complex shapes with wide range of properties, in high volumes.
- Flexibility of material composition, coupled with tailor-made properties imparted to the powder metal components due to wide range of microstructures are added advantages of the process.

The MMCs reinforced with ceramics, which are difficult to process through casting because of their high melting point temperatures, could be processed through the PM route without difficulty ***Groover*** (2007). Because of the above reasons, PM technique is widely used to produce aluminum-based composites.

2.5 Reinforcements used for developing the metal matrix composites

Reinforcement increases the strength, stiffness and the temperature resistance capacity and lowers the density of MMC. Since most ceramics are available as particles, there is a wide range of potential reinforcements for particle-reinforced composites. Particulates are the most common and cheapest reinforcement materials. Ceramics such as; SiC, Al_2O_3, TiB_2, TiC,

B_4C…et are used as reinforcements to produce the MMCs that used in several industrial sectors such as automotive, aerospace, electronics, marine, medical industries and in construction equipment's due to their combinations of high strength and stiffness at both room and elevated temperatures, and also the have low ductility and high wear resistance ***Bozic et al.*** (2010) and ***Hossain et al***. (2018).

2.5.1 Silicon carbide

The silicon carbide is a compound of silicon and carbon known as carborundum. Silicon carbide is produced by a solid-state reaction between sand (silicon dioxide) and petroleum coke (carbon) at very high temperatures in an electric arc furnace. SiC is a prominent abrasive and contemporary engraver due to endurance and low cost. SiC is hard, high wear and heat resistance ceramic material. One of the most important properties of ceramics is that they are very good insulator of heat which means they can hold very high temperature without any failure. Silicon carbide particle grains can be constrained together by sintering to contour very hard ceramics that are universally used in applications like car brake. Silicon carbide (SiC) has received wide attention because of its excellent oxidation resistance, corrosion resistance and even at high temperatures**,** ***Li et al.*** (2020). Other researchers ***Ding et al.*** (2009) and ***Huang et al***. (2011) showed that silicon carbide (SiC) is ideal reinforcement candidate for several matrix materials, including aluminium, magnesium-based matrix and their alloys because of their significant ability to enhance the strength, modulus, thermal stability, and abrasive wear resistance of the matrix materials.

Recent researchers; ***Maleque et al***. (2012) and ***Stojanović et al***. (2015) have shown that aluminium matrix composite possesses desired potential properties such as high specific strength and stiffness, required wear resistance to withstand abrasive properties compared to monolithic materials which are demanded by automotive and aerospace industries for the tribological application. Actually, particulates lead to a favorable effect on properties such as hardness, wear resistance and compressive strength. The reinforcement of Silicon Carbide into Al-MCs had proved that increase in strength, hardness and wear resistance, ***Sijo et al.*** (2016) and ***Ravikumar et al.*** (2018).

2.6 Researches developed on reinforced AlMg matrix composite

Aluminum-Magnesium (AlMg) alloys are an important vital engineering material for mechanical applications due to its low density, high thermal conductivity and improved machinability for automobile, aerospace, marine and mineral processing industries. Due to the wear loss nature of the AlMg material, its application for automobile applications is limited. To avoid the wear loss drawback, AlMg matrix can be reinforced with ceramics particulate, the composites are being explored for the automobile applications. Therefore, the mechanical behavior investigation of the aluminum-based composite material is becoming increasingly important. The incorporation of a hard ceramic phase to a relatively soft matrix alloy, commonly aluminium based matrix alloy, improves the mechanical properties and wear resistance of the alloy. Aluminium-magnesium matrix composites reinforced by ceramics particle is all along one of the research hotspots of metal matrix composites. By reason that the wettability between Al and Mg particles is poor at temperature below 900 °C. ***Salvo et al.*** (1994) consider that in the case of oxidized Mg particles covered with a layer is of advantage to control the formation of A14C3. ***Zhong et al.*** (1995) used an oxidation process that the Mg layer was formed at the surfaces of SiCp particles, which played an important role in preventing the SiCp from being attacked by Al matrix.

Therefore, one of the requirements for strong composite is a strong interfacial bond to permit load to be transferred from matrix to particles or fibers. ***Luo et al.*** (2013) investigated the microstructural evolution of brittle AlMg intermetallic compound (IMC) at the bond interface of Al/Mg multilayer composite sheets during different sintering conditions, which demonstrated that the growth rate of the IMC increased with the increasing sintering temperature, and no observable IMC was observed at the sintering temperature of 200 °C or below. In this work, an AlMg matrix composite reinforced by SiC particles, which has been fabricated by a powder metallurgy process. As ***Scudino et al.*** (2009) had studied, the solid solubility extension of Mg in Al was achieved for the binary Al–Mg system in the range of 10-40 at% of Mg by mechanical milling of Al–Mg pre-alloyed ingots and by Mechanical alloying of elemental powder mixtures. A hexagonal intermediate phase, the phase with approximate composition Al_3 Mg_2 was formed, during heating, at higher temperature. While at low temperatures, an increasing amount of Mg is rejected from the solid solution with increasing temperature.

2.7 Effects of reinforcements on improvement of mechanical properties of MMCs

The attractive physical and mechanical properties that can be obtained with metal matrix composites such as high specific modulus, strength and thermal stability have been documented extensively. ***Kumar et al.*** (2008) fabricated Al-7Si alloy composite reinforced with in situ TiB2 and investigated it's mechanical and wear behaviour. The authors observed that the increase in values of the hardness, ultimate tensile strength, the yield strength and the young modulus were observed with increase in weight percentage of TiB2. Also, the coefficient of friction and war rate decreased with addition of TiB2 compared to pure alloy. ***Ling et al.*** (2010) fabricated Aluminium matrix composite reinforced with Al9 (Co, Ni) 2 particles. They observed that the ultimate tensile strength and the yield strength of the composite increased with increase in volume fraction of reinforcement. While the elongation fracture first increased and then decreased with increase in reinforcement.

Wang et al. (2010) have fabricated the commercial Mg-MCs (8.94% Al, 0.70% Zn, 0.22% Mn, 0.02% Si, balance Mg) using a beta-SiCp reinforcement (0.1%, 0.3%, and 0.5% in mass fraction) with the average diameter of 50 nm by ultrasonic method. The ultimate tensile strength (UTS), yield strength (YS) and elongation of AZ91 alloy are only 174 Mpa, 104 Mpa and 3.6%, respectively. The UTS, YS and elongation of the SiC/AZ91D composite with addition of 0.5% SiC nanoparticles are 216 Mpa, 124Mpa and 6.6%, respectively. Compared with those of the matrix alloy, the UTS, YS and elongation of the composite with addition of 0.5% SiC nanoparticles were improved by 24%, 19% and 83%, respectively. ***Elsayed et al.*** (2011) have fabricated the Mg–7Al–1Zn–1Ca–1.5La (in wt.%) and Mg–6Al–0.26Mn–2.1Ca (wt.%) alloys by PM techniques that improved the mechanical response compared to IM alloys corresponds to the effect from spinning water atomization process (SWAP) of the alloy powder; SWAP produces very high solidification rates of about 10^6K/s and led to refine microstructures and supersaturation of alloying elements. ***Kalaiselvan et al.*** (2011) produced Al (6061-T6)/B4C composite and investigated its mechanical properties. They observed that the hardness and the tensile strength of the composite are linearly increasing with increasing weight percentage of the B4C particulate. ***Kumar et al.*** (2013) fabricated A359/ Al_2O_3 composite via electromagnetic stir casting method. The author revealed that the hardness values increased to 72.8 HRC compared to pure alloy (46HRC). Also, the tensile strength of the composite increased to 148.7N/mm^2 as compared to pure alloy (103.7N/mm^2.

Shen et al. (2014) have employed semisolid stirring assisted ultrasonic vibration method to fabricate magnesium matrix composites (AZ31B) reinforced with volume fraction (3, 5 and 10 vol.%) of submicron-SiC particles (0.5 lm). The grain size of matrix in the AZ31B/SiCp composites was gradually decreased, with increasing the volume fraction of the submicron SiCp. The yield strength and ultimate tensile strength of the 10 vol.% SiCp/AZ31B composites were simultaneously improved. The studied interface in the SiCp/AZ31B composite suggested that; the submicron SiCp bonded well with the matrix without interfacial activity; due to most of the submicron SiC particles exhibited homogeneous distribution in the AZ31B/SiCp composite.

Nie et al. (2015) were adopted to process SiC nanoparticles reinforced magnesium matrix composite by multidirectional forging (MDF) under decreasing temperature conditions. The results showed that grains of the nanocomposite were effectively refined while the quantity of precipitated phases was significantly increased after MDF process. During tensile test at room temperature, the microcrack could initiate within the SiC-nanoparticle dense zones, resulting in decrease of the elongation. The yield strength and ultimate tensile strength of the nanocomposites were increased compared with that of as-cast nanocomposite. ***Karvanis et al.*** (2016) produced Al/SiC metal matrix composite by varying volume percentage of silicon carbide using centrifugal casting machine. The mechanical properties and macrostructure of the composite investigated in order to determine the optimum percentage of silicon carbide in the metal matrix composite. They concluded that the, hardness, compressive and tensile strength of the composite increased due to increasing v.% of silicon carbide. ***Vijayakumar et al.*** (2016) also studied the tensile strength and hardness of Al6061/SiC composite by varying the wt. % SiC reinforcements 3-18%. The composite was manufactured by using stir casting of 600rpm, 5 minute stirring speed and stirring time respectively. The ultimate tensile strength and Rockwell hardness results showed that the tensile strength and hardness of the developed metal matrix more improved during increasing the wt. % of silicon carbide.

Guo et al. (2019***)*** have improved the interface bonding in AZ61/ SiCp composites fabricated by powder metallurgy then followed by hot extrusion, the electroless plating of Ni-P coating on SiCp was also carried out. The relative density of the composite was increased from 97.9% to 98.4% compared with uncoated one and the hardness of the Ni-coated composite increased more rapidly as the volume fraction of SiCp increases. The tensile strength result was increased from

320 to 336 MPa when the volume friction of SiC particle is 9%. ***Vijayabhaskar et al.*** (2019) have fabricated and characterized the magnesium matrix with nano SiC particles as reinforcement within a wt % of (0, 0.5 and 1) by solidification combined with ultrasonic cavitation process. The results obtained shows that, the increase in weight % of nano SiC particles improve the mechanical properties such as density, micro hardness and the microstructure of the composites were observed.

2.8 Wear performance of metal matrix composites

One third of our global energy consumption is consumed wastefully in friction. In addition to this primary saving of energy, very significant additional economics can be made by the reduction of the cost involved in the manufacture and replacement of prematurely worn-out components. The dissipation of energy by wear impairs strongly the national economy and the life style of most of people. So, the effective decrease and control of wear of metals are always desired. The mechanical and wear properties of the MMCs have been extensively investigated by various researchers; ***Sharma*** (2001), ***Hemath et al.*** (2010) and ***Toptan et al.*** (2012). The results have shown that the wear performance of MMCs is higher than that of unreinforced matrices.

Wear of metals depends on many variables; it is not an intrinsic material property but characteristics of the engineering system which depend on load, speed, temperature, hardness, presence of foreign material and the environmental condition. ***Yu et al.*** (1997) demonstrated the effects of applied load and temperature on the dry sliding wear behavior of the Al6061 SiC composites, and concluded that the wear rate decreases with increased applied load. ***Dwivedi et al.*** (2010) statistically studied the dry reciprocating wear behavior of Al-Si-SiC_p composite and observed that composite with high silicon content shoed lower wear loses compared to that of low silicon content composite. Sliding distance is the main factor which affects the wear behavior of the composite followed by load, reciprocating velocity and weight percentage of silicon. The interaction between load and sliding distance also had a pronounced effect on wear behaviour. In case of friction behaviour load is the controlling factor followed by weight percentage of silicon. Effect of matrix alloy and influence of SiC particle on the sliding wear characteristics of high strength aluminium alloys AA7010, AA7009 and AA2024, composites were examined by ***Rao and Das*** (2010) for varying applied pressure and a fixed sliding speed of 3.35 m/s. The results revealed that the wear resistance of the composite was noted to be significantly higher than that of the alloy and is suppressed further due to addition of SiC particles.

Isra (2013) have been studied the effect of addition of different weight percent from SiCp (2, 4, 6, 8) to Al4Cu alloy which have been fabricated by liquid metallurgy method on the dry sliding wear behavior and mechanical properties. Wear characteristics of Al SiC composites have been investigated under dry sliding conditions using pin-on-disk wear test and compared with base alloy. It was found from the experimentation that the wear rate decreases linearly with increasing weight percent of silicon carbide. The best results have been obtained at 8 % wt SiC. It is also observed that the yield strength, tensile strength increases with increasing wt% of SiC, but the ductility decreases.

Pawar and Utpat (2014) developed of aluminum-based silicon carbide particulate metal matrix composite for spur gear by stir casting technique using Melting temperature 750°C. A composite was developed by adding silicon carbide in Aluminum metal by mass ratio 2.5%, 5%, 7.5% and 10% to study hardness, microstructure tests. Experimental results showed that of increased silicon carbide content, the hardness, and material toughness are enhanced and highest value is obtained at 10% SiC content. ***Rana et al.*** (2015) developed and synthesized Al5083 alloy and different weight % of Nano SiC (1, 2, 3 and 4 wt. %) of composite and wear Analysis of Al-Nano SiC Composite Automotive Cam to substitute the steel cam. They concluded that the Al-SiC_p composites can be used as alternative material for the cam due to better mechanical properties, lighter weight and similar wear resistance to the existing alloy steel cams**.**

Sijo et al. (2016) reviewed contemplates the need of simulation or numerical methods for the prediction of mechanical characteristics of Al/SiC MMC manufactured by solid phase processes such as powder metallurgy and diffusion bonding Recent works cleared that clustering of reinforcement particles, wettability of reinforcement (SiC) in molten aluminum are the prime concern in the production of composites through stir casting. There concluded that experimental works to find out the optimum values are difficult and costly. Since stir casting process involves very high temperature, experimentation is difficult and dangerous. ***Govindan and Viji*** (2017) analyzed the behavior of the brake disc with aluminum metal matrix composite material and conventional grey cast iron material in finite element software ANSYS. Comparison of stress distribution, displacement and temperature distribution for conventional and proposed material indicated that Al/SiC MMC with 10% SiC satisfies the requirement for disc brake application. There was concluded that Al/SiC MMC with 10% SiC can be used in automotive to replace the conventional material for improved vehicle performance.

2.9. The powder metallurgy processing parameters effect on mechanical properties and microstructure features

2.9.1 Taguchi method

"Taguchi Method" was developed by Japanese Scientist Genichi Taguchi in the 1950s, using statistics, he was aimed to improve the quality of manufactured goods. This method is based on the principle of performing the minimum number of experiments to minimize costs ***Sirvanc et al.*** (2011). The Taguchi method is tool for improving a most useful product performance, process, design and system with a significant reduction in experimental time and cost ***Wiley*** and ***Sons*** (2008). This method defines the lower-the-better, the larger-the better and the nominal-the-better categories of quality characteristics in the analysis of signal-to-noise ratio ***Ghosh et al.*** (2012). Taguchi's robust design method was used to analyze the dry sliding wear problem of the metal matrix composites ***Basavarajappa et al.*** (2007). The various factors controlling the properties of particulate MMCs and the influence of the manufacturing route on the MMC properties has also been reviewed. Light weight metals such as aluminum, magnesium and their alloy have excellent engineering properties which makes them attractive for different industrial applications, when their microstructure features, mechanical and wear morphology properties have improved well. ***Liu et al.*** (1994) fabricated metal matrix-particulate composites (MMPCs) using powder metallurgy (PM) as the fabricated composites possess a higher dislocation density, a small sub-grain size and limited segregation of particles, which, when combined, result in superior mechanical properties. The various PM-related processes currently in use in the fabrication of MMPCs are reviewed, outlining the common problems encountered in each of these fabrication processes. ***Muratoglu et al.*** (2006) investigated the joining characteristic of SiC particulate reinforced aluminum metal matrix composites (MMCs) with pure aluminum by diffusion bonding process. The experimental results indicate that the application of aging before and after diffusion bonding decreases SiC particulate accumulation, and increases other elemental concentration at interface. The Mg-alloy PM products that successfully produced was utilizing the industrially dominant process of mixed powder blending and the controlled sintering atmosphere have been investigated by ***Burke et al.*** (2009); using uniaxial die compaction and cold isostatic pressing to form the compacts. In the PM process, the optimal processing conditions (powder size, compaction pressure, sintering temperature and time) were found to maximize sintered density and mechanical properties.

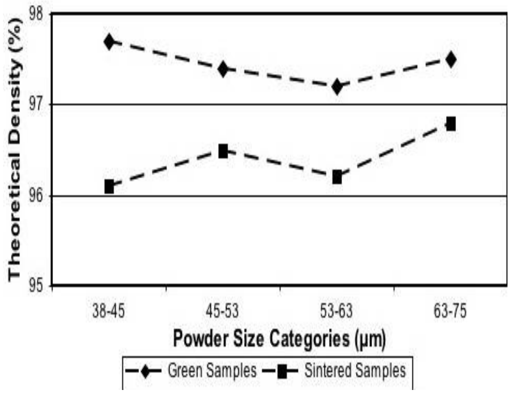


Figure 2.1 Percent theoretical density of uniaxially die compacted ground Mg for green samples and samples sintered at 500 °C for 30 minutes, *Burke et al*. (2009).

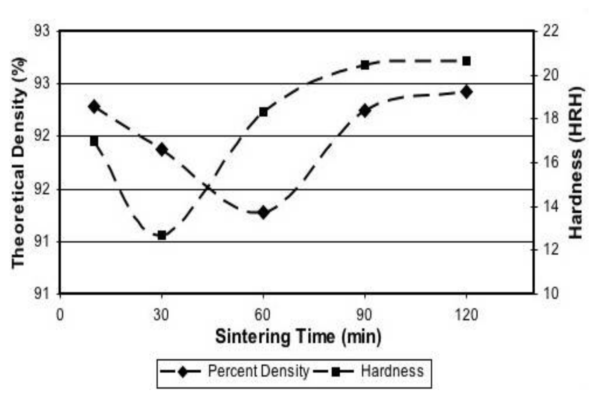


Figure 2.2 Sintering time effect on cold isostatically pressed atomized Mg samples on density and hardness. Sintering was performed at 600 °C.

Li et al. (2008) and ***Velikokhatnyi et al.*** (2010); had studied the thermal stability of the developed amorphous (Mg–Zn–Ca) phase using differential scanning calorimetry (DSC) and isothermal heat treatment at different temperatures. Later on***, Moni et al.*** (2011) have also conducted the development and characterization of amorphous Mg–Zn–Ca based alloys of nominal composition 60at. % Mg–35at. % Zn–5at. % Ca at room temperature using high energy mechanical alloying (HEMA) technique. ***Yu-feng et al.*** (2010) were compressed a series of AZ80 billets with 60% height reduction on hot process simulator at 250,300,350,400°C under strain rates of 0.01, 0.1, 1 and 10s^{-1}. The results (due to the effects of temperature and strain rate on it) show that the critical damage value is not a constant but changes in a range of 0.0218-0.3780. The result shows, with the increase of strain rate, the critical damage value decreases at a certain temperature. While under a certain strain rate with the increase of temperature, the critical damage value has little change.

Zhang et al. (2012) had produced an argon gas atomized to ZK60 Mg alloy powder (with particle size of 10^2-µm in diameter); that was compacted up to the pressure of 360 Mpa at 200°C and further extruded at varied temperature. With the precipitation of $MgZn_2$ finer precipitates, the tensile properties were improved. ***Umasankar et al.*** (2014) have made an attempt to understand the influence of processing parameters on the mechanical properties like sintered density and micro hardness. It has been observed that the compacting pressure and reinforcement percentage have higher impact than the sintering temperature on microhardness and density. Further to evaluate the fracture resistance strength, sintered composites have been subjected to static ball indentation. It has been observed that higher reinforcement and compacting pressure enhance the failure load while sintering temperature and time exert constrained influence. ***Marina et al.*** (2016) had milled a powder mixture of Mg-10wt%Zn in a planetary mill under argon atmosphere using a stainless-steel container and balls; then that was compacted under 400 MPa and sintered in a tube furnace at 350 °C in argon flow. The effect of milling time results obtained shows that, the alloy milled at 10 hrs. of milling time provided the highest properties in both density and microhardness which were 1.813 g/cm^3 and 88.72 HV, respectively.

Gonzales et al. (2016) were revealed the different in microstructure features of extruded conventional cast process (CP) and PM alloy (Mg- Ni-Y-CeMM). The processing route was revealed that the fine precipitates of Mg24Y5 only formed in PM alloy, and homogeneously dispersed in the Mg matrix. While, the second phase particles in cast alloy distributed in bands along the extrusion direction. ***Candan et al.*** (2018) were evaluated a comparative study and the influence of addition of Al on corrosion behaviors of Mg-Al-Zn alloys by immersion tests and potentiodynamic polarization measurements in 3.5% NaCl solution. The addition of Al on corrosion resistance was more pronounced up to 4% for AZ41. The higher Al contents, the deterioration of the corrosion resistance of the Mg-alloys, was attributed to the amount and morphology of β-Mg17Al12 intermetallics and the interruption of continuity of the oxide film on the surface of the alloys owing to coarsened β intermetallics.

Amirnejad et al. (2018) have studied the effect of addition of Si on mechanical properties, bio-corrosion behavior, the microstructure, and cytotoxicity of Mg−6Al −1Zn alloy. After hot pressing, Although the grain sizes of both material systems increased, Si-containing system (Mg−6Al−1Zn−1Si) displayed a smaller grain size, i.e,63nm compared to 71nm in

Mg−6Al−1Zn system, after being exposed to 350°C for 1hr. The nanocrystalline AZ91-Mg alloy bulks (with an average grain sizes of ~15nm) were processed via the combined processing of hydrogenation-disproportionation-desorption-recombination (HDDR), spark plasma sintering (SPS) and hot extrusion. The influence of various holding times and sintering temperatures on the sintering properties of Mg alloy were analyzed and the optimum SPS sintering process parameters of nanocrystalline AZ91 powder were determined by ***Guo et al.*** (2020). ***Li et al*** (2020) have studied the microstructure and sintering mechanism of the silicon carbide (SiC) that was hot pressing sintered under 30 MPa pressure at 1300°C by using Mg additive. The result of the hot-pressing sintered sample composed of both SiC and Mg alloy, shows that no polytype transition has happened. Dislocations and stacking defaults are begin from grain boundaries and move toward the interior. The stacking faults of Mg is located on the SiC matrix as second phase particle.

2.10 Optimization of process parameters to improve the mechanical and wear properties of the composite

A detailed survey was done for different optimization techniques to optimize the process parameters in order to yield optimum performances. Pin-on-disk dry sliding wear tests at sliding speeds ranging from 0.6 to 1.25 m/s and under loads ranging from 3.98 to 6.37MPa (50 80 N) were conducted by ***Tang et al.*** (2008) for pin specimens of composites with Al-5083 matrices reinforced with 5 and 10 wt.% B4C particles. The wear rate of the composite with 10 wt.% B4C was approximately 40% lower than that of the composite with 5 wt.% B4C under the same test condition. ***Taskesen*** and ***Kutukde*** (2014) evaluated the machining parameters and optimized with grey relational analysis in drilling B4C reinforced metal matrix composites (MMCs) produced by powder metallurgy. The drilling parameters such as feed rate, spindle speed, drill material and wt.% of B4C particles were optimized based on multiple performance characteristics including thrust force, torque and surface roughness. The experimental study showed that increasing the weight fraction of the B4C resulted in a considerable increase in the thrust force. ANOVA analysis indicated that the most effective factor on grey grade was found to be weight fraction and followed by drill material, feed rate and spindle speed, respectively.

Sivapragash et al. (2016) were used the Taguchi-Genetic Algorithm (GA) method for optimizing the Physical Vapor Deposition (PVD) process parameters (such as type of gas, chamber pressure and power input); to get higher micro hardness and lower wear rate. The GA approach shows better optimal combination achieved (at $G_2CP_1PI_2$ (G_2=Nitrogen gas, CP_1 = 0.001 bar, PI_2 = 200 W) for attaining higher coating performances.

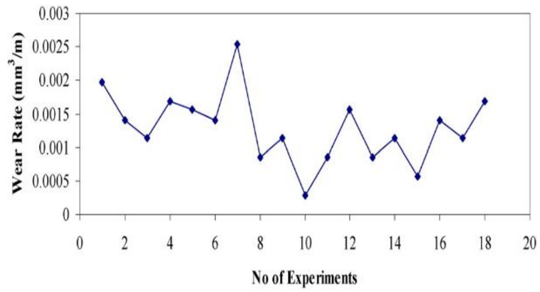


Figure 2.3. Experimental runs with wear rate.

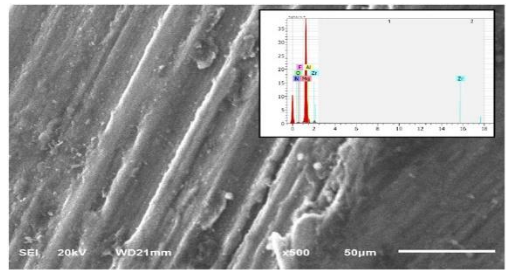


Figure 2.4. SEM & EDX of worn-out surface, *Sivapragash et al*. (2016).

Emre et al. (2018) were produced the magnesium matrix composites reinforced with fullerene by semi powder metallurgy processes. The results showed that, the hardness behavior of pure magnesium was improved considerably with the addition of fullerene. According to the results, ultimate strength and compression yield were improved significantly from compression test results. The composite reinforced with fullerene (Mg/ fullerene) showed lower wear rate and coefficient of friction than unreinforced magnesium. However, when fullerene incorporated into the matrix, the corrosion rate was increased.

2.11 Summary of literature review

The following observations can be drawn from the literature review as the bases of this research. The previous researchers developed and studied different types of composites. The primary advantages of the MMCs materials are, their improved mechanical properties, particularly in the areas of strength, hardness, stiffness and wear resistance. Of the MMCs, Aluminum matrix composites have grown in prominence due to their low density, low melting point and low cost. Aluminium alloy reinforced with SiC particles has distinct properties and the literature review has established clear strategy for achieving high wear resistant. In addition, to extend the wide applications of these composites in various engineering sectors especially in structural members, it is desirable to have better mechanical properties, and wear performance. This can be achieved by proper selection of processing parameters, testing factors, type, size and quantity of reinforcement. The literature survey clearly indicated the need for selection of reinforcement, its quantity, size and suitable process parameters for achieving desired results. The results showed that matrix specific conditions are to be selected for desired results. Various research works have been carried out with different types of reinforcement, various particle sizes of reinforcement, different fabrication techniques and also various testing conditions.

2.12 Literature gaps

From the available literature;

- It can be seen that the optimization and modeling of mechanical properties and wear performance of the composites has not been investigated in detailed way yet.
- Therefore, it needs to investigate the mechanical and wear performance analysis of Al-based matrix composite reinforced with-SiCp particle during hardness, compression strength and wear testing.
- In aluminium metal matrix composites reinforced with SiCp fabricated through powder metallurgy process, not much work has been reported so far.
- And also, there is a challenging task of machining the MMC materials mainly due to the high abrasiveness of the reinforcing phases.

Therefore, in the present research work; investigation of the mechanical properties and wear resistance of both the AlMg matrix and AlMg/SiC composite developed by powder metallurgy route. The optimization of process parameters (like, compaction pressure, sintering temperature and sintering time) with addition of different weight percentage of SiC reinforcement particles have been investigated. To prevent or reduce the machining cost problem, one of the solutions is preventing the machining process or reducing the material removal process is possible by producing a near net part through powder metallurgy manufacturing technique. Because, the next generation manufacturing technology will show interest on production of cost effective, environmental-friendly and good performance products.

CHAPTER THREE

MATERIALS AND METHODS

This chapter consists the materials used for the fabrication of aluminum based (AlMg) matrix composite, fabrication approach and methods for samples preparation, experimental procedure and set ups for testing activities, the instruments and equipment used and methodology of data analysis.

3.1 Materials

3.1.1 Aluminium-Magnesium (AlMg) pre-alloyed matrix

In this study, the AlMg pre-alloyed powder has been selected for developing AlMg-matrix and AlMg/SiC Composite. As mentioned in chapter one, the present determined attempt to achieve reduction of the fuel consumption and for avoiding the exhaust emissions to the environment, fabricating a lightweight structural material that show high performance during both processing and application is required. As a result, Al and Mg alloys have received considerable attention over the past decades as a potential material of choice to achieve significant weight savings. Among the various metal candidates, Mg is the most promising to achieve this target, where it is ~33, 60, and 75% lighter than Al, Ti and steel, respectively ***Miller et al. (***2016). Conversely, Mg alloys have poor mechanical properties (such as low ductility and strength), inferior wear and poor corrosion resistance and these facts limits them for being utilized from a wider range of applications ***Luo et al.*** (2016); unless they reinforced with wear and corrosion resistance materials like, ceramics, aluminium…etc.

The reason to be the AlMg pre-alloyed powder selected is, it has better strength to weight ratio, good ductility and hence finds many appropriate applications in structural and mechanical components like in automotive and aerospace industries. The AlMg pre-alloyed malleable, odorless powder was purchased from (Chengdu Huarui Industrial Co., Ltd. A-1203, Guanghua centre, qngyang district,610015, P. R China) with an average particle size of (50-150μm), density 2.68 g/cm^3 at 25 ºC, and 99% purity) used as matrix. Properties and chemical composition of the AlMg pre-alloyed powder is listed as shown in table 3.1(a) and table 3.1(b) respectively.

Table 3.1(a). The aluminum-magnesium (AlMg) alloy properties.

Properties	AlMg matrix alloy value
Form	Powder
Particle average grain-size	50-150μm
Poisson's Ratio	0.29
Density	2.68 g/cm^3
Yield tensile Strength	130 to 180 MPa
Ultimate tensile Strength	230 to 280 MPa
Specific heat	1040 (J/kg. K)
Gas thermal conductivity	125 (W/m·K)

Table 3.1(b). Chemical composition of AlMg alloy powders (wt.%).

Si	Fe	Cu	Mn	Zr	Mg	Al
0.125	0.2 %	0.03	0.06	0.5	12	Balance

Table 3.2. Properties of Silicon Carbide

Properties	properties' value
Form	SiC powder
Particle average grain-size	50-150μm
Melting point	2730°C
Purity	97 %
Density	3.21 g/cm^3
Hardness	2800 Kg/mm^2
Young's Modulus	410GPa

3.1.2 Silicon carbide (SiC) Reinforcement particles.

Silicon carbide is non-oxide ceramic material made up of silicon and carbon atoms. It is rarely found in natural as mineral, but it has been produced in powder form. From the literature study revealed that among all reinforcements SiC was chemically compatible with aluminum alloy and forms an adequate bond with the matrix without developing inter-metallic phase, have good mechanical properties (such as high hardness and strength,) and other advantages such as chemical and thermal stability, improving oxidation, wear and corrosion resistance to lead longer life of the developed composites ***Venkatesan. et al.*** (2014).

Materials, such as aluminium based matrix composite reinforced with ceramics, which are difficult to process through casting because of their high melting point temperatures, could be processed through the PM technique without difficulty ***Groover*** (2007). Because of having the above exclusive properties, silicon carbide powder is chosen as a reinforcement material. The malleable, odorless and black powder of SiC particles was purchased from (Chengdu Huarui

Industrial Co., Ltd. A-1203, Guanghua centre, qngyang district,610015, P. R China). Properties of silicon carbide particle is shown in table 3.2.

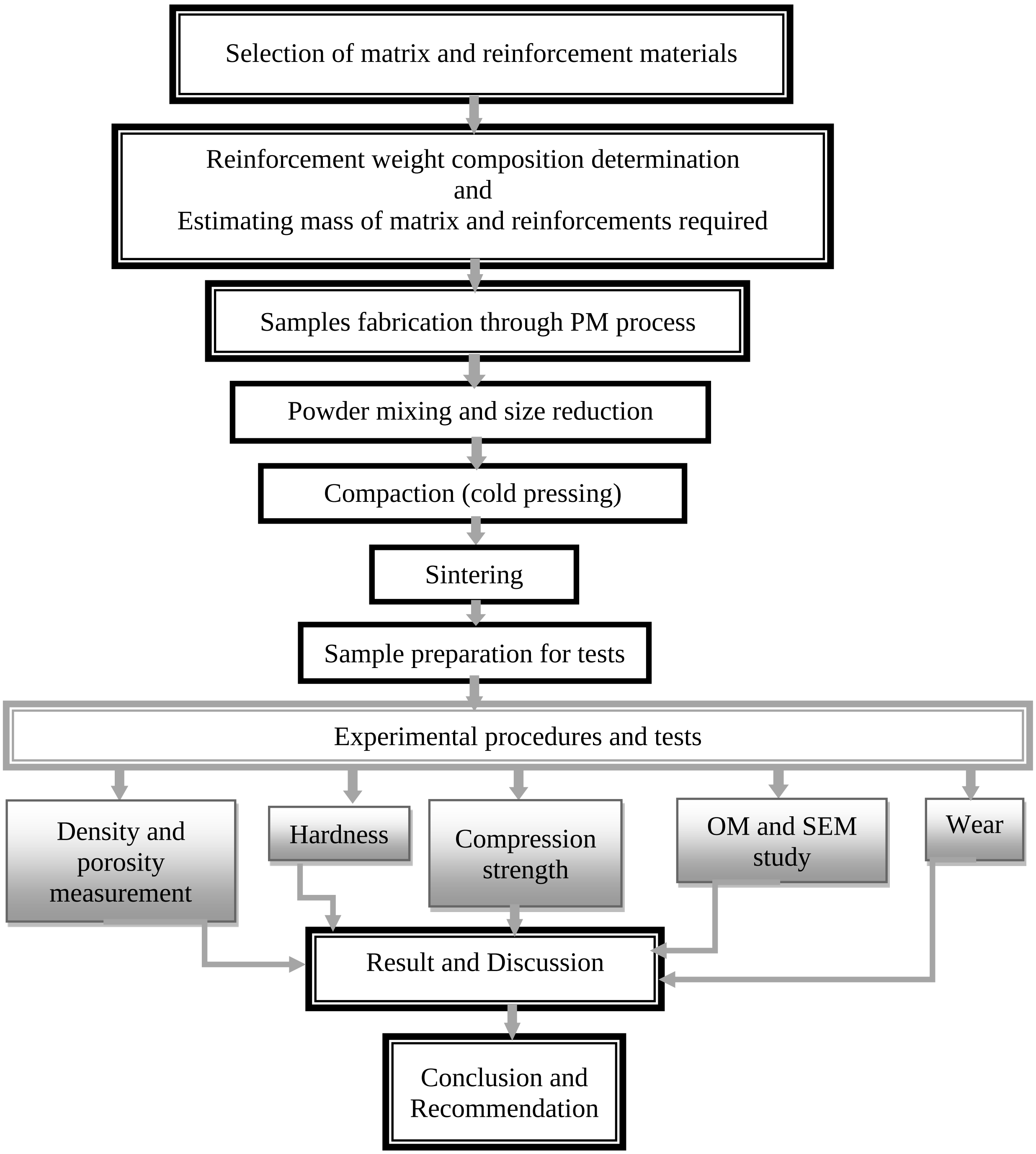


Figure 3.1. General procedure for fabrication and characterization of the AlMg-matrix and AlMg/SiC composite.

3.2 Methods

3.2.1 Matrix and reinforcement material selection

As it is much more than dispersing glue in MMC, the matrix alloy should be chosen only after giving careful consideration to its chemical compatibility with the reinforcement, and its own characteristics properties and processing behaviour. As a rule of alloying element addition, the added element should not form intermetallic compounds with the matrix elements and should not form highly stable compounds with the reinforcements. The best properties can be obtained in a composite system when the reinforcement particulates and matrix are physically and chemically compatible as possible.

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile designers and manufacturers in the present scenario. As mentioned in chapter two (literature review) to enhance vehicle efficiency and fuel economy, reducing the dead weight of the vehicle is required. The primary advantages of the MMCs materials are, their improved mechanical properties, particularly in the areas of strength, hardness, stiffness, wear resistance. also advantages in some of physical attributes such as, high electrical and thermal conductivities and resistance to most radiations ***Russo*** (2006). Of the MMCs, Aluminum matrix composites have grown in prominence due to their low density and excellent mechanical properties, good corrosion resistance, processing flexibility, low melting point and low cost. Therefore, among aluminium based matrix materials, AlMg-matrix alloy has received considerable attention as a potential material of choice to achieve significant weight savings, due to their lesser density of Al and Mg (1.72 and 2.72 g/cm^2 respectively).

Among various ceramics candidates, Silicon carbide has received wide attention because of its excellent oxidation and corrosion resistance and even at high temperatures without any failure, ***Li et al.*** *(2020)*. The SiC-particulate-reinforced aluminum matrix composites have a good potential and a favorable effect on properties such as hardness, compressive strength and wear resistance. The silicon carbide reinforcement into Al-based matrix composites had proved that increase in strength, hardness and wear resistance, ***Sijo et al.*** (2016) and ***Ravikumar et al.*** (2018). From the literature study revealed that among all reinforcements SiC was chemically compatible with aluminum alloy and forms an adequate bond with the matrix without developing inter-metallic phase, have good mechanical properties and other advantages such as excellent thermal conductivity and good workability ***Venkatesan. et al.*** (2014).

3.2.2 Specification of weight percentage composition

The mechanical and wear properties of the developed composite materials are highly depending up on the weight percentage (wt%) of the reinforcements. Therefore, the weight percentage composition of SiC used in this research work have taken based on the literature review and the following researchers' studies are considered for taking the wt% composition of reinforcement in each of the sample. ***Govindan and Viji*** (2017) analyzed the behavior of the brake disc with aluminum metal matrix composite material reinforced silicon carbide. They concluded that, the Al/SiC MMC reinforced with 10% of SiC can be used in automotive to replace the conventional material for improved vehicle performance. ***Pawar and Utpat*** *(2014)* developed the aluminum-based metal matrix composite reinforced with addition of silicon carbide in Aluminum metal by mass ratio 2.5%, 5%, 7.5% and 10% to study hardness and microstructure tests. Experimental results showed that of increased silicon carbide content, the hardness, and material toughness are enhanced and highest value is obtained at 10% SiC content. ***Isra*** (2013) have been studied the effect of addition of different weight percent from SiCp (2, 4, 6, 8) to Al4Cu alloy. It was found from the experimentation that the wear rate decreases linearly with increasing weight percentage of silicon carbide. The best results have been obtained at 8 % wt SiC. It is also observed that the yield strength, tensile strength increases with increasing wt% of SiC, but the ductility decreases.

The above researchers have studied effects of different wt% addition of SiCp reinforcement into Al-based matrix composite with less magnesium content that increases the samples weight. But, in this research work, as tabulated in table 3.1, ten weight percentage (10%) of Mg is present in the AlMg alloy for fabricating the lightweight AlMg composite. So even if the wt% composition of reinforcement addition is possible till 30%, as studied by ***Ramanathan et al.*** (2019), to minimize the porosity formation in the composite, for better uniformly distribution of reinforcement and good densification of the composite fabricated by Powder metallurgy method, five and ten weight percentage (5% and 10%) composition of SiCp have been taken. However, in aluminium metal matrix composites reinforced with SiCp fabricated through powder metallurgy process, not much work has been reported so far. From the available literature, it can be seen that the optimization and modeling of mechanical and wear performance of the AlMg composites has not been investigated in detailed way yet.

3.2.3 Weight (in mass) estimation for matrix and reinforcement inquires

The total weight mass of matrix and reinforcement required for AlMg/SiC composite samples production, is found from the total specimens require for hardness, microstructure, compression and wear tests, based on the die and punch pre-designed dimensions. The pre-designed die and punch have the following dimensions. The inner diameter and length/height of the die is 20mm and 50mm respectively, whereas the punch diameter is 20mm with small clearance to insert it into the die during compaction of the powder by hydraulic pressing machine. Based up on the above dimensions, Cylindrical specimen for AlMg-matrix and
AlMg/SiC composite were fabricated with a size of length (L) and diameter (d) as shown in figure 3.2. The produced specimens' dimensions are limited to produce cylindrical specimen with short-length due to the capacity of the hydraulic pressing machine.

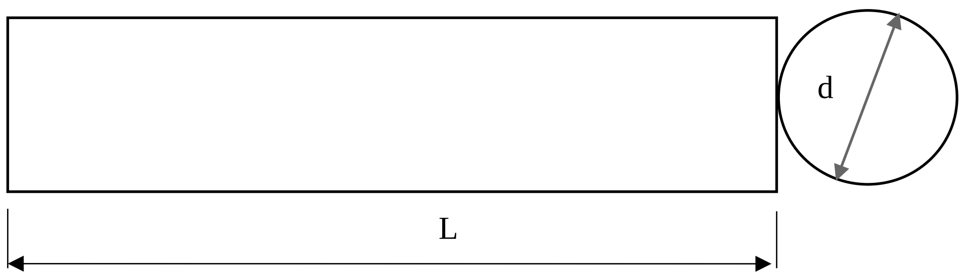


Figure 3.2. Dimension for all samples

The pre-designed die and punch were used to manufacture the required number of specimens based on the following types of tests to be conducted;

- The Hardness and microstructural test specimen length is 6 mm with 18mm diameter.
- The compression test specimen has 18mm length and 6mm diameter.
- The wear test specimen length is 12mm and 6mm diameter.
- The amount of material removes by hand saw, file/rasp and grinding (machining and grinding allowance) 2mm is considered.

The volume of cylindrical specimen is calculated using Eq (3.1);

$$V = \pi \times D^2 \times L/4 = \pi \times L \times r^2 \qquad (3.1)$$

Where, V is volume of specimen in mm^3, L is length = 8mm and d is diameter = 20mm

$$V = \pi \times L \times r^2 = \pi \times 8mm \times (10mm)^2 = 2{,}512mm^2 = 2.512cm^2$$

The required amount of matrix (AlMg) and SiC reinforcement in each specimen are estimated as follows based on the weight composition set in table 3.5. The weight of AlMg matrix and SiC reinforcement in each specimen for the given compositions are estimated using Eq (3.2).

$$m_x = V_{total} \times \rho_x \times y \qquad (3.2)$$

Where, m_x is weight, x is matrix/reinforcement and y is wt% of matrix/reinforcement x.

Table 3.3. The total mass of AlMg and SiC powder required for samples production.

No.	Samples	Required AlMg-alloyed powder in gram (g)	Required SiC powder in gram (g)
1	AlMg-matrix samples (S1, S2 and S3)	20.2	0
2	AlMg/5wt%SiC composite samples (S4, S5 and S6)	19.187	1.21
3	AlMg/10wt%SiC composite samples (S7, S8 and S9)	18.177	2.419
	Total weight required	57.564	3.629

3.3. Taguchi method

Taguchi method is a tool that used for improving a most useful product performance, process, design and system with a significant reduction in experimental time and cost ***Wiley*** and ***Sons*** (2008). The performance characteristic of each product or process needs to have a nominal value or target value. The goal is to reduce the variability around this target value. Optimum working conditions determined at the end of the experimental study should always give the same or very close performance value to each other in different operating environments or at different times. For this reason, the optimization criterion should control the minimization of the variability in the performance value. According to the Taguchi method, such an optimization criterion is a performance statistic.

The optimum condition is determined by studying the main effects of each factor, and these main effects show the general tendencies of the effects of the factors. When it is known that either a high or a low value gives the desired result, it becomes possible to estimate the levels of the factors expected to yield the best results.

Analysis of variance (ANOVA) is a common statistical process applied mostly to experimental results to determine the percentage effect of each factor. The ANOVA table given for an analysis helps to determine which factors need to be controlled. Since the quality of any product is measured with a single criterion, or the combination of multiple criteria, regardless of the quality of the measurement, the performed measurement will belong to one of the following three characteristics ***Canakci et al***. (2013) and ***Das et al.*** (2020).

A. The bigger, the better;

B. The smaller, the better;

C. Nominal values are better

Performance statistics formulas of the above three characteristics for determination of the optimum levels of the parameters are as follows.

A. For the characteristic of “the larger, the better”: In this case, the target value of *y* is infinite and the signal-to-noise ratio is defined as:

$$SN_S = -10\log\left[\frac{1}{n}\sum_{n=1}^{n} y^{-2}\right] \tag{3.3}$$

B. For the characteristic of “the smaller, the better”:

In such problems, the target value of quality variable *y* is zero. In this case, the signal-to noise ratio is defined as:

$$SN_S = -10\log\left[\frac{1}{n}\sum_{n=1}^{n} y^{2}\right] \tag{3.4}$$

C. For the characteristic of “nominal values are better”: In such problems, a certain target value is given for *Y*. In this case, the following equation is used.

$$SN_n = -10\log\left[\frac{y^2}{S}\right] \tag{3.5}$$

In all three problems, the goal is to maximize the *SNs* ratio. According to the Taguchi method, maximizing the *SN* ratios increases the signal on the one hand, and reduces the variance on the other hand. In the above equations, *n* is the number of repeated experimental tests, *y* is the performance value (it can be density, porosity, hardness or compression strength in this study). If the purpose of a process is to reach the maximum value, the parameter levels maximizing the

*SN*s value are optimum. If the goal is to reach the minimum value, in this case, the parameter levels maximizing the *SN*s are optimal.

3.3.1 Selection of Orthogonal array

In this paper, the Taguchi's L9 Orthogonal array has been used for the experimental trial run as it is the basis for the analysis of Taguchi method. Taguchi orthogonal arrays provide that all controlled variables are equally considered in experiments. The minimum number of trial run must be more than or equal to the total degrees of freedom. Each row of orthogonal array represents different combination of level parameters.

3.3.2. Taguchi design of experiment

The four powder metallurgy process parameters such as the weight percentage of SiC reinforcement, with different compaction pressure (40, 50 and 60MPa), sintering temperature (350, 450 and 550°C) and sintering time (30, 60 and 90 minute) were selected, based on the size of the sample to be fabricated, the required compaction pressure should enough for compressing the sample. And the sintering temperature range should less by 70% to 90% than the matrix melting temperature point. In this study experiment with four factors and three levels are conducted and hence orthogonal array L9 with nine rows and three columns was chosen. The three levels of the four control variables used in the production of AlMg-matrix and composite are shown in table 3.4. In the run order obtained from Taguchi model L9 experiments were performed and the objective of this model is to obtain higher hardness, compression strength and good wear resistance composite with lower density and porosity.

Table 3.4. Parameters used in the production of Mg-Al/SiC composite and their levels

No.	Controlled variables/parameters	Levels		
		1	2	3
1	SiC particle (wt%) (A)	0	5	10
2	Compaction pressure (Mpa) (B)	40	50	60
3	Sintering Temp.(°C) (C)	350	450	550
4	Sintering Time(min.) (D)	30	60	90

Table 3.5. L9(3^4) Orthogonal factorial Taguchi experimental design for preparation of AlMg-matrix and AlMg/SiC composite Samples

Samples (S) No.	Pressure (MPa)	Sintering Temp.(oC)	Sintering Time(min.)	SiC(wt%)	AlMg Alloy(wt%)
S_1	40	350	30	0	100
S_2	50	450	60	0	
S_3	60	550	90	0	
S_4	40	450	90	5	95
S_5	50	550	30	5	
S_6	60	350	60	5	
S_7	40	550	60	10	90
S_8	50	350	90	10	
S_9	60	450	30	10	

3.4 Equipment's and tools used to fabricate and prepare the matrix and composite samples

The basic tools and equipments used in this thesis work are mentioned in table 3.6 and in table 3.7 respectively with their functions. The usage of each tools and equipments used in this thesis are described in detail in the fabrication and specimen preparation methods.

Table 3.6. Tools used to prepare the specimens for different tests

No.	Tools	Function/task
1	Hack Saw	Used for sectioning the fabricated small size samples
2	File/rasp	For filing/rasping the sectioned sample for further grinding and polishing processes
3	Caliper	To measure the test specimen's dimensions

Table 3.7. Equipments required for the thesis work

No	Equipments	Function/usage
1.	High energy ball milling	For mixing and powder size reduction of the AlMg-alloy and SiCp reinforcement
2.	Hydraulic pressing machine	To compact the mixed AlMg-SiC powder
3	Furnace	For sintering the green-compacted samples at a given temperature for further samples strength increment
4	Argon gas with cylinder	An argon gas was inserted through copper tube into the furnace during sintering process for atmospheric air control to prevent reaction of the AlMg-samples.
5	Grinder/Polisher	To obtain a flat mirror like surface free from excessive deformation
6	Chemical (Killer's etchant) solution.	To avoid any particles, dust, debris…. etc, from the prepared specimen for micro structural characterization
7	Optical microscope (OM)	For examining the structural characteristics of the AlMg-matrix and AlMg/SiCp composite specimens
8	Scanning Electron Microscope (SEM)	For morphological characterization of the wear surfaces the AlMg matrix and AlMg/SiC composite.
9	Vickers hardness machine	To test hardness of the matrix and composite
10	Universal testing machine (UTN)	To test the compressive strength or capacity of the AlMg-matrix and AlMg/SiCp composite material to withstand loads tending to reduce size.
11	Pin-on-disc	For wear and friction test, to know the wear resistance performance of the AlMg-alloy and AlMg/SiC materials.
12	Electronic weighting machine	To measure the weight loss of the specimens during the wear test.

3.5 Fabrication of the AlMg-matrix and AlMg/SiC composite samples

In this study, all the AlMg-matrix and AlMg/SiC Composite samples were fabricated using powder metallurgy method.

3.5.1 Powder metallurgy process

Many techniques were developed for producing particulate reinforced MMCs, from those methods, PM route is one the most economical process for fabricating the near net particulate reinforced MMCs and thereby allowing greater flexibility, a significant reduction in manufacturing costs due to minimizing machining process and minimized scrap losses. Since powder metallurgy fabrication method offers more uniformity in the distribution of the reinforcement material and it eliminates clustering problem to some extent thereby increasing the mechanical properties as studied by ***Kumar et al.*** (2016), ***Kanthavel et al.*** (2016) and ***Nassar et al.*** (2017). In this research work, the same procedure is adopted to fabricate the entire specimens of matrix and composite shown above in table 3.5 using Powder metallurgy (PM) process. The steps of powder metallurgy technique are shown as follows (***Hussain et al.*** (2016) ***Hussain et al.*** (2017). The basic steps in powder metallurgy (PM) processes are powder mixing, powder compaction, and sintering process.

3.5.1.1 Powder mixing

Mixing refers to the uniform mixing of powders of different kind. In order to give the desired performance of the powders selected in the composite production, it is extremely important to distribute them homogeneously in the matrix. For this purpose, high energy ball milling machine were used. The metal alloy powders are ball-milled in a high-speed chamber using tungsten balls. This process results in production of mechanically alloyed intermetallics. High energy ball milling is also used for producing fine particles from alloy powders that ensure physical and structural homogeneity of the finished part. The measured weight percentage of SiCp was added into the ready pre-alloyed of AlMg-matrix powder for mixing, and also used for size reduction purpose. One weight percentage of n-butanol was added into the composite powder mixture in order to prevent the distribution disturbance, for the matrix powders not to pour out from the graphite molds, and to minimize the frictions between the mold and powder. After the mixing process was completed, the mixture was kept in storage vacuum tube in order prevent oxidation by contact with the air. In this study, the 5% and 10% weight percentage (wt%) of SiC particles and Al-Mg based alloy powders were mixed and grinded using a high energy milling machine as shown in figure 3.3(a) having steel ball to powder weight ratio of 2:1. This mixture have been done at setting of 300rpm and 120 milling time (constant for all powder mixtures run), ***Hussain et al.*** (2018).

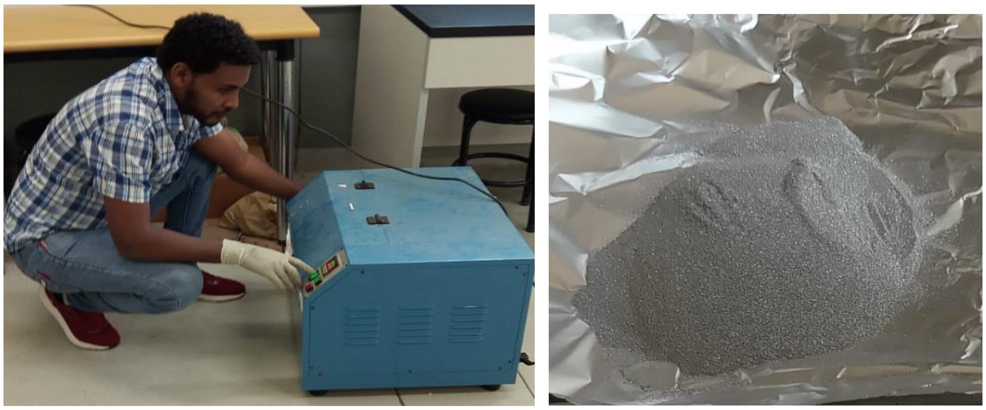


Figure 3.3 (a). High energy ball milling machine for powder mixing process and (b) the final milled powder mixture of the AlMg-SiC composites.

3.5.1.2 Powder compaction

Powder compaction is the process of compressing or compacting of the mixed AlMg/SiC powder in a die through the application of hydraulic pressing machine. Typically, the tools are held in the vertical orientation with the punch tool forming the bottom of the cavity, as shown in figure 3.4.

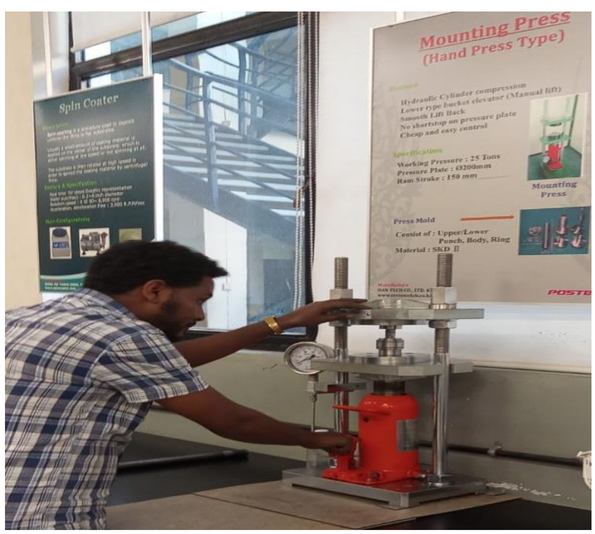


Figure 3.4. Experimental set up for powder compaction by hydraulic pressing machine.

The mixed powders had weighed (6.5gram) for each sample of matrix and composite powder mixture had filled into in the die and punch set-up was placed on a 25-tons of hydraulic press machine. And then, the cold die compaction was done at a pressure of 40, 50 and 60MPa for 30 minutes of holding time to make a green compacted sample having 20mm diameter and various height (the green compacted sample height depends on the applied compaction pressure and compressibility of the matrix and composite powders). Compressibility of powders gives an indication of the extent to which the mixed powder can be compacted and densified by the application of a certain pressure. Larger compressibility means larger pressure is required for compacting a given mixed powder. The green-compacted sample shape, is then ejected from the die cavity. The density of the compacted powder is directly proportional to the amount of pressure applied. A homogeneous and uniform mixture of powder particle will promote uniform density of compacts. The softer matrix powders promote higher green density. Similarly, the higher compaction pressure leads to higher density of the compact. The high carbon chromium steel made of die and punch material were used. The pre-designed dimension of the die and punch tools are given in table 3.8.

Table 3.8. The die and punch dimensions.

S. No.	Parameters of die and punch	Dimension, mm
1.	Outer diameter of die	50
2	Inner diameter of die	20
3	Length of the die	50
4	Diameter of the punch	20-clearance
5	Length of the punch	50

3.5.1.3 Sintering

Green compacts do not have sufficient strength and they may collapse even under small loads, because the particles are loosely bonded with each other. They may also contain porosity between the particles. In order to eliminate porosity and to establish metallurgical bond between powder particles, sintering is carried out after compaction. Sintering can be considered to proceed in three stages. During the first, neck growth proceeds rapidly but powder particles remain discrete. During the second, most densification occurs, the structure recrystallizes and particles diffuse into each other. During the third, isolated pores tend to become spheroidal and densification continues at a much lower rate. Solid state sintering is the process in which the green compact is heated to a temperature 70-to-90 percent below the melting point of the base matrix for a specified period of sintering time in order to achieve chemical bonding between the porous aggregate particles by the process of interparticle diffusion, plastic deformation, grain formation and grain growth and once cooled the powder has bonded to form a solid piece.

During sintering bonding takes place between the aggregate powder particles. The word solid state in solid state sintering simply refer to the state in which the material is when it bonds, solid meaning the material was not turned molten to bond together while sintering. If the sintering temperature is higher than the melting temperature of one of the metallic components of the compact, then liquid phase sintering occurs. Liquid phase sintering enhances the density of the compact. Sintering is to be performed in controlled atmosphere in order to prevent oxidation of the surface of the compacts. Gases such as argon, helium, nitrogen and nitrogen-hydrogen gas mixture are used as sintering atmosphere.

In this study, the green compacted of the AlMg-matrix samples (S_1, S_2 and S_3) and the SiCp/AlMg composite samples (S_4-to-S_9) were subjected to sintering process. The compacted samples were heated to varying sintering temperatures (350 ^oC, 450 ^oC and 550^oC) at a heating rate of 15^oC/min in the furnace (with insertion of an argon gas for atmospheric air control) and the holding time were 30,60 and 90 minutes, based on the Taguchi experimental run design, as shown in table 3.5. The sintered samples of the matrix and composite samples (S_1-to S_9) product are shown in figure.3.6.

Figure 3.5. Experimental set up for sintering the green compacted samples in the furnace.

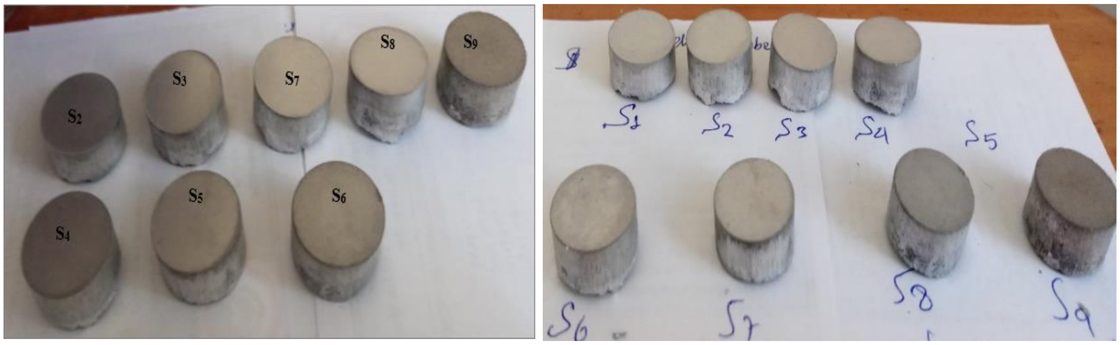


Figure 3.6. The AlMg-matrix (S_1, S_2, S_3) and AlMg/SiC composite samples (S_4-to-S_9).

3.6. Specimens preparation for different tests

The matrix and composite samples were successfully fabricating through powder metallurgy process. To perform the hardness test, compression test, wear test and microstructural characterization for the developed products, the required shape and size of specimens' preparation was done based on the ASTM standard by using hand saw and file/rasp, as shown in figure 3.7.

3.6.1 Specimen preparation for microstructure studies

The main steps of specimen preparation for light microscopy include; sectioning, mounting, grinding (course grinding and fine grinding), polishing and etching and then microscopic examination.

3.6.1.1 Sectioning

Sectioning serves two purposes: generating a cross-section of the specimen to be examined; and reducing the size of a specimen to be placed on a stage of light microscope. In this study, the samples sectioning was done using hand-saw and file/rasp, as shown in figure 3.7.

Figure 3.7. Specimen preparation for different tests

3.6.1.2 Mounting

Mounting refers to embedding specimens in mounting materials (commonly thermosetting polymers) to give them a regular shape for further processing. Mounting is not necessary in this study, because the specimens were enough to handle. It is required for specimens that are too small or oddly shaped to be handled.

3.6.1.3 Grinding and polishing processes

The AlMg-matrix and AlMg/SiCp composite sintered samples were ground using emery paper of gradually increasing fineness and then polished on polishing machine for hardness test and microstructural analysis. The objective of grinding and polishing is to obtain a flat mirror like surface free from excessive deformation. This is achieved in the three steps; rough grinding, fine grinding, and polishing. Grinding is the process of making AlMg-matrix and AlMg/SiCp composite sample clear surface from scratches using the sand paper of gradually increasing scale 120, 400, 800, 1200, and 2000 grits, that is shown in figure 3.8. Polishing is the process of creating a smooth and shiny surface by rubbing the sample using a diamond suspension with gradually reduction of the pressure and the sand wheel rotation speed using RB 204 Metpol-II Model polishing process, as shown in figure 3.9.

Figure 3.8. Grinding process

Figure 3.9. Polishing process

3.6.1.4 Etching

The polished samples of both the matrix and composites were etched with recommended mixed etchants solution (25ml-methanol, 25ml-hdrochloric acid, 25ml-nitric acid and 1-drop of hydrofluoric acid) and simply performed by immersion the samples into the prepared etchant solution for 20 seconds and washed with distilled water before the microstructural characterization of the specimens.

3.7 Experimental test procedures

The experimental test procedures were conducted to measure the density and porosity value, to know the mechanical properties (hardness and compression strength), wear performance and microstructural characterization of the AlMg-matrix and AlMg/SiC composite materials.

3.7.1 Mathematical determination for density and porosity measurement

The AlMg-matrix and composite theoretical-density (ρ_{th}) is determined with the summation of the constituents in the volume of the sample with matrix and composite powder mixing regulation by equation (3.6) ***Premnath et al.*** (2014).

$$\rho_{theo} = (\rho_{mat} \times V_{mat.}) + (\rho_{rein1} \times V_{rein1}) \tag{3.6}$$

Where, V_{mat} and V_{rein1} represents fraction of the volume, ρ_{mat} is the matrix density, ρ_{rein1} is the reinforcement density, respectively.

A. The actual or experimental density for the AlMg-matrix and AlMg/SiC composite can be calculated as stated by Archimedes-principles. First of all, the sintered specimens were weighed in the air (W_{air}), and then weighted in the distilled water (W_{water}) by suspended the sample in it. The actual or experimental density of the sintered composite sample was calculated according to Eq. (3.7) ***Wang et al.*** (2004) and ***Wang et al.*** (2018).

$$\rho_{ac} = \frac{W_1}{W_1 - W_2} \times \rho_w \tag{3.7}$$

Where ρ_{ac} is actual density of samples, W_{air} is weight of samples in the air, W_2 is weight of samples in the distilled water and ρ_w is the distilled water density ($1 g/cm^3$)**.**

B. Porosity of the all samples were determined by equation (4**)** ***Alaneme et al.*** (2019).

$$\text{Porosity} = 1 - \frac{\rho_{ac}}{\rho_{th}} \tag{3.8}$$

Where, E_s = porosity (%), ρ_{ac} is the actual density (in g/cm^3), ρ_{th} is theoretically calculated density (in g/cm^3).

C. The relative-density of the samples were calculated by equation (3).

$$\rho_r = \frac{\rho_{ac}}{\rho_{th}} \times 100 \tag{3.9}$$

Where, ρ_r is relative density (%) and ρ_{th} is theoretically calculated density (in g/cm^3).

3.7.2 Hardness test

The main purpose of Hardness test is to evaluate the acceptance of a composite material for a particular engineering application (specially in wear resistant applications, the composite hardness is important). The Vickers hardness tester machine that consists of a right pyramid shape diamond indenter with a square base angle of 136^o between opposite faces was used to measure the hardness of both the AlMg-matrix alloy and AlMg/SiC composite. All the specimens for hardness and microstructural tests were prepared in cylindrical shape having 18mm in diameter and 7mm of height and polished by using sand grinding papers having 120 to 800 grits. The load is applied smoothly, without impact, forcing the indenter into the test piece, as shown in figure 3.10 (a). The indenter is held in place for 5 seconds with 10kgf indenting load. The test was repeated at different positions of the samples to get the average hardness value.

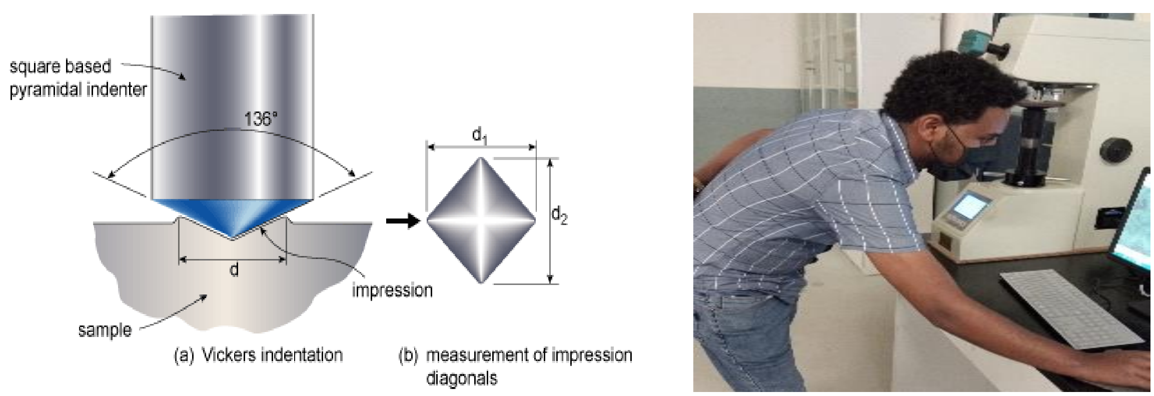


Figure 3.10. The pyramid shape diamond indenter and Vickers hardness machine.

$$HV = P = \frac{Constant\ x\ test\ force}{surface\ area\ of\ indentation} = \frac{0.102x2F(sin\frac{136^2}{2})}{d^2} \tag{3.10}$$

Where, Vickers hardness (HV), P is pressure, F is the force of the indentation(kgf) and d is an average distance between both opposite corners of the indentation (d_1 and d_2 (mm)).

3.7.3 Microstructure examination test

Microstructure is a very small-scale structure of a material, defined as the structure of a prepared surface of material as revealed by an optical (light) microscope. Metallurgical optical microscope was used for examination of the AlMg-matrix and AlMg/SiCp composite specimens, as shown in figure 3.11. The absolute necessity for examination arises from the fact that many microscopically observed structural characteristics of a metal such as grain size, segregation, distribution of different phases and mode of occurrence of component phases and nonmetallic inclusions such as slag, sulfides etc. As mentioned during specimen's preparation, the polished specimens of the matrix and composites were etched with recommended mixed etchants solution (25ml-methanol, 25ml-hydrochloric acid, 25ml-nitric acid and 1-drop of hydrofluoric acid) and simply performed by immersion the specimens into the prepared etchant solution for 20 seconds, washed with distilled water and dried with pressure before the microstructure studies. A number of optical micrographs of samples have been taken for microstructural characterization.

Figure 3.11. The microstructural and hardness test specimens.

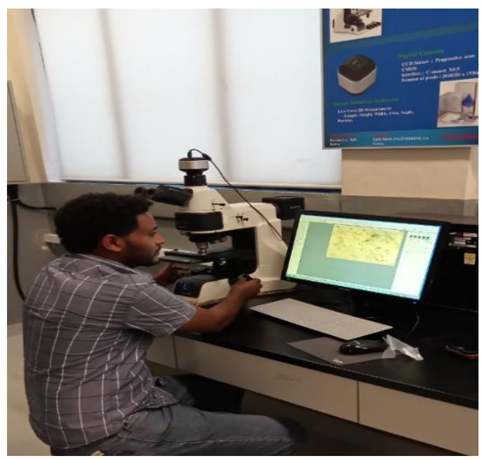


Figure 3.12. Research metallurgical optical microscope.

3.7.4 Compression test

Compression strength is the capacity of a material or structure to withstand loads tending to reduce size. By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely.

The compressive strength is usually obtained experimentally by means of a compressive test, with applying of a uniaxial compressive load. The cylindrical specimens for compression test were prepared based on ASTM E-9 standard with length-to-diameter ratio of 3 (L= 18mm with 6mm diameter), and then the test was performed using universal testing machine (UTM) of 50KN load capacity as shown in figure 3.13. The load was applied till fracture of the specimens occur.

Figure 3.13. Universal testing machine (UTM)

3.7.5 Wear test

Wear is the progressive loss of material from a contact surface during relative motion between a surface and the contacting substance or substances. A process of interaction in the surfaces or a face of bonded solid which is working to loss parts from dimensions solid during working in its environment can be defined as a wear without or with losing of material. In the results in the wear standard tests, the removing of part from weight of the test sample can be used to expression the ear formals of the wear test. In this paper, the dry sliding wear behavior of the samples fabricated form AlMg-matrix and AlMg/SiC composite was investigated using pin-on-disc (DUCOM TR-20 MICRO) equipment with the sample size of 6mm diameter and 12mm height pins dimension and then polished metallographically for the wear test based on the ASTM G99-05 standard, as shown in figure 3.14.

Figure 3.14. Pin-on-disc (DUCOM TR-20 MICRO) equipment and testing

The test was conducted at room temperature (25°C) under the applied load of 10, 30, and 50N with a sliding speed of 250 rpm on a wear track diameter of 25mm. The friction coefficient and wear rate are considered as the main response functions for evaluating the wear performance of the composites. The wear mass loss of each specimen was calculated by measuring the weight difference between the specimens before and after conducting the wear test. The weight or mass loss of each specimens were used to calculate the wear rate (W.R). The wear rate (W.R) of the specimen by weight technique is calculated using equation (3.11). This way can be giving result of wear more accurate from weight techniques, as stated by ***Modi et al.*** (1992), ***Prasad*** (2002) and ***Rao et al***. (2009).

$$\mathbf{W.R} = \frac{\mathbf{WL}}{\boldsymbol{\pi} \times \mathbf{d} \times \mathbf{n} \times \mathbf{t}} \tag{3.11}$$

Where, W.R is wear rate, d is diameter of wear track of the disc, n is revolution per minute, t is time, WL is weight (or mass) loss (Weight before wear (W_b) – weight after wear (Wa)).

The percentage improvement in the wear resistance of composites (IWRca) with respect to an alloy could be calculated from the measured wear rate values using the following equation (3.12), ***Mondal*** and ***Das*** (2006).

$$\mathbf{IWR_{ca}}(\%) = \frac{\mathbf{W_a} - \mathbf{W_c}}{\mathbf{W_a}} \times \mathbf{100}\% \tag{3.12}$$

Where, IWRca is the percentage improvement in the wear resistance of the composite with respect to an alloy, W_a is the wear rate of an alloy, and W_c is the wear rate of the composite.

CHAPTER FOUR

RESULTS AND DISCUSSION

4. Analysis of density and porosity measurement

The AlMg-matrix and composite theoretical-density (ρ_{th}) was determined with the summation of the constituents in the volume of the sample with matrix and composite powder mixing regulation using equation (3.6) and the actual or experimental density of the sintered matrix and composite sample was calculated by Archimedes-principles, as described in chapter three, Eq. (3.7). Whereas, Porosity of the AlMg-matrix and AlMg/SiC composite samples were determined using Eq. (3.8). The product-quality can be determined by one-criterion, with consideration of the measurement-quality, researchers accomplished that the measurement will belong one of the following statistics quality indicative formulas by ***Canakci et al***. (2013) and ***Das et al.*** (2020). These qualifications are; "the smaller, the better", "nominal value the better" or/and "the larger is the better".

To measure and characterize the porosity and actual density performance quality of the matrix and composite, the statistics formula of "the smaller, the better" have been used, because less value of experimental density and porosity is desired for experimentally investigated data are transformed into SNs-ratio, it is interpreted as enhancement of light-weight good strength material. In the case of "smaller is the better", the ratio of signal noise can be given by equation (3.4; to find or approach to the minima or lowest value of porosity and actual density, then the response variable levels are maximizing optimally the S/Ns ratio in this considered case. For both the porosity and actual density of the AlMg matrix and AlMg-SiC composite samples (S_1-S_9) developed by powder metallurgy (PM) processes based on L9 Taguchi experimental design as tabulated in chapter three (table 3.5), the measured and experimentally obtained signal-to-noise (S/Ns) ratio results are shown in table 4.1.

Table 4.1. The measured and experimentally obtained results for the actual density and porosity using the L9 Taguchi design method.

Experimental run samples number	The parameters response		S/Ns ratios	
	Actual-density(g/cm^3)	Porosity (in %)	Actual-density(g/cm^3)	Porosity (in %)
$\mathbf{S_1}$	2.500	2.91	-7.95880	-9.2779
$\mathbf{S_2}$	2.517	2.25	-8.01766	-7.0437
$\mathbf{S_3}$	2.520	2.13	-8.02801	-6.5676
$\mathbf{S_4}$	2.509	3.27	-7.99001	-10.2910
$\mathbf{S_5}$	2.519	2.89	-8.02456	-9.2180
$\mathbf{S_6}$	2.517	2.97	-8.01766	-9.4551
$\mathbf{S_7}$	2.548	3.15	-8.12399	-9.9662
$\mathbf{S_8}$	2.537	3.57	-8.08641	-11.0534
$\mathbf{S_9}$	2.544	3.31	-8.11034	-10.3966

From table 4.1, the lowest measured actual-density and porosity of the AlMg matrix samples are (2.5g/cm^2 of sample one, $\mathbf{S_1}$) and (2.13% of sample three, $\mathbf{S_3}$) respectively. The lowest porosity value for the AlMg-matrix sample (S_3) was obtained due to the high sintering temperature (550°C), compaction pressure (60MPa) and sintering time (60min) performance. The actual density and porosity for both the AlMg-matrix and composites has been decreased with increasing of the compaction pressure, sintering temperature, and time, whereas, when the wt% addition of SiC increases in the matrix, the actual-density and porosity of the composites were slightly increased

4.1. Optimization of the PM process parameters for density and porosity responses

The presence of optimum conditions was investigated by including all of the performance statistical values, and the optimum conditions were determined by studying the main effects of each factor; that shows the general tendencies of the effects of the factors using “MINITAB 18” software.

4.1.1 The variables influence on the actual density

The signal-to-noise (S/Ns) ratio helps for knowing the variables that have an effect on the acquired result. The S/Ns ratio designed rank for each factor leverage accordance with their significances, as shown in table 4.2.

Table 4.2. The signal-to-noise ratios responses for actual-density(g/cm^3) versus SiC, process variables with S/Ns "smaller is better" product qualification.

Level	SiC(wt%)	Pressure (MPa)	Sintering temp.(°C)	Sintering time (Min)
1	-8.001	-8.024	-8.021	-8.031
2	-8.011	-8.043	-8.039	-8.053
3	-8.107	-8.052	-8.059	-8.035
Delta	0.105	0.028	0.038	0.022
Rank	1	3	2	4

From table 4.2, the S/Ns ratio rank of the actual density response result shows that the SiC weight percentage is the greatest significant factor on the composite actual-density following to it, the sintering temperature, compaction pressure and sintering time have less effect on the density increment of the composites.

4.1.2 The optimal prediction conditions

The optimum prediction condition for the S/Ns ratio in which, the less actual-density of the matrix (2.5g/cm^2) obtain with the terms setting in table 4.3 was –7.95880. As shown in table 4.3, the significant effect on actual-density of the AlMg-matrix sample was occurred at level one ($A_1B_1C_1D_1$) (i.e., shown in table 3.4) of setting parameters.

Table 4.3. The actual density attained at the following optimum prediction-conditions.

SiC(wt%)	Compaction pressure (MPa)	Sintering temperature(°C)	Sintering time (Min)
0	40	350	30

The predicted-values	
S/Ns Ratio	Mean
-7.95880	2.58

4.1.3 The signal to noise ratio appraisal performance model coefficient

Table 4.4. The processing variables significant on actual-density.

Terms.	Effects	COEF	SE COEF	T-Values	P-Values
Constant.		2.4624	0.0289	85.33	0.000
SiC(wt%)	0.006133	0.003067	0.000809	3.79	0.019
Compaction-pressure in MPa	0.000800	0.000400	0.000404	0.99	0.379
Sintering-temperature in °C	0.000110	0.000055	0.000040	1.36	0.245
Time of sintering in minute	0.000033	0.000017	0.000135	0.12	0.908

4.1.4 The actual density model summary

The actual-density model of summary discloses that the statistics-data is excellently agreed with an investigate inquiry. The coefficient and correlation-coefficient model expected of the S/Ns ratio for actual-density is shown in table 4.4 and table 4.5. The R-square value for actual-density is 99.81%.

The ANOVA result for actual density is used to demonstrate the variable that have significant statistics at the confidence level of 95-percentage with the approval of P-values. When the P value is ≤ 0.05, it is showing the higher significance level.

Table 4.5. The actual-density correlation-coefficient.

S	R-sq	R-sq(adj)	R-sq(pred)
0.0099065	99.81%	98.81%	98.83%

Table 4.6. Analysis of variance (factorial regression) for actual density.

Sources	DoF	Adj. S.S	Adj. M.S	F-values	P-values	(PC)%
Models	4	0.002078	0.000519	4.30	0.093	
Linear.	4	0.002078	0.000519	4.30	0.093	
SiC(wt%)	1	0.001411	0.001411	14.37	0.019	67.77%
Comp.pressure (MPa)	1	0.000096	0.000096	0.98	0.379	4.61%
Sintering temp.(°C)	1	0.000182	0.000182	1.85	0.245	8.74%
Sintering time (Min)	1	0.000001	0.000001	0.02	0.908	0.05%
Error	4	0.000393	0.000098			
Total	8	0.002082				

ANOVA table 4.6 for actual density is showing the silicon carbide (SiC) has the highest percentage contribution (i. e 67.77%). Since, the P-value of SiC (0.019) is ≤ 0.05), SiC has the highest significance level, following to it, the sintering temperature (8.74%), compaction pressure (4.61%) and sintering time (0.05%) has less significance respectively.

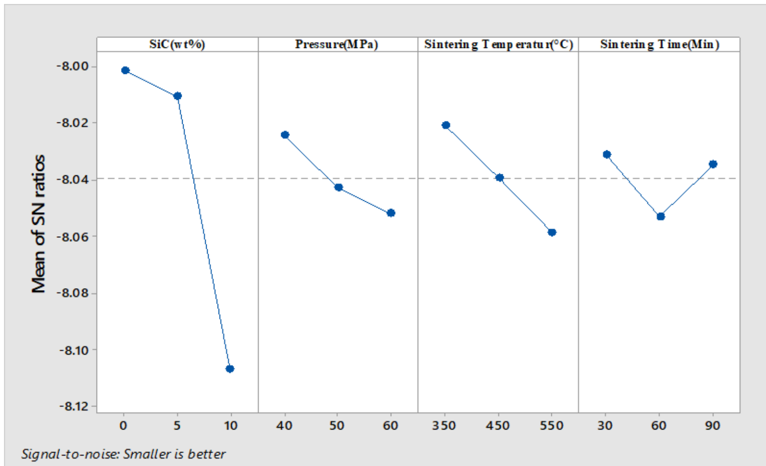


Figure 4.1. Plot for a) actual density for SiC (wt %), compression-pressure (MPa), sintering-temp.(°C), and duration of sintering (min).

From figure 4.1, when addition of silicon carbide weight percentage (wt%) into the matrix is increased, the mean of signal-to-noise ratios for actual-density is decreased with the smaller is better product-qualification. The reason for actual-density increment in the AlMg/SiC composite is, density of silicon carbide is higher in 16.51% than the AlMg-matrix.

The residual-plot of the actual-density is shown in figure 4.2, and as well as figure 4.3, and figure 4.4, are showing the surface and contour plot for the actual density with respect to (w.r.t) SiC-wt%, versus compression pressure, sintering temp. and duration respectively.

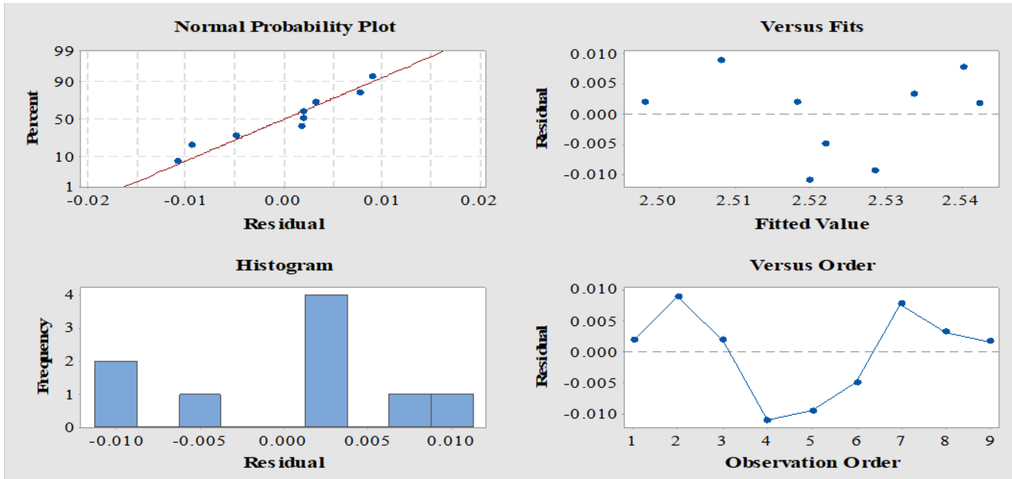


Figure 4.2. The residual-plotting of the SNs ratio for actual-density.

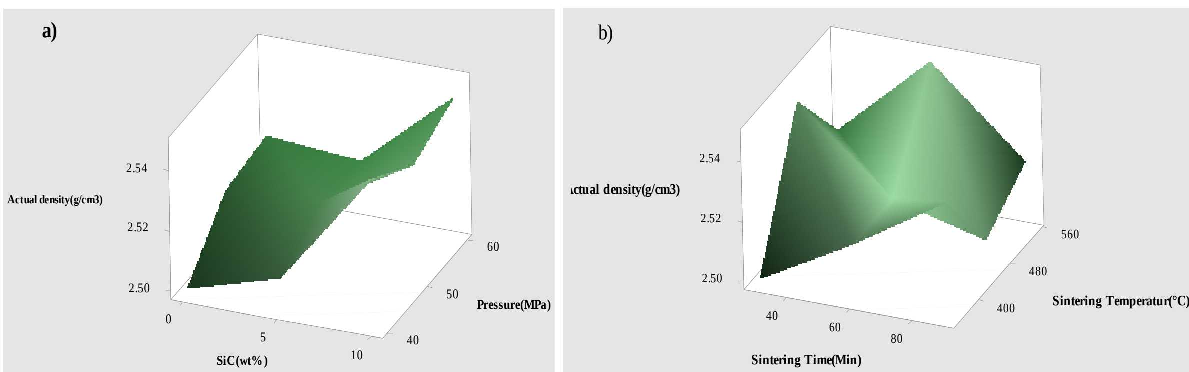


Figure 4.3. The surface-plotting for actual-density w.r.t SiC, compaction pressure (a), and w.r.t sintering temperature and sintering duration (b).

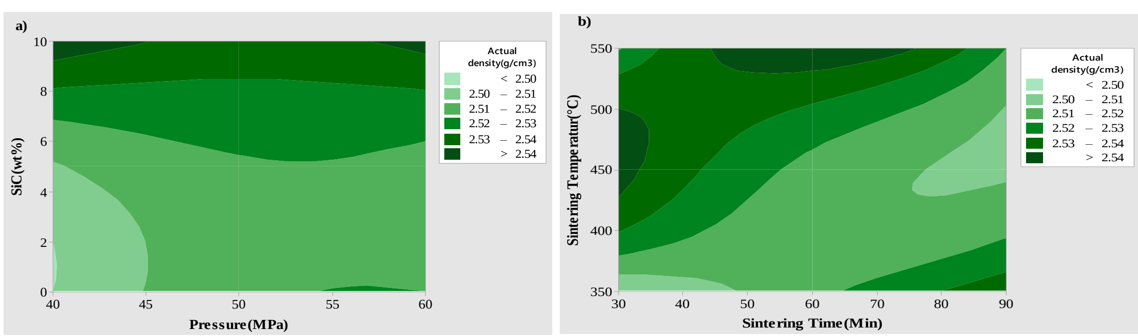


Figure 4.4 (a). The contour-plotting for the actual-density w.r.t SiC, compaction pressure and (b) w.r.t sintering temperature and sintering duration.

As shown in contour-plotting figure 4.4 (a) and (b), actual-density of both the AlMg-matrix and composite has been decreased with increasing of the compaction pressure, sintering temperature and time, but actual-density of the composite sample is slightly increased with increasing of the addition of silicon carbide wt%, this is because of the SiC density is higher than that of the AlMg matrix.

4.1.5 The variables influence on the porosity

As shown in table 4.7, the signal to noise ratio helps to know the variables that has more effect on the acquired result. The ranks designated each factor leverage accordance with their significances. Following to the highest significant SiC factor, the sintering temperature, as well as the compaction pressure and sintering time are the significant variables in the porosity value determination.

Table 4.7. The signal to noise (S/Ns) ratio responses for porosity (in %) versus SiC, PM process variables with S/Ns "Smaller is better".

Level	SiC(wt%)	Comp.pressure (in MPa)	Sintering temp.(°C)	Sintering time (in min)
1	-7.630	-9.845	-9.929	-9.631
2	-9.655	-9.105	-9.244	-8.822
3	-10.472	-8.806	-8.584	-9.304
Delta	2.842	1.039	1.345	0.809
Rank	1	3	2	4

4.1.6 The optimum prediction conditions

The optimum prediction-condition for the signal-to-noise ratio in which, the less porosity (2.13%) of the matrix obtained with the terms setting in table 4.8, is -6.5676. As shown in table 4.8, the significant effect on porosity of the AlMg-matrix sample was occurred at level $A_1B_3C_3D_2$ (shown in table 3.4) of parameters setting.

Table 4.8. The porosity attained at the following optimum prediction-conditions.

SiC(wt%)	Compaction pressure (MPa)	Sintering temperature(°C)	Sintering time (min.)
0	60	550	60

The predicted-values

S/Ns Ratio	Mean
-6.5676	2.1633

4.1.7 The porosity model summary

The porosity model summary reveals the statistics-data is excellently agreed with an investigated inquiry. The correlation-coefficient and coefficient model expected of the S/Ns ratio for porosity is shown in table 4.9 and table 4.10. The R-square value for porosity is 99.93%.

Table 4.9. The porosity correlation-coefficient.

S	R-square	R-square(adj.)	R-square (predicted)
0.196610	99.93%	98.92%	98.84%

Table 4.10. The processing variables significant on porosity.

Terms.	Effects	COEF.	S.E COEF.	T~values.	P~values.
Constant.		4.256	0.573	7.43	0.002
SiC(wt%)	0.1827	0.0913	0.0161	5.69	0.005
Pressure (MPa)	-0.03067	-0.01533	0.00803	-1.91	0.129
Sintering temperature(°C)	-0.004267	-0.002133	0.000803	-2.66	0.057
Sintering time (Min)	-0.00156	-0.00078	0.00268	-0.29	0.786

The following ANOVA table 4.11, is showing the variables contribution percentage (PC %) for porosity, following to the highest significant level of SiC (68.63% contribution), the sintering temperature (14.98%), compaction pressure (7.74%) and sintering time (0.18%) has less significance contribution. The ANOVA result is also used to demonstrate the variable that have significant statistics at the confidence level of 95-percentage with the approval of P~values. When the P value is ≤ 0.05, it is showing the higher significance level. Therefore, the silicon carbide P-value is 0.005, which is less than 0.05, so SiC has the highest significant effect for the occurrence of porosity composite.

From figure 4.5, the graphical interpretation is showing, the sintering temperature and compaction pressure play a great-role to minimize the AlMg-matrix and AlMg/SiC materials porosity. The composite porosity decreased and increasing slightly from 30min to 60min and from 60min to 90min of sintering time respectively. The signal-to-noise ratio of the sample's porosity decreased as the wt% of silicon carbide increases. But porosity slightly increase after 5% of SiC reinforcement.

Table 4.11. The analysis of variance (factorial regression) for porosity.

Sources	DoF.	Adj. S. S	Adj. M. S	T-values	P-values	PC*
Model.	4	1.66867	0.41717	10.79	0.020	
Linear.	4	1.66867	0.41717	10.79	0.020	
SiC(wt%)	1	1.25127	1.25127	32.37	0.005	68.63%
Compression-pressure (in MPa)	1	0.14107	0.14107	3.65	0.129	7.74%
Sintering-temp. (in °C)	1	0.27307	0.27307	7.06	0.057	14.98%
Sintering-duration (in min)	1	0.00327	0.00327	0.08	0.786	0.18%
Error	4	0.15462	0.03866			
Total	8	1.82329				

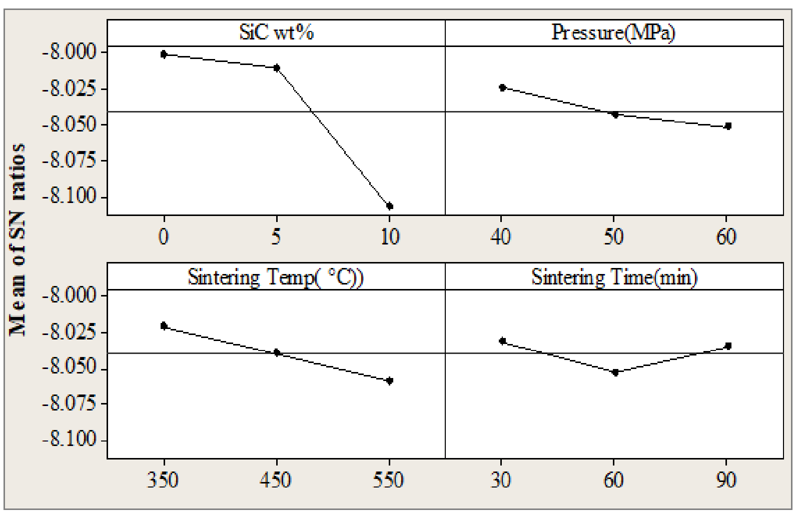


Figure 4.5. Plot for mean of S/Ns ratio of porosity for SiC, compaction pressure, sintering temperature and time.

From figure 4.6 (a) and (b), porosity of both the AlMg-matrix and composite has been decreased with increasing of the compaction pressure, sintering temperature and time, but porosity of the composite sample is increased with increasing of the addition of silicon carbide wt%. The basic control variables in the PM route (such as, compaction pressure, sintering temperature, and sintering time have a great-roles to minimize porosity of both the matrix and the composites.

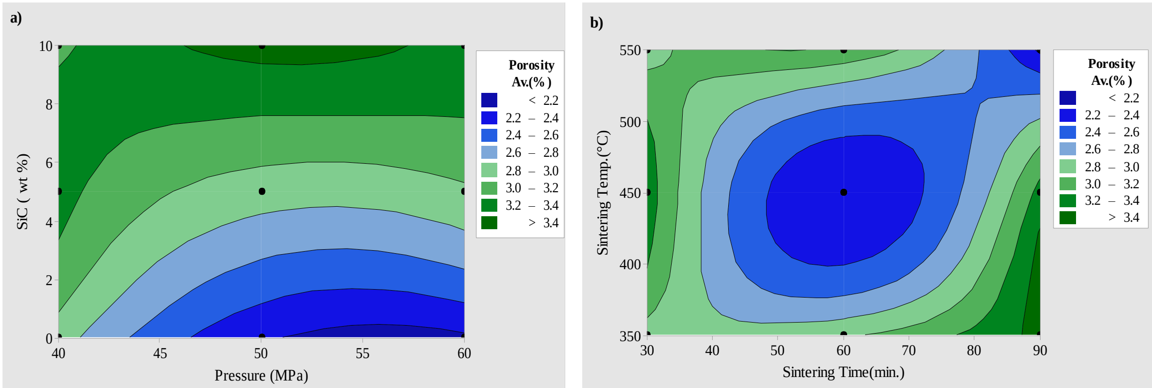


Figure 4.6. The contour-plotting for the porosity (in %) w.r.t SiC Vs compaction pressure (MPa) (a), and w.r.t sintering temperature (°C) Vs sintering time(min) (b).

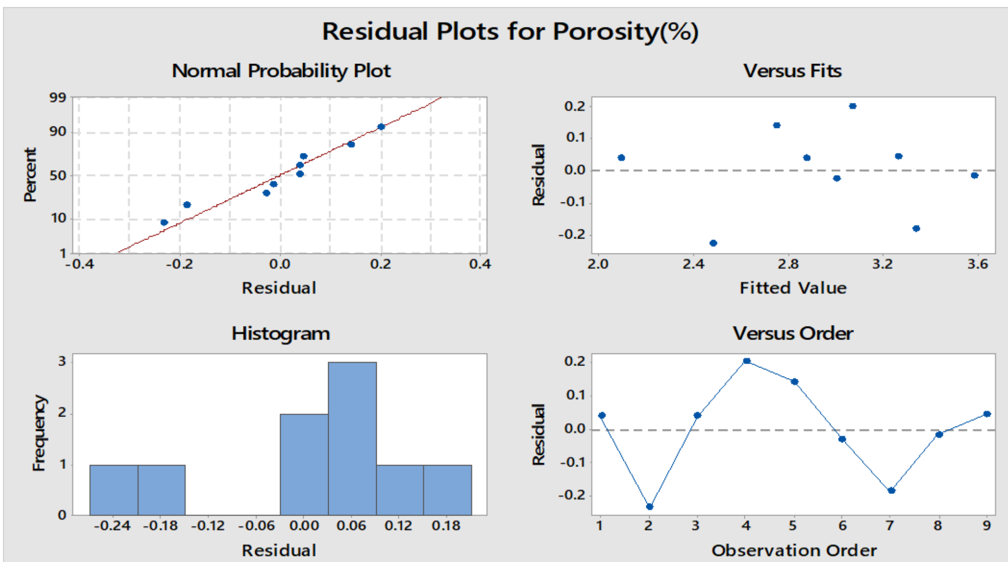


Figure 4.7. The residual-plots of the S/Ns ratio for porosity.

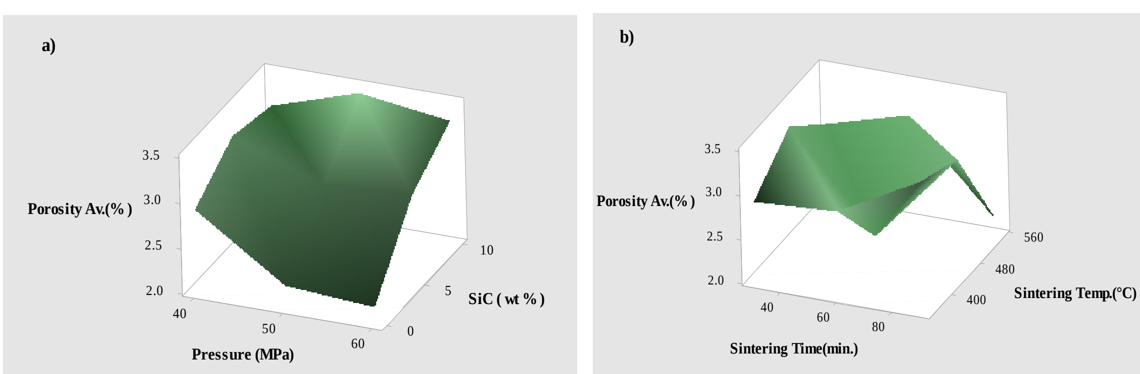


Figure 4.8. The surface-plotting for porosity w.r.t SiC, compaction pressure (a), and w.r.t sintering temperature and sintering duration (b).

4.2. Hardness test

The Vickers hardness test was used to measure hardness of the AlMg-matrix alloy and AlMg/SiC composite. The load was applied smoothly, without impact, forcing the indenter into the test piece, as shown in chapter three, figure 3.10.

4.2.1 Taguchi analysis of signal to noise (S/NL) ratios for hardness test

Hardness of the matrix and composite material was investigated based on the L9 Taguchi experimental design, that is shown in chapter three (table 3.4). Upon the three signal-to-noise ratios "the bigger, the better", characteristics was chosen to reach the maximum value of products hardness using Eq. (3.3), Since, high hardness value is required (example in wear resistance application areas). For each sample three readings were taken at different locations (shown at Appendix table A-I) and the experimental average results of the matrix and composite hardness-response with its corresponding (S/N_L) ratio is shown in table 4.12.

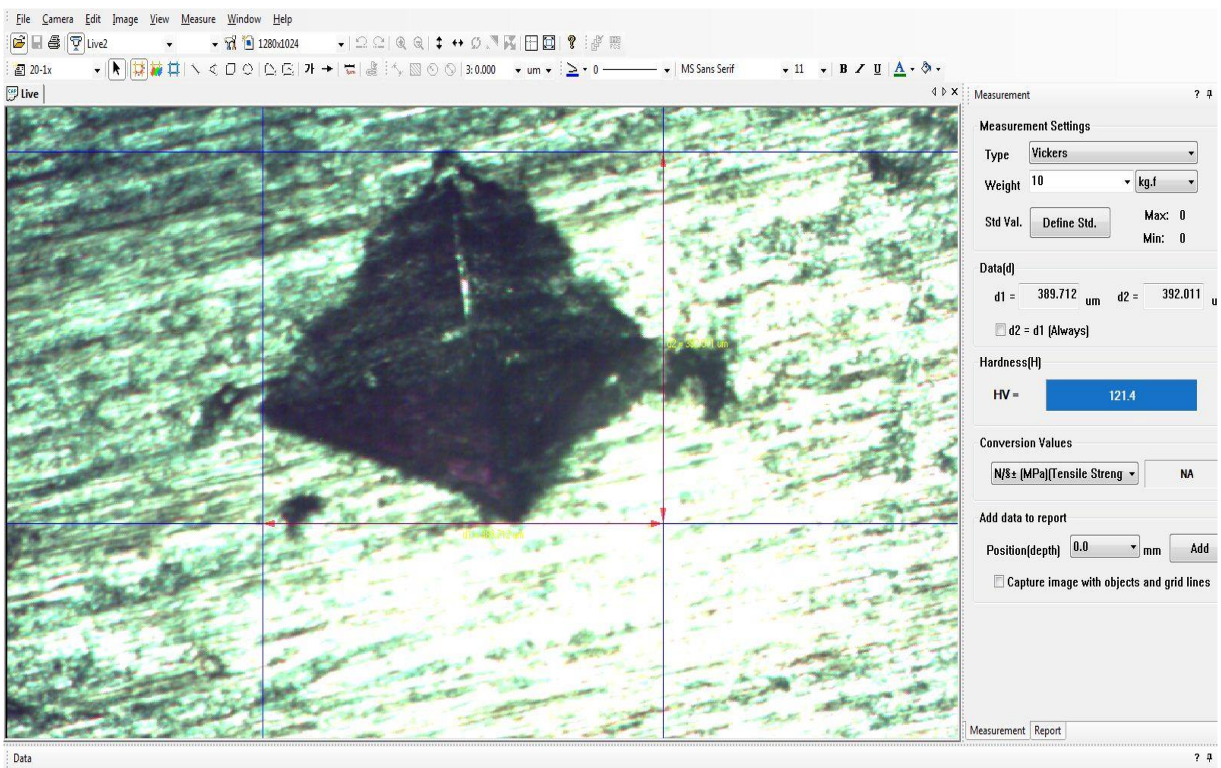


Figure 4.9. Vickers hardness value trial-1, for AlMg-SiC composite.

Table 4.12. The vickers hardness experimental results and their corresponding (S/NL) ratio based on L9 Taguchi design.

Experiments Samples No	Experimental result Hardness average value (HV)	Predicted S/N_L ratio result
S_1	60.467	35.6303
S_2	64.367	36.1732
S_3	67.533	36.5904
S_4	77.467	37.7823
S_5	90.167	39.1009
S_6	94.5	39.5086
S_7	109.733	41.6193
S_8	104.933	40.4183
S_9	106.633	40.5579

4.2.2 Optimization of the PM process variables' influence on hardness value

The signal-to-noise (S/N_L) ratio helps for knowing the variables that have an effect on the acquired result. The S/N_L ratio designed rank for each factor leverage accordance with their significances, as shown in table 4.13.

Table 4.13. The signal-to-noise ratios responses for hardness test (HV) versus SiC and processing variables with S/NL "bigger is better" product qualification.

Level	SiC(wt%)	Compaction pressure (MPa)	Sintering temperature (°C)	Sintering time (min)
1	36.13	38.07	38.52	38.43
2	38.80	38.56	38.17	38.83
3	40.59	38.89	38.83	38.26
Delta	4.46	0.81	0.66	0.57
Rank	1	2	3	4

From table 4.13, the S/N_L ratio rank of the hardness response result shows that the SiC weight percentage is the greatest significant factor on the composite hardness following to it, the compaction pressure, sintering temperature and sintering time have effect on the composite hardness increment.

4.2.3 The optimal prediction conditions for hardness test

The optimum prediction condition for the S/N_L ratio in which, the higher hardness result of the composite obtain with the terms setting in table 4.14 was 41.6193. As shown in table 4.14, the significant effect on hardness of the AlMg composite sample was achieved at level-$A_3B_1C_3D_2$, at the parameter settings in chapter three, table 3.5.

Table 4.14. The optimum conditions for hardness result prediction-settings

SiC(wt%)	Compaction pressure (MPa)	Sintering temp.(°C)	Sintering time (Min)
10	40	550	60

The predicted-values

S/Ns ratio	Mean
41.6193	116.733

4.2.4 The S/N_L ratio appraisal performance model coefficient for hardness test

Table 4.15. The processing variables significant on hardness test.

Term	Effect	COEF	SE COEF	T-Value	P-Value
Constant		44.0	15.1	2.91	0.044
SiC(wt%)	8.596	4.298	0.424	10.13	0.001
Compaction pressure (MPa)	0.700	0.350	0.212	1.65	0.174
Sintering Temp. (°C)	0.0251	0.0126	0.0212	0.59	0.586
Sintering time (Min)	-0.0815	-0.0407	0.0707	-0.58	0.595

4.2.5 The hardness test model summary

The hardness test model of summary discloses that the statistics-data is excellently agreed with an investigate inquiry. The coefficient and correlation-coefficient model expected of the S/N_L ratio for hardness test is shown in table 4.16 and table 4.17. The R-square value for hardness test is 96.37%.

Table 4.16. The hardness test correlation-coefficient.

S	R-sq	R-sq(adj)	R-sq(pred)
5.19519	96.37%	92.73%	81.76%

Table 4.17. Analysis of variance of factorial regression for hardness test.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	PC (%)
Model	4	2862.56	715.64	26.51	0.004	
Linear	4	2862.56	715.64	26.51	0.004	
SiC(wt%)	1	2770.63	2770.63	102.65	0.001	93.27 %
Compaction pressure (MPa)	1	73.50	73.50	2.72	0.174	2.47 %
Sintering Temp. (°C)	1	9.46	9.46	0.35	0.586	0.32%
Sintering time (Min)	1	8.96	8.96	0.33	0.595	0.3%
Error	4	107.96	26.99			
Total	8	2970.52				

The last column of the ANOVA table shown in table 4.17, it indicates the percentage contribution (PC) in which SiC wt% has the highest level of contribution (93.27%), since the P-value of SiC is 0.001≤ 0.05. Following to the SiC, the compaction pressure (2.47%), sintering temperature (0.32%) and sintering time (0.3%) has less level of contribution.

From figure 4.10, it is observed that with an increase in weight percentage (wt%) of silicon carbide addition into the matrix, the (a) mean of signal to noise S/N_L ratio and (b) mean of mean for hardness test is increased. One reason for the increment of hardness with increasing in weight percentage of silicon carbide is because the density of silicon carbide is 16.51% greater than density of AlMg matrix alloy. The higher hardness value (109.733HV) of the AlMg/SiC composite was obtained based on the L9 Taguchi experimental design as shown in chapter three (table 3.5) for sample7 (S_7); the optimal condition is pledge to a level of $A_3B_1C_3D_2$. But, based on figure 4.10 of the (a)mean of signal to noise ratio and (b) mean of mean for hardness test; to attain the highest hardness value (132.63HV) of AlMg/SiC composite; the optimum condition for hardness test is pledge to $A_3B_2C_3D_2$ level.

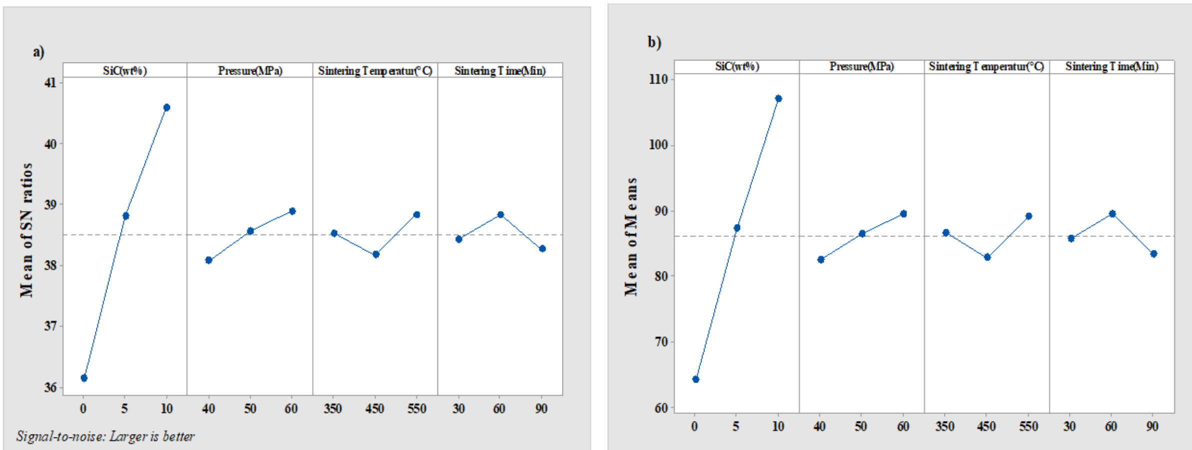


Figure 4.10. Plot for a) mean of signal to noise (S/NL) ratios and b) mean of mean for hardness test with respect to SiC, Compaction Pressure, Sintering Temperature and time.

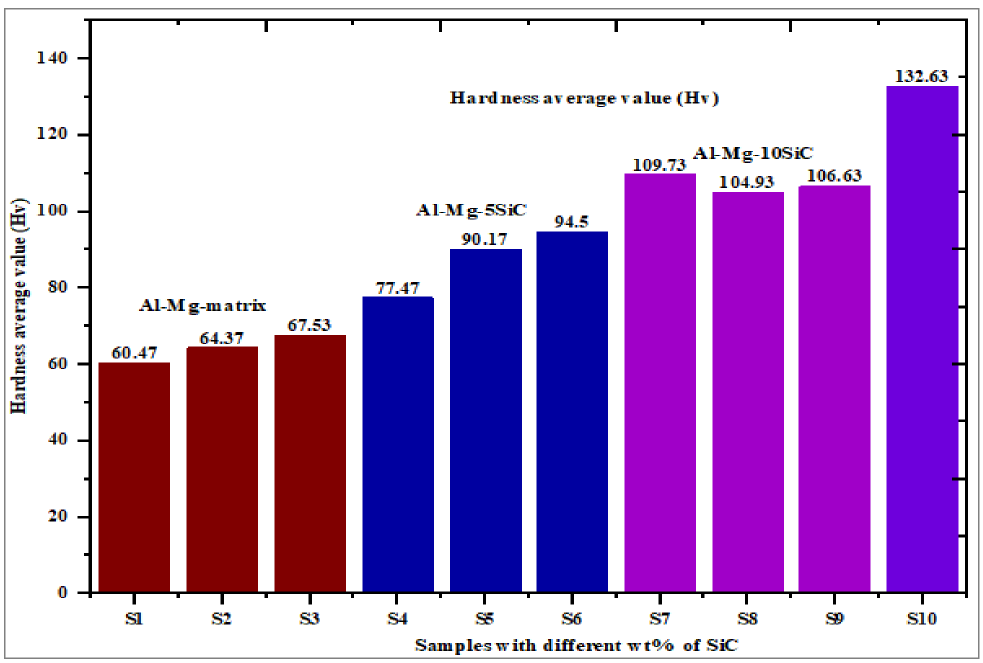


Figure 4.11. Hardness average value (HV) for both AlMg-matrix and AlMg/SiC composite.

From figure 4.11, the average hardness value of AlMg-matrix alloy is observed to be 60.47HV to 67.53HV. When 5wt% of SiC is added to the AlMg-matrix alloy the hardness is increased in 21.9-28.5% (i.e., 77.47-94.5HV) and addition of 10wt% of SiC is increased the hardness by 38.5-42.4% (i.e., 104.93-132.63Hv). The silicon carbide reinforcement into Al-based matrix composites had proved that increase in strength, hardness and wear resistance, ***Sijo et al. (2016)*** and ***Ravikumar et al.*** (2018).

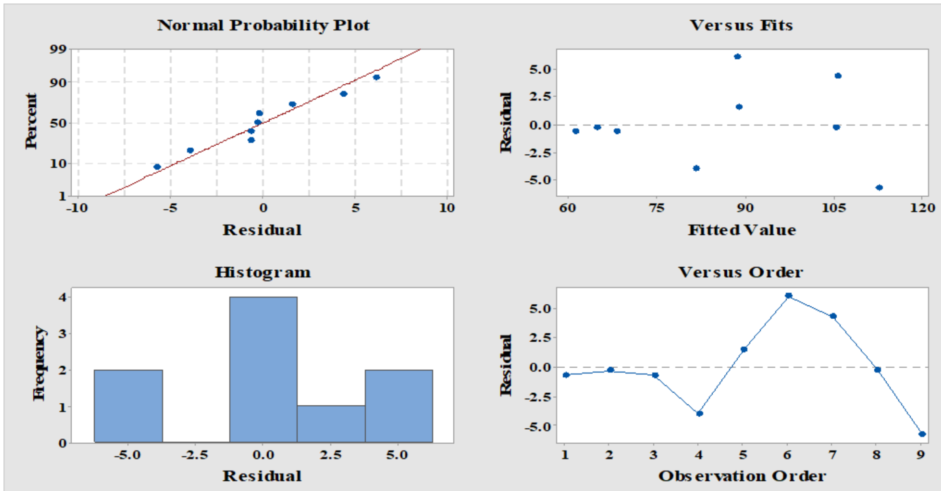


Figure 4.12. Residual plots of the S/NL ratios for hardness test (Hv).

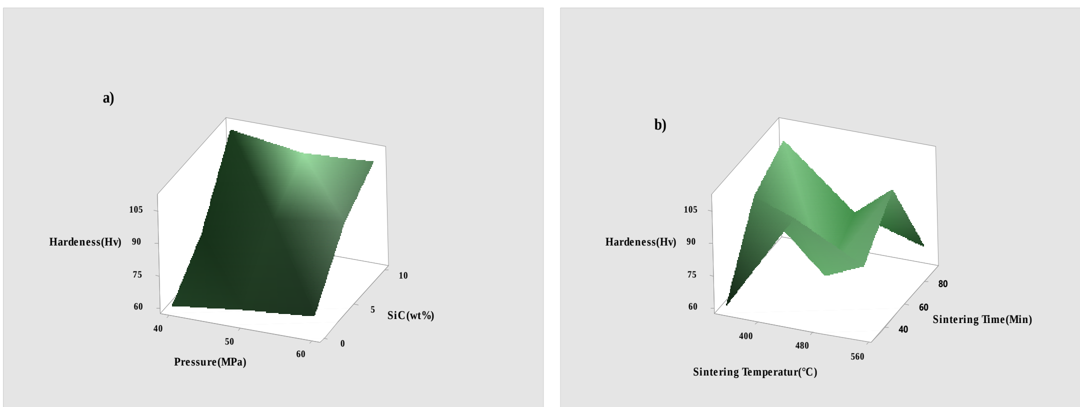


Figure 4.13 (a). Surface plots for hardness (Hv) with respect to weight % of SiC, compaction pressure) and (b) hardness value (Hv) with respect to sintering temperature and time.

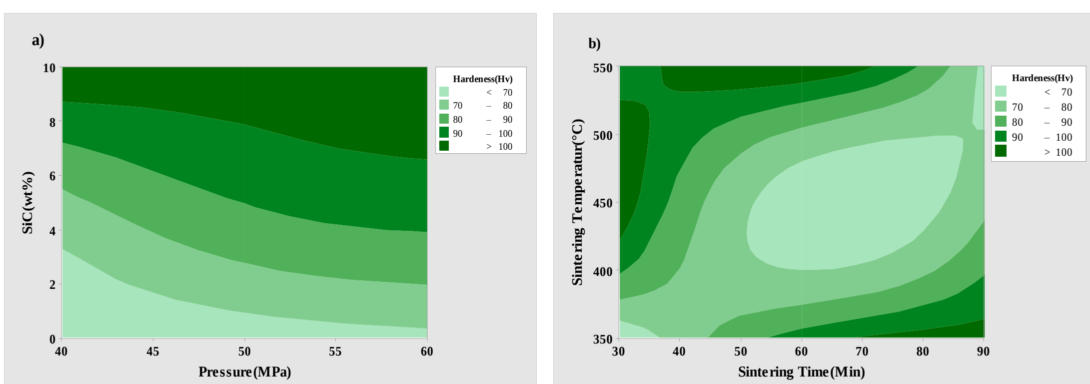


Figure 4.14 (a). Contour plots for hardness value (Hv) with respect to SiC wt% and compaction pressure, (b) with respect to sintering temperature and sintering time.

Figure 4.12, figure 4.13 and figure 4.14 are showing the residual, surface and contour plots of hardness test with respect to weight percentage of SiC, and compaction pressure, sintering temperature and sintering time respectively.

From figure 4.14 (a) and (b), hardness value of the matrix and composite materials are increased, with addition of SiC reinforcement is added to the AlMg-alloy matrix. The basic powder metallurgy process parameters (compaction pressure, sintering temperature and sintering time), also have a great contribution in the increment of the matrix and composite's hardness.

4.3 Compression test

The compression test was done using universal testing machine for knowing the capacity of the AlMg-matrix and AlMg-SiC composite to withstand loads tending to reduce size or fracture of the specimens occur with applied load of ten kilonewton force (10KNf).

4.3.1 Taguchi analysis of signal to noise ratios for compression test

Compression strength of the matrix and composite material was investigated based on the L9 Taguchi experimental run design, that shown in chapter three (table 3.5). Upon the three signal-to-noise ratios "the bigger, the better" characteristics was chosen to determine compression strength of the products, since high compression strength value is required (example in structural application areas). The experimental results for compression strength of the AlMg-matrix samples **(S_1, S_2, S_3)** and AlMg/SiC composites (S_4**,** **S_5, S_6, S_7, S_8, S_9**) with their corresponding signal to noise (S/N_L) ratio are shown in table 4.18.

Table 4.18. The compression strength experimental results and their corresponding (S/NL) ratio based on L9 Taguchi design.

Experiments Samples No	Experimental result	Predicted S/N_L ratio result
	Compression strength value (MPa)	
S_1	299.59	49.5305
S_2	304.41	49.6692
S_3	313.32	49.9198
S_4	323.15	50.1881
S_5	327.26	50.2979
S_6	332.14	50.4264
S_7	350.37	50.8905
S_8	345.42	50.7669
S_9	339.96	50.6286

4.3.2 Optimization of the PM process parameters effect for compression strength

The signal-to-noise (S/N_L) ratio helps for knowing the variables that have an effect on the acquired result. The S/N_L ratio designed rank for each factor leverage accordance with their significances, as shown in table 4.19.

Table 4.19. The signal-to-noise ratios responses for compression test versus processing variables with S/NL "larger is better" product qualification.

Level	SiC(wt%)	Compaction pressure (MPa)	Sintering temperature (°C)	Sintering time (min)
1	49.71	50.20	50.24	50.15
2	50.30	50.24	50.16	50.33
3	50.76	50.32	50.37	50.29
Delta	1.06	0.12	0.21	0.18
Rank	1	4	2	3

Table 4.20. The mean of mean responses for compression test versus processing variables with S/NL "larger is better" product qualification.

Level	SiC(wt%)	Comp. pressure (MPa)	Sintering temperature (°C)	Sintering time (min)
1	305.8	324.4	325.7	322.3
2	327.5	325.7	322.5	329.0
3	345.3	328.5	330.3	327.3
Delta	39.5	4.1	7.8	6.7
Rank	1	4	2	3

From both table 4.19 and table 4.20, the S/N_L ratio and mean rank of the compression strength response result shows that the SiC weight percentage is the greatest significant factor on the composite strength increment following to it, the sintering temperature, sintering time and compaction pressure, have contribution for strengthening the AlMg composite materials.

4.3.3 The optimal prediction conditions for compression test

The optimum prediction condition of the predicted-values for the S/N_L ratio and mean of mean in which, the higher compression strength result of the composite obtain with the terms setting in table 4.21 is 50.8905 and 352.783 respectively, the significant effect on compression strength of the AlMg composite sample was achieved at level ($A_3B_3C_3D_2$), at the parameter settings in table 5.21.

Table 4.21. The optimum conditions for compression strength result prediction-settings

SiC(wt%)	Compaction pressure (MPa)	Sintering temp.(°C)	Sintering time (Min)
10	60	550	60

The predicted-values	
S/Ns Ratio	Mean
50.8905	352.783

4.3.4 The S/N_L ratio appraisal model coefficient for compression test

Table 4.22. The processing variables significant on compression test.

Term	Effect	COEF	SE COEF	T-Value	P-Value
Constant		326.18	1.71	191.06	0.000
SiC(wt%)	39.48	19.74	2.09	9.44	0.001
Compaction pressure (MPa)	4.10	2.05	2.09	0.98	0.382
Sintering Temp. (°C)	4.60	2.30	2.09	1.10	0.333
Sintering time (Min)	5.03	2.51	2.09	1.20	0.296

4.3.5 The compression test model summary

The compression test model of summary discloses that the statistics-data is excellently agreed with an investigate inquiry. The coefficient and correlation-coefficient model expected of the S/N_L ratio for compression test is shown in table 4.23 and table 4.24. The R-square value for compression test is 95.86%.

Table 4.23. The hardness test correlation-coefficient.

S	R-sq	R-sq(adj)	R-sq(pred)
5.12161	95.86%	91.73%	80.39%

T Table 4.24. Analysis of variance (ANOVA) of factorial regression for compression test.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	PC (%)
Model	4	2432.51	608.13	23.18	0.005	
Linear	4	2432.51	608.13	23.18	0.005	
SiC(wt%)	1	2337.61	2337.61	89.12	0.001	92.13 %
Compaction pressure (MPa)	1	25.26	25.26	0.96	0.382	1%
Sintering Temp. (°C)	1	31.74	31.74	1.21	0.333	1.25%
Sintering time (Min)	1	37.90	37.90	1.44	0.296	1.5%
Error	4	104.92	26.23			
Total	8	2537.43				

The last column of the ANOVA table shown in table 4.24, it indicates the percentage contribution (PC) in which SiC wt% has the highest level of contribution (92.13%), since the P-value of SiC is 0.001≤ 0.05. Following to the SiC, the sintering time (1.5%), sintering temperature (1.25%) and compaction pressure (1%) has less level of contribution on compression strength value.

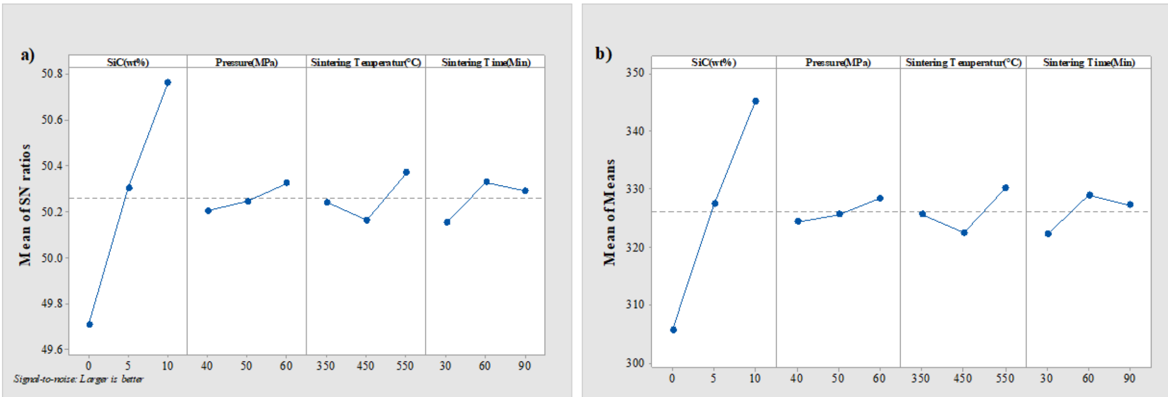


Figure 4.15. Plot for a) mean of signal to noise (S/NL) ratios and b) mean of mean for compression strength test with respect to SiC, Compaction pressure, sintering temp. and time.

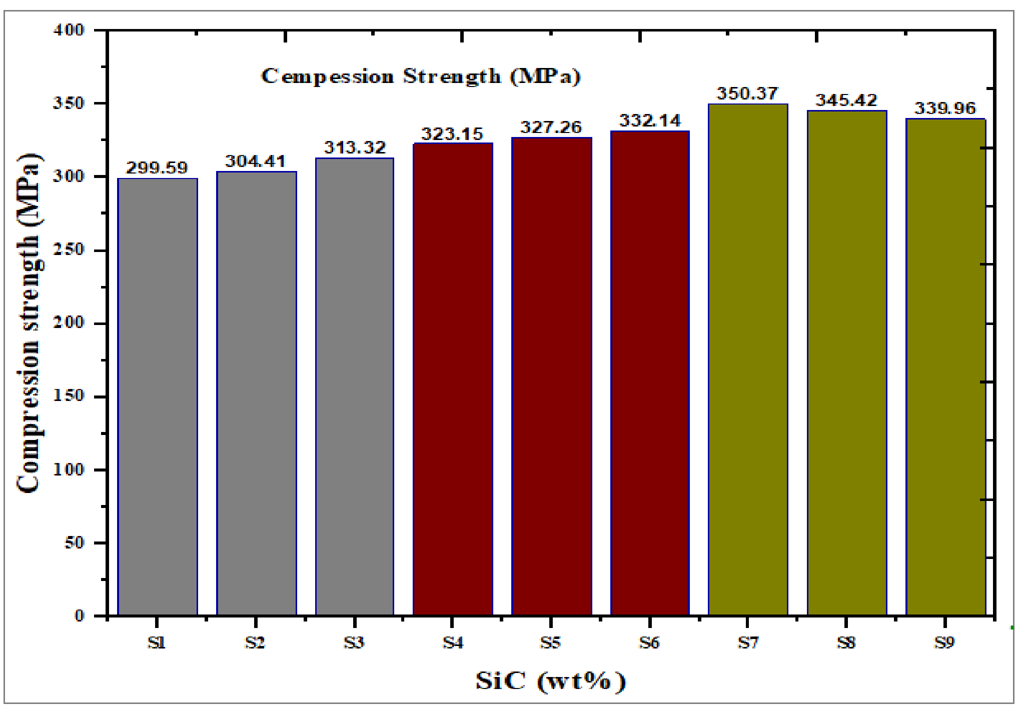


Figure 4.16. Compression strength value (MPa) for both AlMg-matrix (S1, S2.S3) and AlMg/SiC composite (S4-S9).

From figure 4.15, it is observed that with an increase in weight percentage (wt%) of silicon carbide addition into the AlMg-matrix, the (a) mean of signal to noise (S/N_L) ratios and (b) mean of mean for compression strength test is increased. The compression strength of the composite is increased, when the hardness of the composite materials increasing. Due to these reasons, the capacity of the AlMg/SiC composite material is greater than that of AlMg-matrix material to withstand compressive loads tending to reduce size. The higher compression strength value (350.37MPa) of the AlMg/SiC composite was obtained at the optimal condition is pledge to $A_3B_3C_3D_2$ level, as shown in chapter three (table 3.5).

From figure 4.16, the compression strength value (MPa) of AlMg-matrix alloy is observed to be 299.59MPa to 313.32MPa. When 5wt% of SiC is added to the AlMg-matrix alloy the compression strength is increased from 299.59 to 332.14MPa and the addition of 10wt% of SiC to AlMg-matrix, the composite compression strength is increased from 299.59 to 350.37MPa.

The following figure 4.17, figure 4.18, and figure 4.19, are showing the residual, surface and contour plots of compression test with respect to weight percentage of SiC, and compaction pressure, sintering temperature and sintering time respectively. Figure 4.17 (a) and (b), shows that, the compression strength value of the matrix and composite materials are increased, with addition of SiC reinforcement is added to the AlMg-alloy matrix, as shown with green color. The basic powder metallurgy process parameters (compaction pressure, sintering temperature and sintering time), also have a great contribution in the increment of strength of the matrix and composite materials, as shown more clearly in figure 4.16.

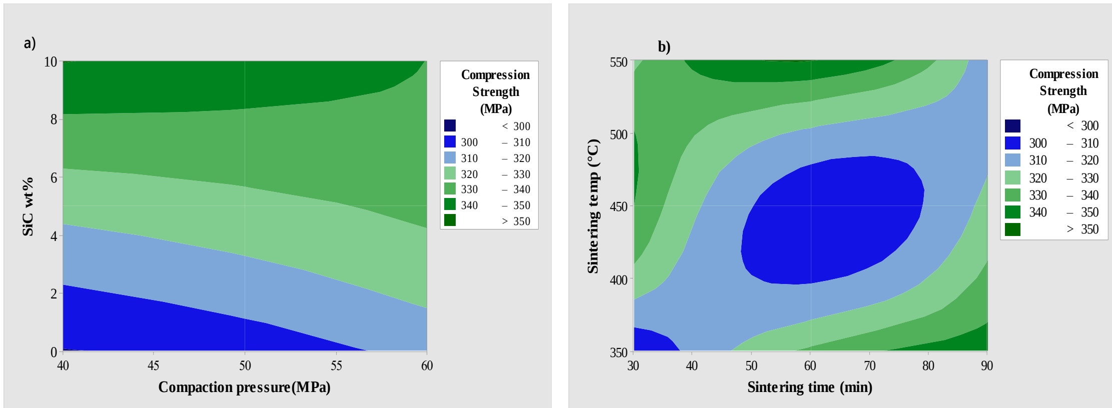


Figure 4.17. Contour plots for compression strength value (MPa); (a) with respect to SiC wt% and compaction pressure, and (b) with respect to sintering temperature and time.

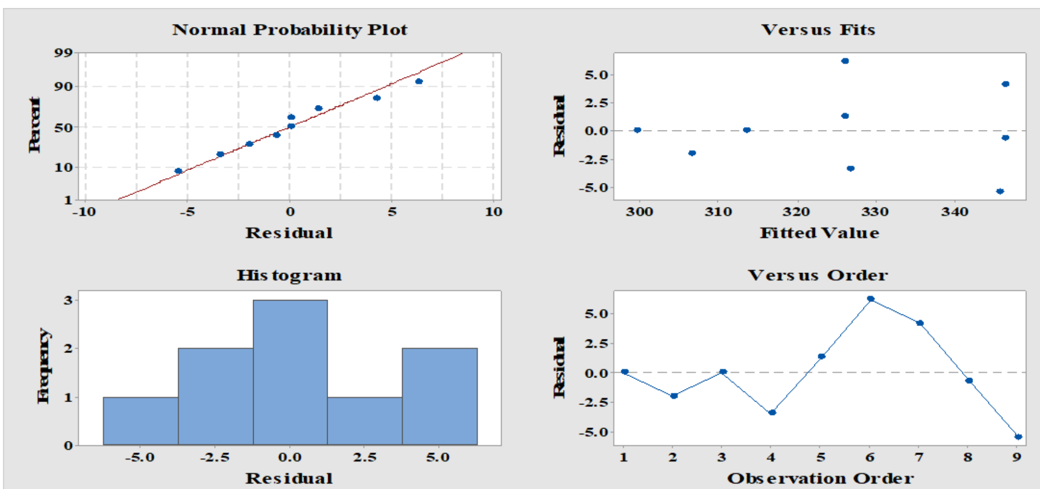


Figure 4.18. Residual plots of the S/NL ratios for compression test.

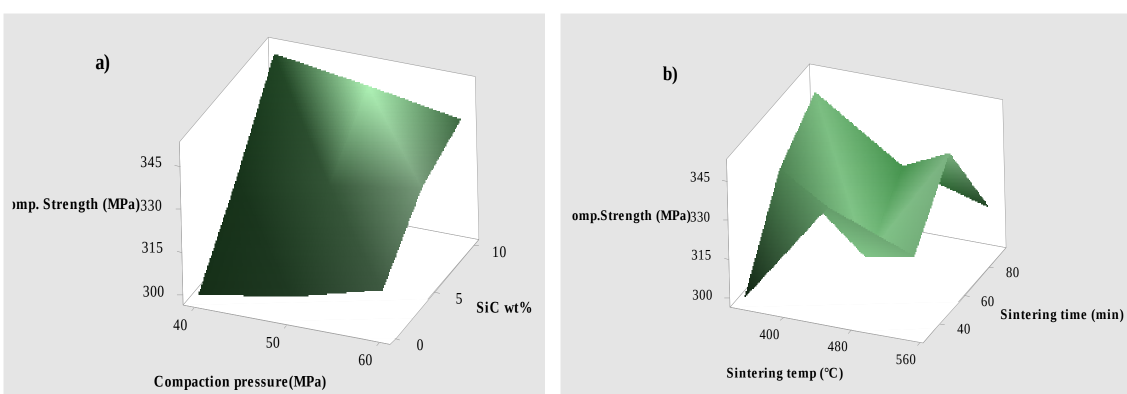


Figure 4.19. Surface plots for compression strength value (MPa); (a) with respect to weight % of SiC, compaction pressure) and (b) with respect to sintering temp. and time.

4.4 The experimental results verification

After an optimum combination of process parameters and addition of SiC wt% had obtained, the predicted result and experimental result was confirmed. The results of validation experiment mean and S/N obtained from the experiment were compared with the predicted mean and S/N results as shown in table 4.25 for actual density and porosity with "small is the better" characteristics, to obtain less porosity and density values. And, for hardness and compression test "the larger is the better" characteristics was chosen to get the hardened and high strength composite with addition of SiC reinforcement in the AlMg-alloy matrix.

Table 4.25. Comparison between predicted and experimental confirmation

Response variables	Level combination	Predicted value		Experimental value
		S/N ratio	Mean	
Actual-density (g/cm^3)	A1B1C1D1 (sample 1)	-7.9588	2.58	2.5
Porosity (%)	A3B3C3D3 (sample 3)	-6.5676	2.1633	2.13
Vickers hardness (HV)	A3B1C3D2 (sample 7)	41.6193	116.733	109.733
Compression strength (MPa)	A3B1C3D3 (Sample 7)	50.8905	352.782	350.37

From table 4.25, the difference between experimental results and the predicted results are very small. The values of predicted by using Taguchi approach is approximately near to the value which is experimentally obtained for actual density and porosity compared to the measured value using Archimedes principle, as mentioned in chapter three. And also, the experimental results of both hardness and compression strength are highly correlated with the predicted results, even there is small increment on the experimental results.

4.5. Microstructure test

The microstructures for both the AlMg-matrix and AlMg/SiCp composites have taken using optical microscope (OM) and scanning electron microscope (SEM). The absolute necessity for examination of specimen arises from the fact that many microscopically observed structural characteristics of a metal such as grain size, segregation, distribution of different phases (example; reinforcement distribution) and mode of occurrence of component phases can be analyzed. As shown in figure 4.20, the uniform distribution of SiC reinforcement into the AlMg-matrix have been observed in the developed AlMg-SiC composite specimen by SEM.

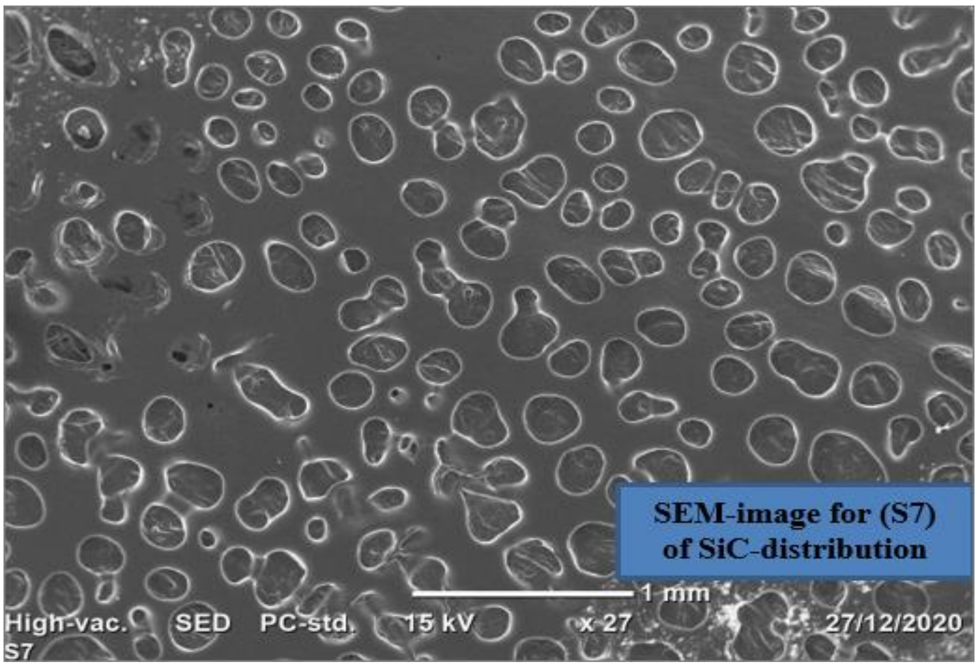


Figure 4.20. The AlMg/SiC composite specimen observed by SEM.

4.5.1 Microstructural image analysis

The microstructural image analysis has done by determination of the grain size area for scaled dimension of each grain particle using “imagej” software. To find the average grain size area, all the particles found in the scaled dimension of specimen area are counted.

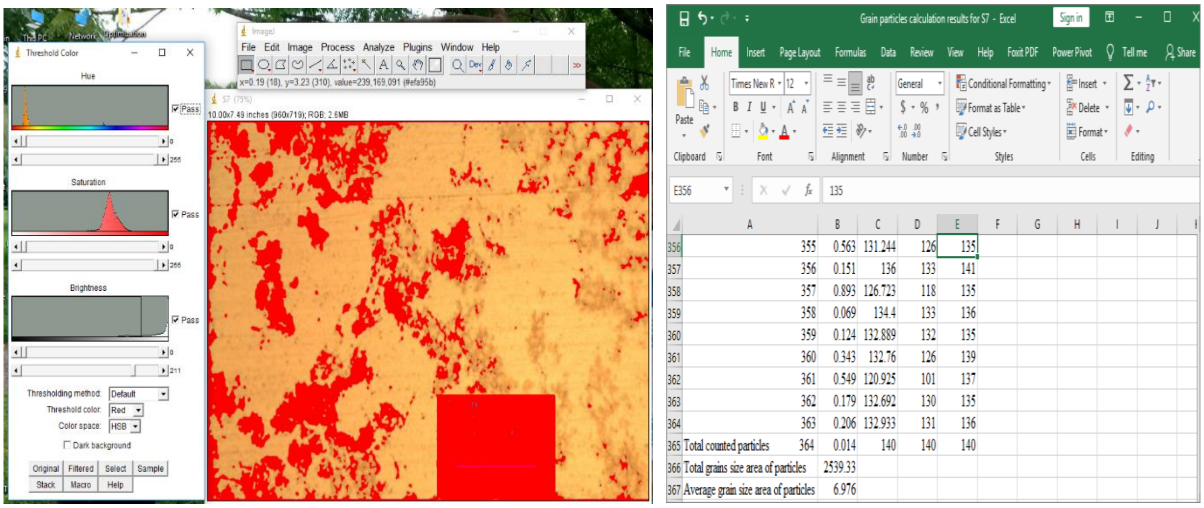


Figure 4.21. Indication of grain size particles to analysis the average grain size area.

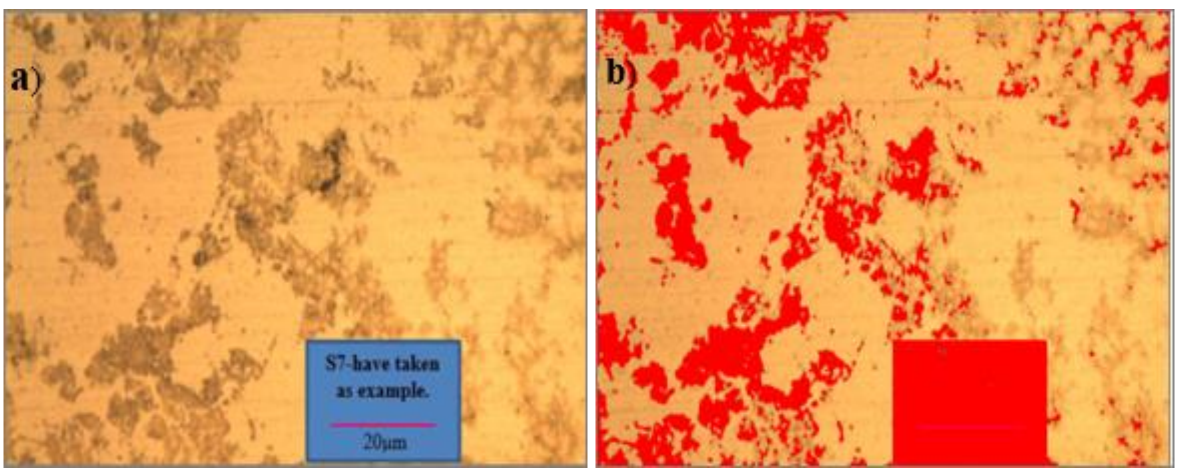


Figure 4.22. The optical micrographs of AlMg/SiC composite (a) before microstructural analysis and (b) after microstructural analysis.

The average grain size area of the microstructural analyzed composite for counted grain size particles and the volume fraction area of the grains size results obtained are shown in table 4.26.

Table 4.26. The grain size area of the counted particles

Sample No.	Total counted particles	Total grain size area (μm^2)	Average grain size area (μm^2)	volume fraction area of the grains size (%)
S_7	364	2539.325	6.976	26.780

From the microstructural analysis, there are two phases indicated by color of red and white, as shown in figure 4.22 (b). The red color indicates that the phase area of the grain size which is

26.780% and the average grain size area of grain particles obtained is 6.976μm^2. This result is better than the previous studies of ***Huskins et al.*** (2010) for Al-Mg alloys, using the linear intercept method by drawn the measurement lines perpendicular to the sub-grain regions.

The microstructure images have been acquired by metallurgical optical microscope (EC Epiplan-NEOFLUAR objective lens of 20X, 50X, and 100X were used with an eyepiece of 10X) for AlMg-matrix samples (S1, S2, S3), AlMg/SiC composite samples having 5% of SiC weight contents (S4, S5, S6) and 10% of SiC weight contents (S7, S8, S9) respectively.

The microscopically observed structural characteristics of the composite samples shows the SiC reinforcement distribution phases with the AlMg-matrix, as shown in figure 4.24, figure 4.25 of OM images. Since the residual mechanical behavior of several Al-Mg alloys is sensitive at high temperature, the initial dislocation cell structure may transform to the subgrains region, so the component occurrences mode of the grain size and lamellar boundary found in the examined microstructure images have not seen perfectly. Less number of irregular shape of pores having smaller in size are found in the specimens' microstructure images, especially in comparison to the number of pores present at the end edge of the specimen. ***Narayan and Rajeshkannan*** (2016) have reported similar findings.

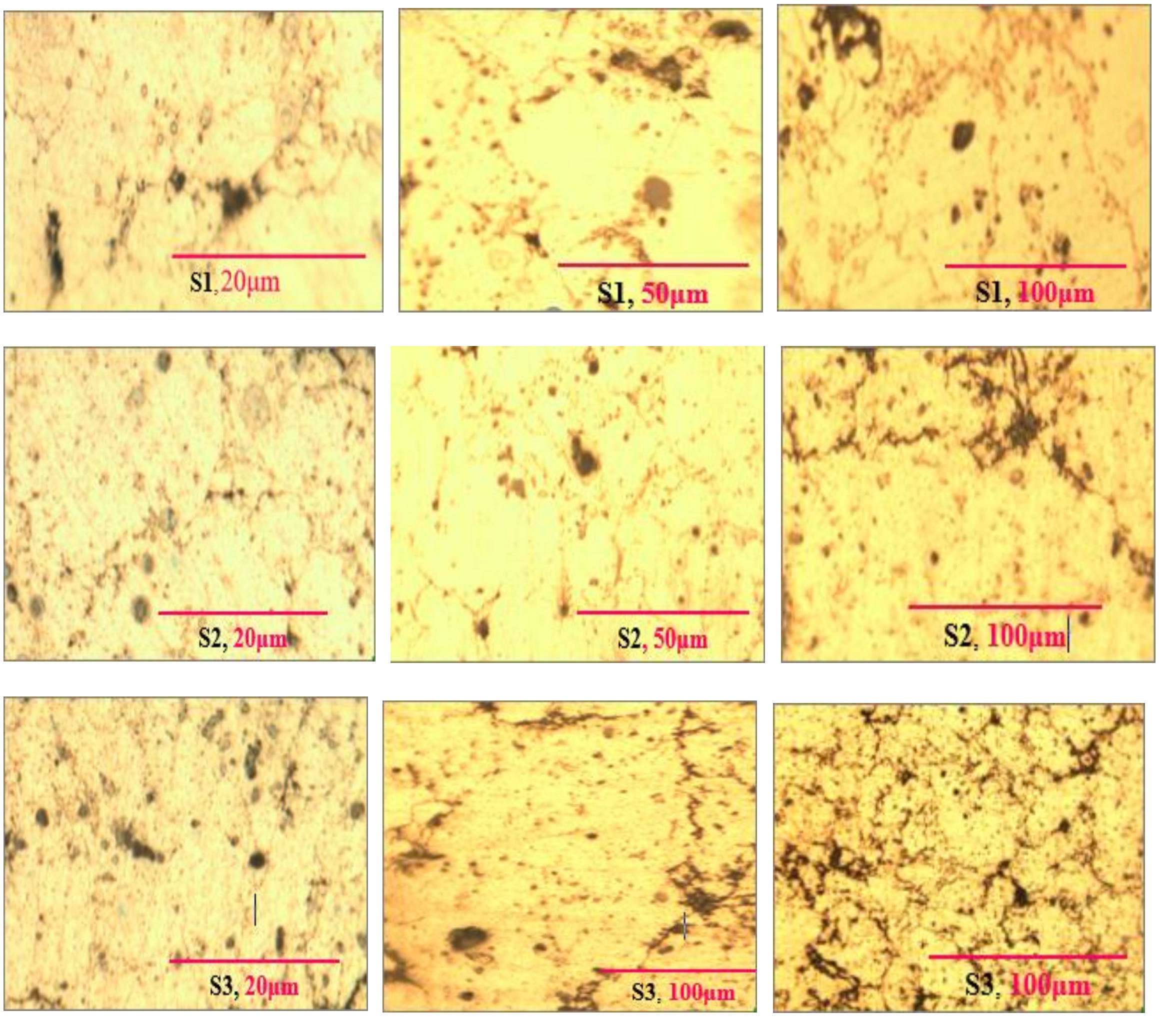
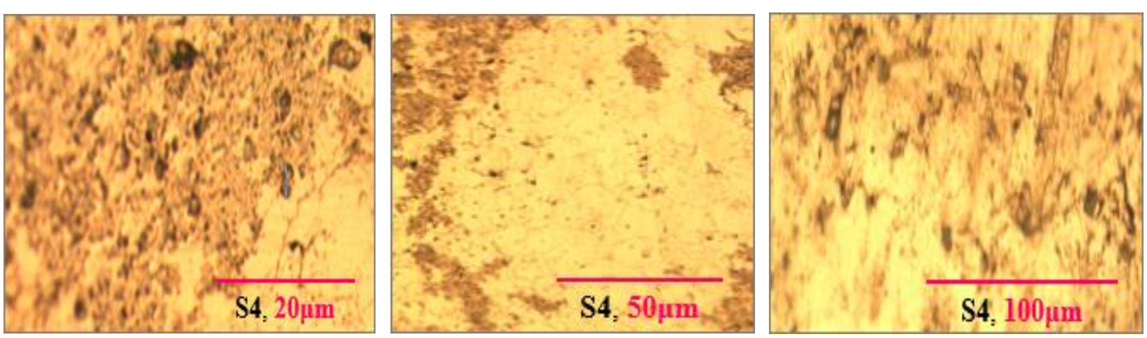


Figure 4.23. AlMg-matrix samples (S1, S2 and S3) optical microstructure.



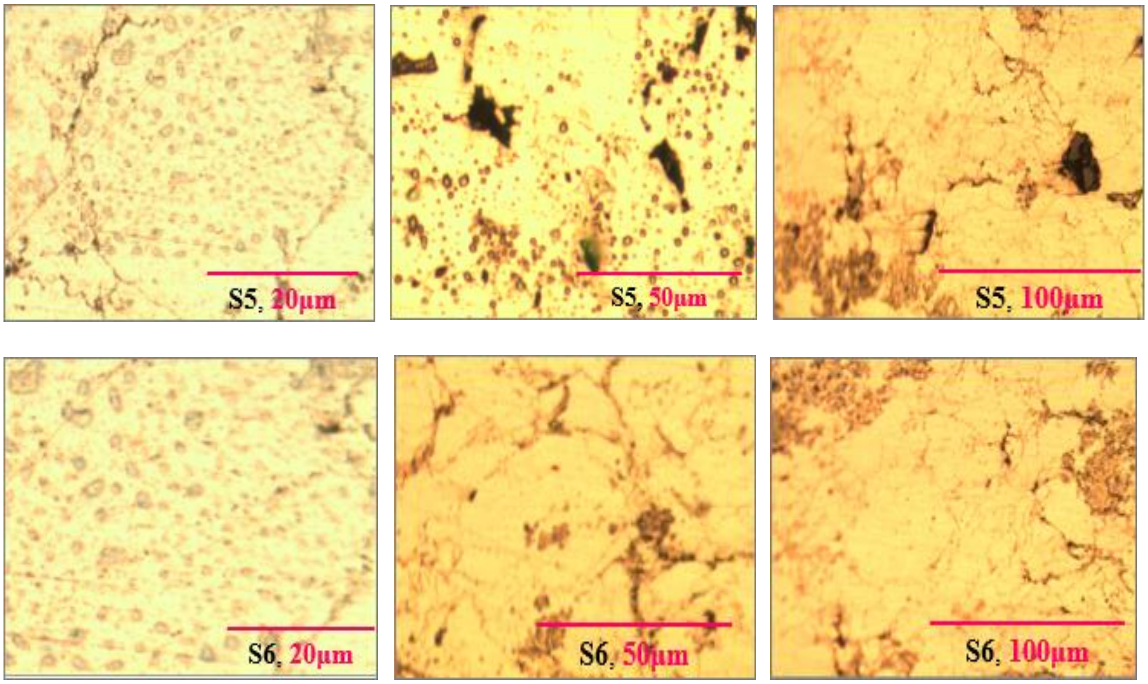


Figure 4.24. AlMg-5SiC samples (S4, S5 and S6) optical microstructure.

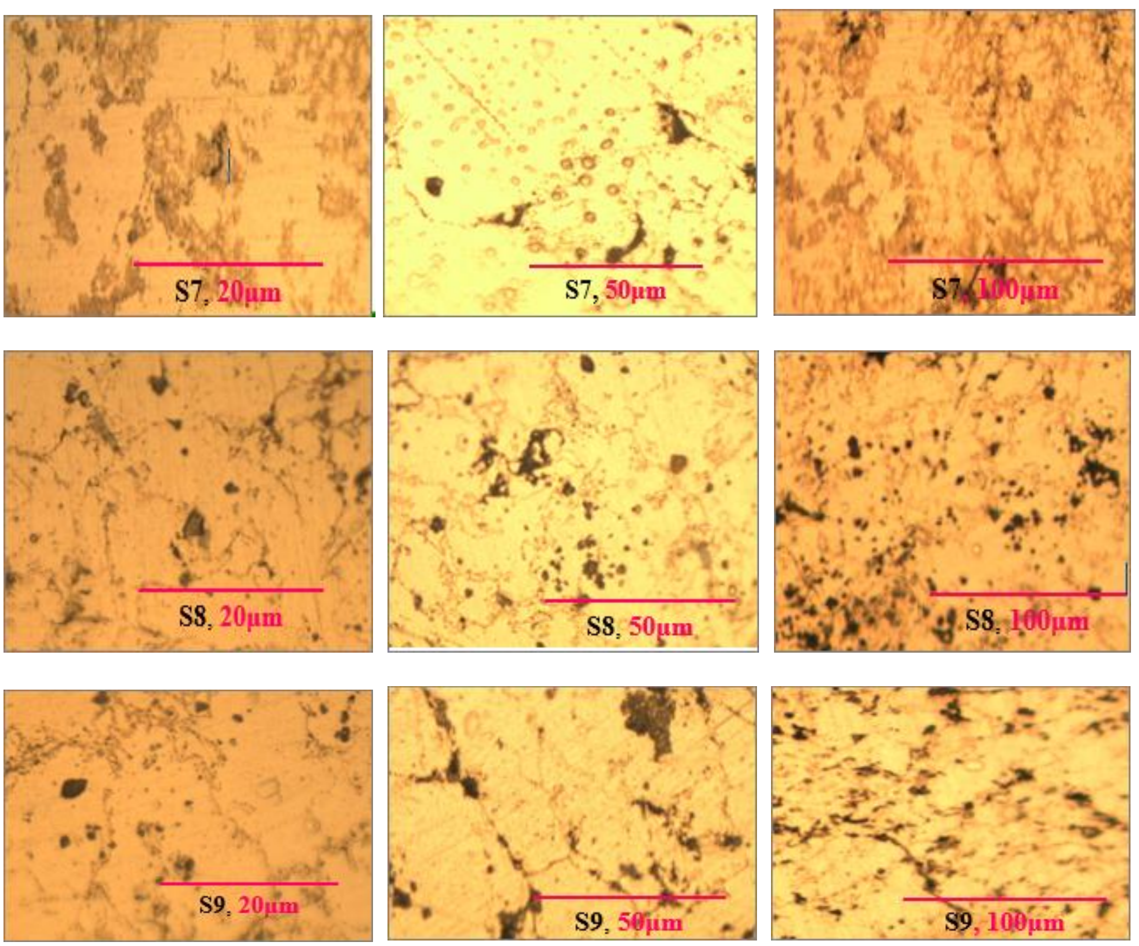


Figure 4.25. AlMg-10SiC samples (S7, S8 and S9) Optical micrographs.

4.6. Wear test

In the wear statistical analysis, the wear rate and friction coefficient are considered as the main response functions for evaluating the wear performance of the AlMg-matrix and AlMg-SiC composites.

4.6.1 Wear behavior of AlMg alloy matrix and AlMg-SiC composite

In this research work, the wear behavior of AlMg-matrix and AlMg/SiC composite materials were investigated using (DUCOM TR-20 MICRO) pin-on-disc equipment. The test was conducted at room temperature under dry sliding condition with the effect of 10, 30, and 50N normal applied load and a sliding speed of 250 rpm on 25mm-wear track diameter for 5-minute running duration. The weight (or mass) loss of each specimens was calculated by measuring the weight difference between the specimens before and after conducting the wear test. The weight loss of each specimens was used to calculate the wear rate using equation (3.11), as mentioned in chapter three). This way can be giving result of wear more accurate from weight techniques ***Alaneme et al***. (2019) and ***Das et al.*** (2020). The specimens weight loss and wear rate results altogether are tabulated in appendix table A-2. But, the results of mass loss (in gram) and Wear rate ($x10^{-8}Kg.m^{-1}$) Versus the applied loads (N) are shown in table 4.27 and table 4.28 respectively.

Table 4.27. Mass loss (loss in weight) Vs load.

Load(N)	**Mass loss (g)**								
	AlMg alloy			**AlMg-5SiC(wt%)**			**AlMg-10SiC(wt%)**		
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
10	0.0019	0.0015	0.0015	0.0012	0.0011	0.001	0.0004	0.0007	0.0005
30	0.0025	0.0023	0.002	0.0018	0.0016	0.0014	0.0005	0.0009	0.0007
50	0.0039	0.0037	0.0032	0.0028	0.0023	0.002	0.001	0.0014	0.0014

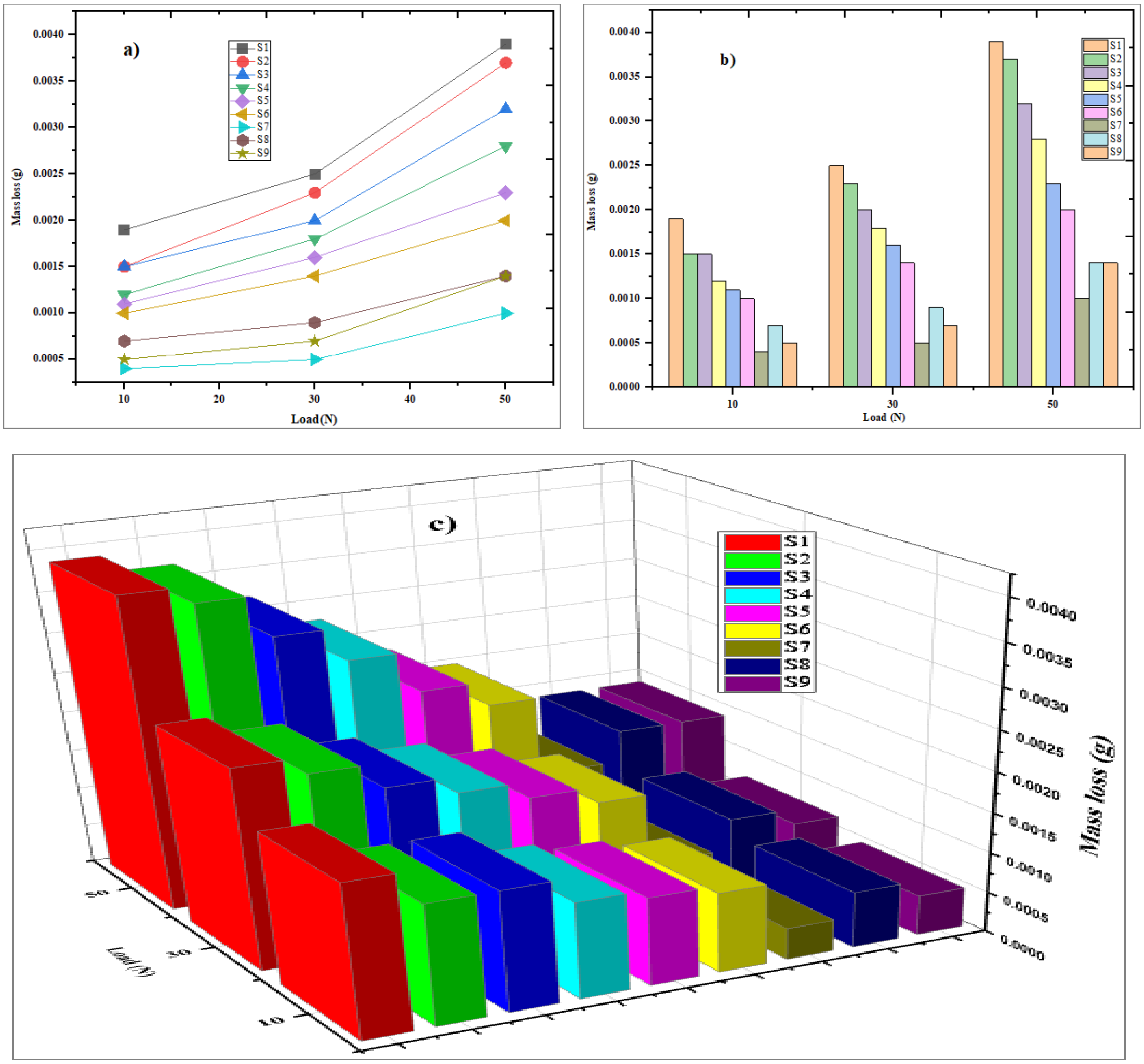


Figure 4.26. Mass loss(g) Vs load(N) for the AlMg-matrix and AlMg/SiC composite; a) in line, b) in bar and c) 3D graph using Origin 18 software.

During dry sliding wear test, the SiC particles strengthen the aluminium-magnesium matrix and also protect the softer matrix. From figure 4.26, high mass loss is observed in AlMg-base alloy (samples; S1, S2 and S3) and minimum mass loss is noticed when the weight percentage of silicon carbide content increases in the composite samples (S4 to S9). The mass loss increases with increasing the applied load in all load conditions, due to increasing temperature at the contact surfaces of the sample pin and disc at higher loads as shown clearly in figure 4.26 (a) and (c) 3D graph using 'Origin 18' software and the minimum weight loss have been seen for 10wt.% of SiC composites at the applied load of 10N for three samples (S7, S8 and

S9). This is similar to the previous work of *Lim et al.* (2003), who claimed that the wear resistance of composites had slight improvement at the lower load. ***Alpas et al.*** (1992) also reported that the wear rate of the SiCp/A356 Al matrix composite was lower than that of the alloy at lower load.

Table 4.28. Wear rate Vs load.

Load(N)	Wear rate ($x10^{-8}Kg.m^{-1}$)								
	AlMg alloy			AlMg-5SiC(wt%)			AlMg-10SiC(wt%)		
	S1	S2	S3	S4	S5	S6	S7	S8	S9
10	1.936	1.528	1.528	1.223	1.121	1.019	0.408	0.713	0.51
30	2.548	2.344	2.031	1.834	1.631	1.427	0.51	0.917	0.713
50	3.974	3.771	3.261	2.853	2.344	2.038	1.019	1.427	1.426

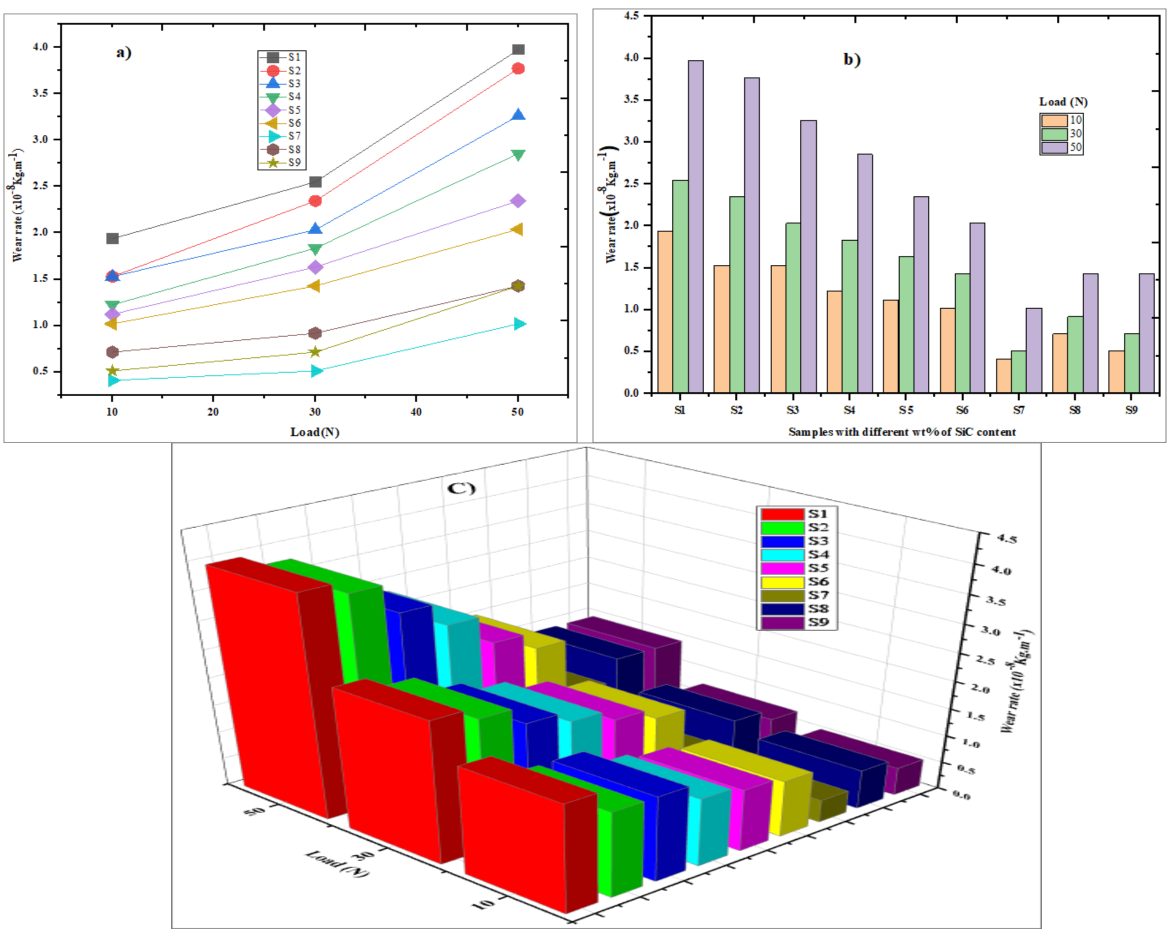


Figure 4.27 (a). Wear rate (x10-8Kg.m-1) Vs load(N) for the AlMg and AlMg/SiC; (b) Wear rate (x10-8Kg.m-1) Vs effect of weight percentage of SiC and (c) Wear rate (x10-8Kg.m-1) Vs load(N) in 3D graph using ‘Origin 18’ software.

The wear rate (W.R) variation for different wt % of SiC is presented in table 4.28. The wear rate of AlMg/SiC composite is lower compared to the AlMg -matrix wear rate. As shown in table 4.28 and in figure 4.27 (a and b), the 10wt % of SiC content composite samples (AlMg-10SiC; S7, S8 and S9) have the lowest wear rate value compared to both the 5wt % of SiC content composite samples (AlMg-5SiC; S4, S5, S6) and AlMg-matrix samples (S1, S2 and S3) at various load applied conditions (10, 30 and 50N) within 250 sliding speed for 300 seconds. The wear rate of the composite is much lower than that of the matrix alloy at the applied load of 10 N, and the wear rate value of the composite is increased slightly, but rapidly increment of wear rate for the AlMg matrix have seen at the applied loads of 30 N and 50 N. But, as shown in figure 4.27, there is an excellent improvement of wear rate with the addition of SiC for all load conditions; which is similar with previous work of ***Ying Yu et al***. (1997), they demonstrated the effects of applied load and temperature on the dry sliding wear behavior of the Al6061/SiC composites, and they concluded that the addition of SiCp could promote the wear resistance of the composite at the lower load.

An unreinforced AlMg matrix was softer than the SiC reinforced composites and due to this reason, the AlMg alloy-matrix undergoes losing of material on the surface which causes the high wear rate of the AlMg matrix samples (S1, S2 and S3), as shown in figure 4.27 (c). The increase in the resistance of wear is expected because SiC is harder in nature and when it reinforced it makes the matrix also harder and restricts to wear. When there is an increase in percentage of SiC, the percentage of particle distribution in the matrix and in the surface also increases thereby, the wear resistance also increases. From table 4.28, Addition of 5wt.% of SiC to the matrix (AlMg/SiC) composite samples (S4, S5 and S6) had less wear rate value (there is a range of 44 to 48.7% decrease in wear rate) when compared with the matrix for all load conditions, but it increases the wear resistance. The wear rate value of AlMg-10%SiC composite samples (S7, S8 and S9) were the lowest (there is a range of 64.12 to 73.7 % decrease in wear rate) compared to the AlMg-matrix samples for all load conditions.

Generally, the wear resistance of the AlMg-5SiC composites were improved with a range of 26.3 to 47.4% for all load conditions, whereas the wear resistance of the AlMg-10SiC composites were improved by the range 47.4 to 78.9% compared to the AlMg matrix alloy. In general, increasing the reinforcement content enhances the wear resistance of composite materials. This is mainly due to the fact that the mechanical properties such as hardness and strength of MMCs increase with increase in the volume fraction of the reinforcements ***Das et al.*** (2008), while the wear rate of the MMCs decreases, and then the wear resistance of MMCs linearly increased. This reveals that the volume fraction of the reinforcement is proportional to the wear resistance of the composite.

4.6.2 Friction coefficient behavior of AlMg-matrix and AlMg/SiC composite

The friction coefficient of the AlMg matrix alloy and AlMg/SiC composite result was recorded during experiment by data procurement system, as shown in figure 4.28, (the COF Vs time recorded results for all the matrix and composite specimens are shown in appendix figures B1-to-B3. The coefficient of friction recorded result during wear test for all applied load condition is shown in table 4.29.

Table 4.29. Coefficient of friction (COF) Vs load.

Applied Loads (N)	Coefficient of friction (COF)								
	AlMg alloy			AlMg-5SiC(wt%)			AlMg-10SiC(wt%)		
	S1	S2	S3	S4	S5	S6	S7	S8	S9
10	0.44	0.4	0.39	0.36	0.32	0.3	0.19	0.25	0.22
30	0.52	0.44	0.43	0.4	0.37	0.36	0.25	0.33	0.32
50	0.71	0.52	0.49	0.44	0.43	0.42	0.33	0.4	0.4

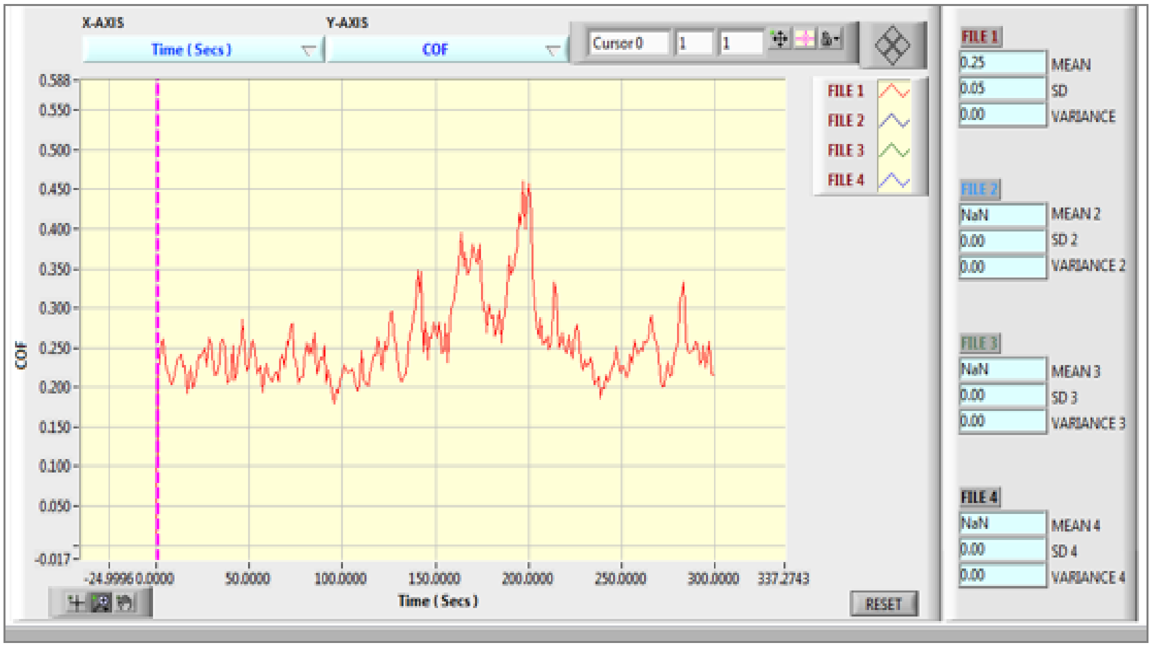


Figure 4.28. Coefficient of friction (COF) Vs time for AlMg-10%SiC composite.

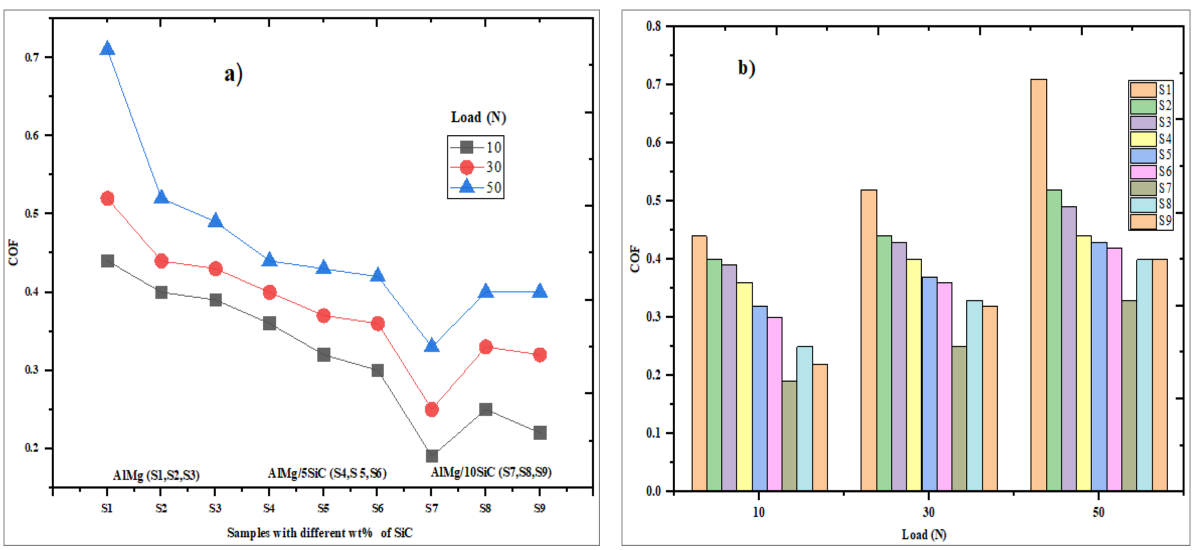


Figure 4.29 (a). Coefficient of friction (COF) Vs effect of wt% of SiC, (b) COF Vs Load(N); for the AlMg-matrix and AlMg/SiC composite

From figure 4.29 (a) and (b), the friction coefficient of the AlMg matrix alloy and AlMg/SiC composites increased with increment of the normal load, that was carried in dry sliding condition of pin-on-disc materials contact. As the applied load increases, there is gradual increase in wear rates and COF for both AlMg matrix and AlMg/SiC composites. The above result was occurred because of the following reason; (a) With increase in load, the contact between sliding surface of specimen and rotating disc surface becomes intimate as time increases resulting in higher wear rates. (b) With increase in load, the temperature at specimen interface increases and leads to softening the materials and plastic flow of materials. However, the wear rate is lower for AlMg/SiC composite compared with AlMg matrix alloy, because of some particles of silicon carbide break into small pieces and crushed the disk rotates and act as abrasive medium. These powdered silicon carbide particles along with AlMg small particles made a layer. These layers prevent the plastic flow and reduce the wear rates compared with AlMg matrix alloy, although plastic flow of composites occurs at later stage. The other reason for the lower wear rate value of AlMg/SiC composites were, they have higher hardness value compared to the AlMg-matrix resulting in lower real area of contact.

4.6.3 Morphological characterization of the wear surfaces

The wear surfaces of the AlMg matrix and AlMg/SiC composite specimens are analyzed under scanning electron microscope (SEM) with different magnifcation as shown in the folloeing scanning electron micrographs. From the wear surface analyses, different damage mechanisms are observed on the worn surfaces. From figure 4.30, 4.31 and 4.32 of the SEM images, it can be observed and concluded that the wear occurs mainly due to abrasive wear, delamination, oxidation and fatigue wear mechanisms. In these wear mechanisms, as shown below in the SEM images, damages such as wear debris, surface scratches, plastic deformation, worn surface, surface crack and such damages are observed.

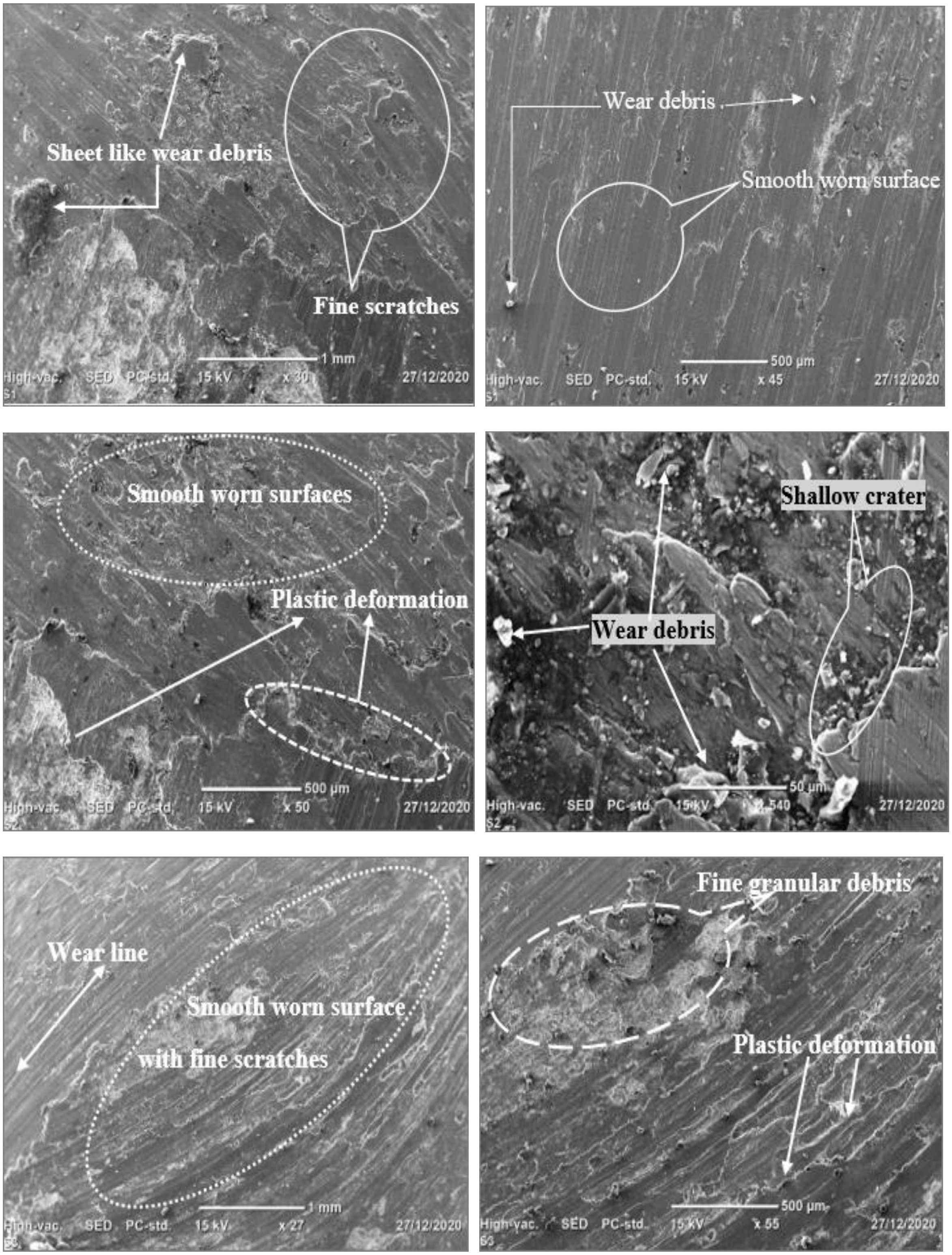


Figure 4.30. Scanning electron micrograph of worn surfaces of AlMg alloy samples (S1, S2 and S3) with different magnification using SEM.

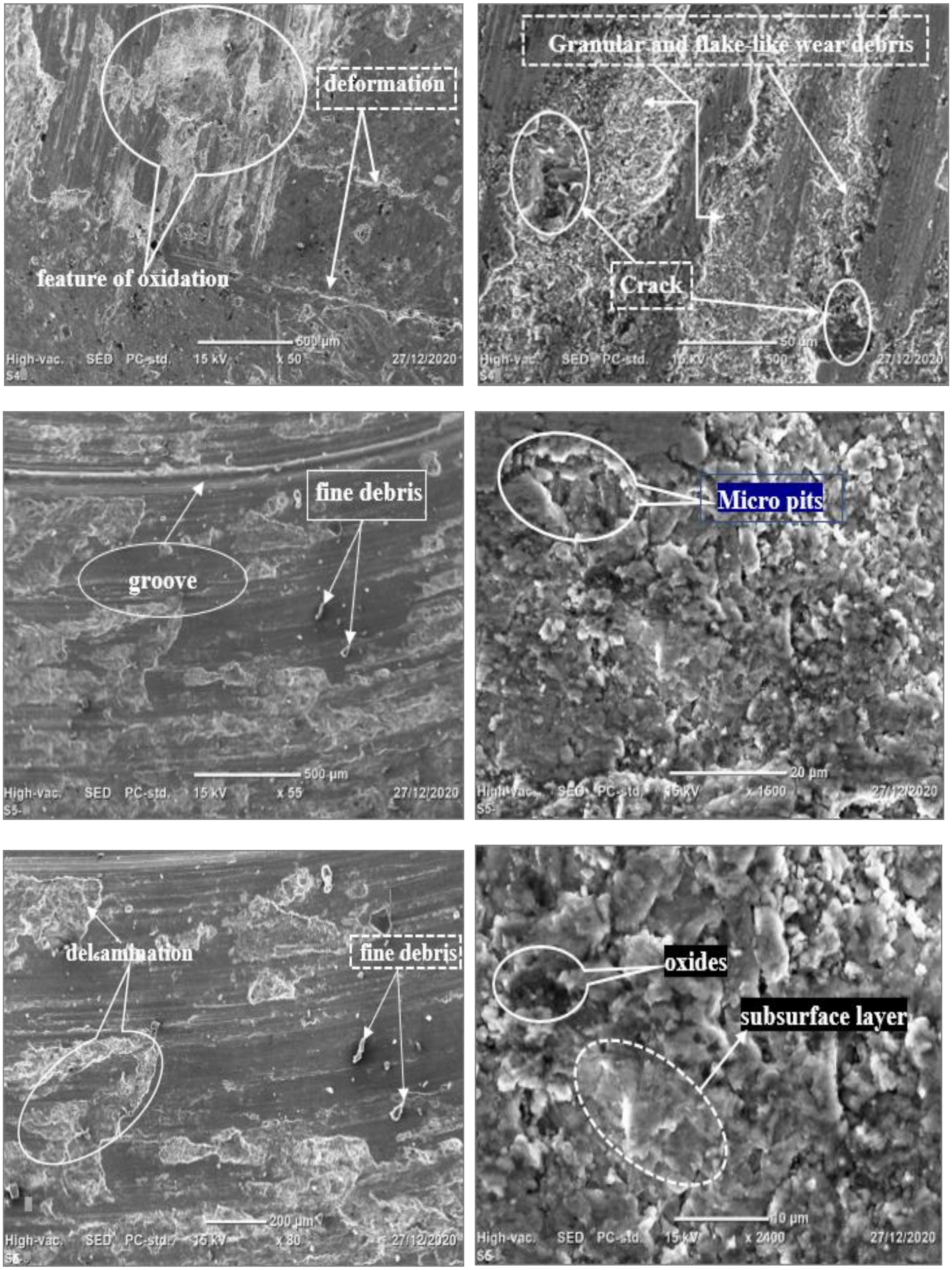


Figure 4.31. Scanning electron micrograph of worn surfaces of AlMg-5% SiC composite samples (S4, S5 and S6) with different magnification using SEM.

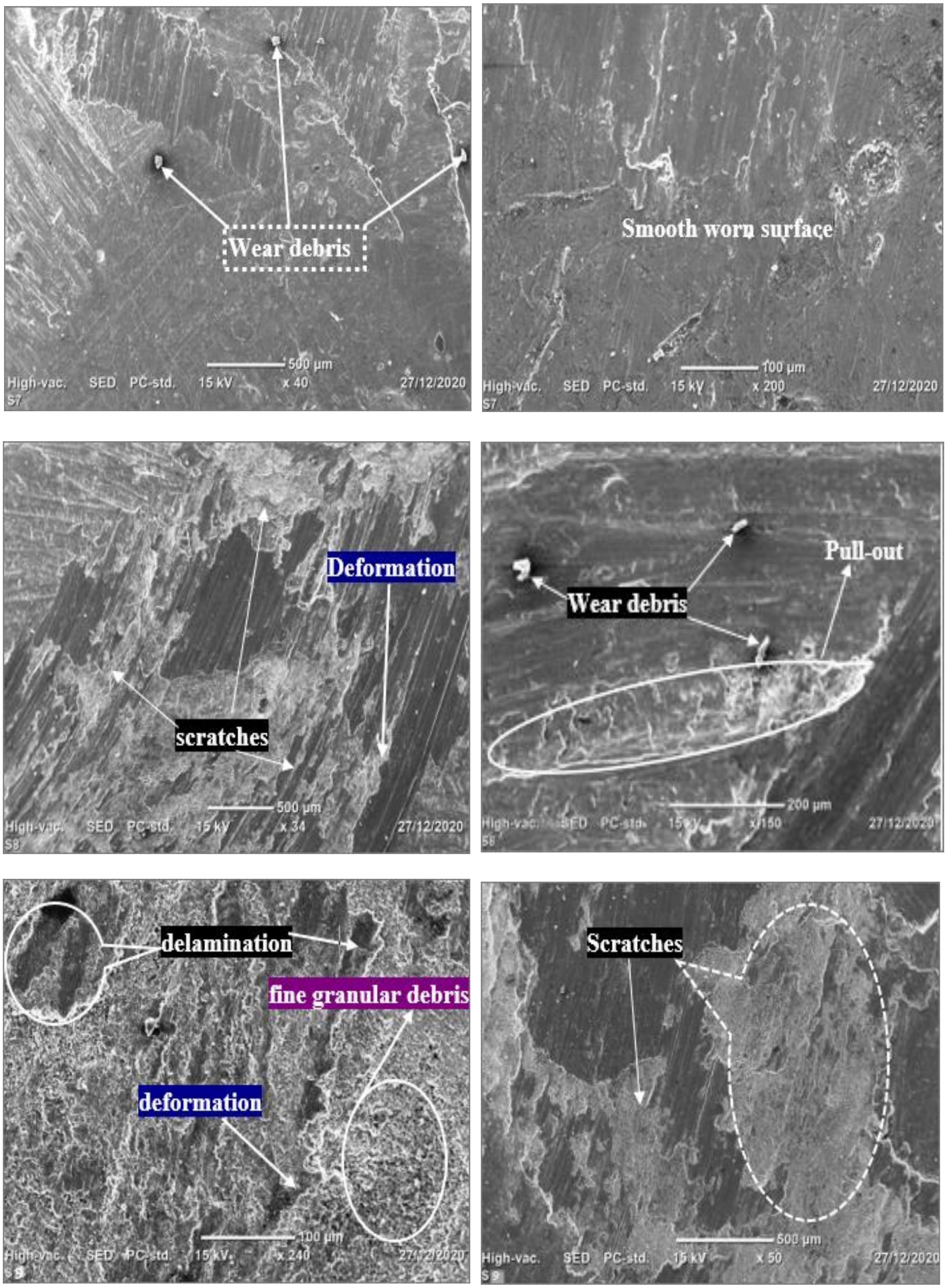


Figure 4.32. Scanning electron micrograph of worn surfaces of AlMg-10% SiC composite samples (S7, S8 and S9) with different magnification using SEM.

An unreinforced AlMg matrix alloy was softer than the SiC reinforced composites and due to this the AlMg-matrix alloy undergoes losing of material on the surface which causes the high wear rate of matrix samples (S1, S2 and S3), shown in figure 4.30. As sliding continues, wear is developing, considerable wear debris may enter into the materials pin–disc contact. The presence of debris between the contact surfaces somewhat enhances the surface roughness; this result was occurred due to the grain particles tend to pull-out from the specimen pin-on-disc contact surfaces during dry sliding condition. As the sliding continues further, for all load increment conditions, the pin temperature at specimen interface increases and leads to softening the materials, plastic flow of materials and phase transformation may occur and results plastically deformation of the pin-specimen due to the applied load during the dry sliding condition within the disc rotation duration, all of which are influence the friction behavior of the matrix and composites. From the SEM images, an oxide layer and fine granular debris were formed, that is may due to the increment of SiC, which reveals that formation of transfer layer increases as the wt% of SiC increase in the AlMg-SiC composites, this transfer layer improves the wear resistance of the composite materials, this is similar with the ***Yang et al.*** (2015) studies, they concluded that, the wear-loss decreases with increase in weight percentage of SiC reinforcement in the MMCs. ***Van et al.*** (1999) reported that the Al-Mg alloy exposed up to 400°C in an air circulation furnace formed surface oxide layer. The main problems related to the properties of Al that is high thermal conductivity, high chemical reactivity with oxygen at high temperature as studied by ***Beck et al.*** (1967). An oxidation features were formed due to the temperature increment during dry sliding wear test condition and reactive properties of Al and Mg metals at high temperature.

CONCLUSIONS AND RECOMENDATION

5.1 Conclusion

The experimental study reveals the following conclusions:

Porosity of the AlMg-matrix and composites has been decreased with increasing of the compaction pressure, sintering temperature, and sintering time, whereas, when the wt% addition of SiC increases in the AlMg-matrix, the actual-density and porosity of the composites were slightly increased, but hardness and compression strength of the composites were increased. The higher hardness (132.63HV) and compression strength (350.37MPa) value for the composite was obtained, with addition of 10% of SiC into the matrix. While, the composite hardness increasing, the wear resistance of the composite also increased. The wear rate increases linearly with the increase in normal load. However, the AlMg/SiC composites have a lower wear rate as compared to that observed in the AlMg-matrix, under dry sliding conditions. The reason for lower wear rate of the AlMg/SiC composites were due to their high hardness as compared to the AlMg-matrix result. The wear resistance of the AlMg-5SiC composites were improved with a range of 26.3 to 47.4% for all load conditions, whereas the wear resistance of the AlMg-10SiC composites were improved by the range 47.4 to 78.9% compared to the AlMg matrix alloy. The SEM studies showed that the silicon carbides distribution in the AlMg-matrix were homogeneous.

5.2 Recommendation

The use of powder metallurgy technique is increasingly applied in preparing AlMg components with the correct variables especially in compaction and sintering process. The brilliant result associated with near net shape production of these processes that is of most interest, which could lead to the wider acceptance of the PM AlMg alloy and ceramics reinforced composite components; due to the significant improvement in hardness, strength and wear resistance performances of these PM AlMg composite components. But, the addition of silicon carbide caused the formation of pores. So, to reduce or prevent such porosity and for further increment of the mechanical and wear properties of the PM AlMg composite components; it is recommended for the future researchers to perform forging or extrusion operation depending up on the application area requirement of these component.

Acknowledgement

This research project is funded by Adama science and Technology University under the grant number ASTU/SM-R/135/19, Adama, Ethiopia.

References

[1] Alpas, A.T., Zhang, J., (1992). Wear rate transitions in cast aluminum-silicon alloys reinforced with SiC particles. *Scr. Metall. Mater. 26*, 505–509.

[2] Alpas, A.T.; Zhang, J., (1992). Effect of SiC particulate reinforcement on the dry sliding wear of aluminum silicon alloys (A356). *155,* 83–104.

[3] Amal, E., Nassar, Eman, E. (2017). Journal of King Saud University-Engineering Sciences 29 295-29.

[4] AMIRNEJAD, M., RAJABI, A., MOTAVALLI. (2018). "Effect of addition of Si on microstructure, mechanical properties, bio-corrosion and cytotoxicity of Mg−6Al−1Zn alloy" Trans. Nonferrous Met. Soc. China 28, 1755−1762.

[5] Anil Kumar Bodukuri, Eswaraiah, K., Katla Rajendar, V.Sampath, Perspect. (2016). Sci. 8 428 431.

[6] Baradeswaran, A., & Perumal, A. E. (2013). Influence of B4C on the tribological and mechanical properties of Al 7075–B4C composites. *Composites Part B: Engineering*, *54*, 146-152.

[7] Basavarajappa S., Chandramohan G., Davim JP., (2007). Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites. Materials & Design.; 28:1393-8.

[8] Beiss, P., Dalal, K., Peters R., (2002). International atlas of powder metallurgical structures. Princeton (NJ): Metal Powder Industries Federation.

[9] Bharath, V., Nagaral M., Auradi V., and Kori, S. A., (2014). Preparation of 6061Al-Al2O3 MMC's by Stir Casting and Evaluation of Mechanical and Wear Properties Procedia Mater. Sci. 6 1658–67.

[10] Bozic, D., Dimcic, B., Stasic, J,, Rajkovic, V., (2010).Influence of SiC particles distribution on mechanical properties and fracture of DRA alloys. Materials & Design; 31:134-41.

[11] Burke, P., Petit, C., Yakoubi, S., Kipouros, G.J., (2011). Thermal Effects of Calcium and Yttrium Additions on the Sintering of Magnesium Powder, in: Magnesium Technology, John Wiley & Sons, Inc., 2011, pp. 481-484.

[12] Burke, P., Kipouros, G. J., Fancelli, D., and Laverdiere, V., (2009). Sintering fundamentals of Mg powders, Can. Metall. Q 48, 123–132.

[13] Canakci, A., Erdemir, F., Varol, T., Patir, A., (2013). Determining the effect of process parameters on particle size in mechanical milling using the Taguchi method: measurement and analysis. Measurement 46 (9), 3532–3540.

[14] Cerri, E., Leo, P., De Marco, P.P., (2007). Material Process. Technol., 189, 97-106.

[15] Cheng Su-ling, Yang Gen-cang, Zhu Man, Wang Jin-cheng, Zhou Yao-he, (2010). Mechanical properties and fracture mechanisms of aluminum matrix composites reinforced by Al9(Co, Ni)2 intermetallics, Trans. Nonferrous Met. Soc. China 20, 572-576.

[16] Das, S., (2008). Synergic effect of reinforcement and heat treatment on the two-body abrasive wear of an Al–Si alloy under varying loads and abrasive sizes. 264:47–59.
[17] Das,S., Madheshiya, A., Gautam,S.S., Gautam, C.R., (2020). Mechanical, Suraface morphological and multi objective optimization of tribological properties of V2O5 doped lead calcium titanate borosilicate glass ceramics, Ceram. Int. 46, 19170–19180.
[18] Ding, Z., Fan, Y., Qi, H., Ren D., Guo, J., (2009). Study on the SiCp. /Al-Alloy composite automotive brake rotors. Acta Metallurgical Sinica (English Letters); 13:974-80.
[19] Dinwoodie, J., (1987). "Automotive applications for MMCs based on short staple alumina fibers". SAE Technical Paper Series, Int Con Exp. Detroit, MI, February, pp. 23-27.
[20] Ehsan Ghasali, Masoud Alizadeh, Touradj Ebadzadeh, Amir hossein Pakseresht, Ali Rahbari, Mater, J., (2015). Technol. 4(4) 411-415.
[21] Elsayed, A., Umeda, J., and Kondoh, K., (2011). The texture and anisotropy of hot extruded Mg alloys fabricated via rapid solidification powder metallurgy, Mater. Des. 32, 4590–4597.
[22] Emee Marina Salleha, Sivakumar Ramakrishnana and Zuhailawati Hussaina. (4-6 August 2015) "Synthesis of Biodegradable Mg-Zn Alloy by Mechanical Alloying: Effect of Milling Time" 5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP),
[23] Fogagnolo, J.B., Robert, M.H., Torralba, J.M., (2006). Mater. Sci. Eng., A, 426 ,85-94.
[24] Ghosh, S., Sahoo, P., Sutradhar G., (2012). Wear behaviour of Al-SiCp metal matrix composites and optimization using taguchi method and grey relational analysis. Journal of Minerals and Materials Characterization and Engineering. 11:1085-94.
[25] González, S., P. Pérez, Garcés, G., and Adeva, P., (2016). Influence of the processing route on the mechanical properties at high temperatures of Mg-Ni-Y-RE alloys containing LPSO-phases, Mater. Sci. Eng. A 673, 266–279.
[26] Govindan and Viji, B., (2017). Design and Analysis of Automobile Brake Disc by Using Al/SiC MMC. *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 6, Issue3.
[27] Hemath Kumar G. (2010). The abrasive wear behaviour of Al-SiCp composites for automotive parts: Frontiers in automobile and mechanical engineering. Chennai, India.
[28] Huang, SJ., Jeng, YR., Semenov V., Dai YZ., (2011). Particle size effects of silicon carbide on wear behavior of SiCp-reinforced magnesium matrix composites. Tribology Letters. 42:79-87.
[29] Huskins, E.L., Cao, B., and Ramesh, K.T., (2010). "Strengthening Mechanisms in an Al-Mg Alloy," *Materials Science and Engineering: A*, 527, 1292–1298. 23.
[30] Hussain, M.Z., Khan, S., Gaur, A., Shuaib, M., (2017). Optimum yield parameters of MWCNT/MnO2 nanocomposite. Int. J. Adv. Res. Innovation 5 (2), 279–282.

[31] Hussain, M.Z., Khan, S., Nagarajan, R., Khan, U., Vats, V., (2016). Fabrication and micro hardness analysis of MWCNT/MnO2 nanocomposite. J. Mater.

[32] Hussain, M.Z., Khan, U., Chanda, A.K., Jangid, R., (2017). Fabrication and hardness analysis of F-MWCNTs reinforced aluminium nanocomposite. Procedia Eng.173, 1611–1618.

[33] Hussain, M.Z., Khan, U., Jangid, R., Khan, S., (2018). Hardness and wear analysis of Cu/Al2O3 composite for application in EDM electrode. IOP Conference Series: Materials Science and Engineering (Vol. 310, No. 1, p. 012044). IOP Publishing.

[34] Jesús Noé Rivera Olvera, G.J. Gutiérrez Paredes, Antonio Romero Serrano, E. Rivera López, E. Martínez Franco, P. Tamayo Meza, L. Díaz Barriga Arceo. (2015). “Synthesis and characterization of a MoWC-WC-NiC composite via mechanical alloying and sintering” Powder Technology 271, 292–300.

[35] Jingkun Li, Xueping Ren, Yanling Zhang, Hongliang Hou., (2020). Silicon carbide hot pressing sintered by magnesium additive: - microstructure and sintering mechanism, JMATERRESTECHNOL, 9(1):520 529.

[36] John Wiley & Sons, Montgomery DC. (2008). Design and analysis of experiments.

[37] Alaneme, K.K., Fajemisin, V.A., Maledi, V.N., (2019). Original Development of aluminum-based composites reinforced with steel and graphite particles: structural, mechanical and wear characterization, J. Mater. Process. Technol. 8, 670–682.

[38] Kanthavel, K., Sumesh, K.R., Saravanakumar, P., (2016). Alexandria Engineering Journal, 55, 13-17.

[39] Kala, H., Mer, K. K. S., & Kumar, S. (2014). A Review on Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites. Procedia Materials Science, 6, 1951-1960.

[40] Kalaiselvan, N. Murugan, Siva Parameswaran. (2011). Production and characterization of AA6061–B4C stir cast composite, Materials and Design 32, 4004–4009.

[41] Karvanis, K., Fasnakis, D., Maropoulos, A., & Papanikolaou, S., (November, 2016). Production and mechanical properties of Al-SiC metal matrix composites. In *IOP Conference Series: Materials Science and Engineering* (Vol. 161, No. 1, p. 012070). IOP Publishing.

[42] Kocazac, M.J., Khatri, S.C., Allison, J.E., Bader, M.G. (1993). “MMCs, for ground vehicle, aerospace and industrial applications”. In: Suresh et al. (Eds), Fundamentals of Metal Matrix Composites. Butterworth, Guildford, UK, pp.297.

[43] Kok, M., (2005). “Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites”. J Mater Process Technol 161, 381-387.

[44] Kumar A., Shyam Lal, Sudhir Kumar, (2013). Fabrication and characterization of A359/Al2O3 metal matrix composite using electromagnetic stir casting method, J. Mater. Res. Technol.; 2(3):250–254.

[45] Kumar, M. Chakraborty, V. Subramanya Sarma, B.S. Murty. (2008). Tensile and wear behaviour of in situ Al–7Si/TiB2 particulate composites, Wear 265, 134–142.

[46] Li, J.-y., Xie, J.-x., Jin, J.-b., Wang, Z.-x., (2012).Transactions of Nonferrous Metals Society of China, 22,1028-1034.

[47] Li, Z., Gu, X., Lou, S., Zheng, Y., (2008). Biomaterials 29,1329–1344.

[48] Lim, C.Y.H.; Lim, S.C.; Gupta, A., (2003). Wear behaviour of SiCp-reinforced magnesium matrix composites. *255*, 629–637.

[49] Luo, A.A., (2016). Magnesium casting technology for structural applications, J. Magness. Alloy 1,2e22.

[50] Luo, C., Liang, W., Chen, Z., Zhang, J., Chi, C., and Yang, F., (2013). Mater. Charact. 84, 34-40.

[51] Maleque M, Adebisi AA, Shah QH. (2012). Energy and cost analysis of weight reduction using composite brake rotor. International Journal of Vehicle Structures & Systems. 4:69-73.

[52] Mendoza-Duarte, J.M., I. Estrada-Guel, C. Carreno-Gallardo, R. Martinez-Sanchez, J. (2015). Alloys Compd. 643, S172-S177.

[53] Mikell Groover, P., (2007). Fundamentals of modern manufacturing Materials, processes, and systems third edition. ISBN-13 978-0-471-74485-6, Printed in USA.

[54] Miller, V.M., Berman, T.D., Beyerlein, I.J., Jones, J.W., Pollock, T.M., (2016). Prediction of the plastic anisotropy of magnesium alloys with synthetic textures and implications for the effect of texture on formability, Mater. Sci. Eng., A 675, 345e360.

[55] Mishra A.K., Sheokand, R., Srivastava R., (2012). Tribological behaviour of Al 6061/SiC metal matrix composite by Taguchi’s Techniques. International Journal of Scientific and Research Publications. 2(10):1-8.

[56] Modi, O.P, Prasad, B.K. Yegnewaran, A.H., and Vaidya, M.L. (1992). Dry sliding wear behaviour of squeeze cast aluminium alloy silicon carbide composites. Materials Science Engineering A, 151, 235-44.

[57] Mondal DP., Das S., (2006). High stress abrasive wear behaviour of aluminium hard particle composites: effect of experimental parameters, particle size and volume fraction. Tribology Int 39:470–478.

[58] Moni K., anchan Datta, Da-Tren Chou, Daeho Hong , Partha Saha , Sung Jae Chung , Bouen Lee , Arif Sirinterlikci , Madhumati Ramanathan , Abhijit Roy , Prashant N. Kumta, (2011). “Structure and thermal stability of biodegradable Mg–Zn–Ca based amorphous alloys synthesized by mechanical alloying” Materials Science and Engineering B 176 1637–1643.

[59] Muni, R.N., (2016). “Aluminium matrix hybrid composites: a review of different reinforcements on mechanical and tribological characteristics”, International Journal of Exploring Emerging Trends in Engineering (IJEETE) Vol. 03, Issue 06, NOV-DEC, Pg. 367 – 376.

[60] Narayan S., Rajeshkannan, A., (2016). Workability studies of sintered aluminium composites during hot deformation. *P I Mech Eng B-J Eng* 230: 494–504.

[61] Nikhilesh Chawla (2006), “METAL MATRIX COMPOSITES”, springer.

[62] Patil O.M., Khedkar N.N., Sachit, T.S., and Singh, T.P., (2018). A review on effect of powder metallurgy process on mechanical and tribological properties of Hybrid nano composites Mater. Today Proc. 5 5802–8.

[63] Pawar, P. B., & Utpat, A. A. (2014). Development of aluminium based silicon carbide particulate metal matrix composite for spur gear. *Procedia Materials Science*, *6*, 1150-1156.

[64] Pease III LF, Pease DL. (1998). ASM handbook: powder metal technologies and applications, vol. 7. Materials Park (OH): ASM International. p. 719– 48.

[65] Pease III LF. (1984). Metals handbook: powder metallurgy, ninth edition, vol. 7. Metals Park (OH): American Society for Metals. p. 485– 9.

[66] Prasad, B. K., (2002). "Influence of Some Test Parameters on Dry Sliding Wear Characteristics of a Zinc-11.5 Aluminum Alloy", Journal of Materials Engineering and Performance, Vol. 11, N0.4, 2002.

[67] Premnath, A.A., Alwarsamy, T.M, Rajmohan, T., Prabhu, R., (2014). The influence of alumina on mechanical and tribological characteristics of graphite particle reinforced hybrid Al-MMC, J. Mech. Sci. Technol. 28, 4737–4744.

[68] Qu, X., Wang, F., Shi, Ch., Zhao, N., Liu, E., Ch., He, F., (2018). In situ synthesis of a 317 gamma Al2O3 whisker reinforced aluminum matrix composite by cold pressing 318 and sintering, Mater. Sci. Eng., A 709, 223–231.

[69] Ramanathan, A., Krishnan P.K., and Muraliraja R., (2019). A review on the production of metal matrix composites through stir casting-Furnace design, properties, challenges, and research opportunities J. Manuf. Process. 42, 213–45.

[70] Rana, R. S., Purohit, R., Soni, V. K., & Das, S. (2015). Development and Wear Analysis of Al-Nano SiC Composite Automotive Cam. *Materials Today: Proceedings*, *2*(4-5), 3586-3592.

[71] Rao, R.N, Das S. (2010). Effect of matrix alloy and influence of SiC particle on the sliding wear characteristics of aluminium alloy composites. *Mater Des* **31**: 1200–1207.

[72] Rao,R., Das, S., Mondal, D., and Dixit, G., (2009). "Dry Sliding Wear Behavior of Cast High Strength Aluminum Alloy and Hard Particle Composites „Journal of Wear", Vol. 267, No.10.

[73] Ravi B., Balu Naik B.B., and Udaya Prakash J. (2015) Characterization of Aluminium Matrix Composites (AA6061/B4C) Fabricated by Stir Casting Technique Mater. Today Proc. 2 2984– 90.

[74] Ravikumar M., Reddappa H.N., and Suresh R. (2018). Aluminium Composites Fabrication Technique and Effect of Improvement in Their Mechanical Properties - A Review Mater. Today Proc. 5 23796–805.

[75] Ravindranath V.M., Shiva Shankar G.S., Basavarajappa S., and Siddesh Kumar N.G., (2017). Dry sliding Wear Behavior of Hybrid aluminum Metal Matrix composite reinforced with Boron carbide and graphite particles Mater. Today Proc. 4 11163–7.

[76] Roy, R.K., (1990). A Primer on the Taguchi Method, 1st ed.; Van Nostrand Reinhold Company: New York, NY, USA. p. 247.

[77] Russo, M., (2006). Ceramics and metal matrix composite: routes and properties. Journal of material processing technology, 175, 364-375.

[78] Sajjadi, S. A., Ezatpour, H. R., & Parizi, M. T. (2012). Comparison of microstructure and mechanical properties of A356 aluminum alloy/Al2O3 composites fabricated by stir and compo-casting processes. *Materials & Design*, *34*, 106-111.

[79] Salvo, L., L'esperance, G., M. Suery, and J.G. Legoux, (1994). Mater. Sci. Eng. A **177**, 173-183.

[80] Scudino, S., Sakaliyska, M., Surreddi, K.B., Eckert J., (2009). "Mechanical alloying and milling of Al–Mg alloys" Journal of Alloys and Compounds 483 (2009) 2–7.

[81] Sharma SC. (2001). The sliding wear behavior of Al6061–garnet particulate composites. Wear 249: 1036–1045.

[82] Sijo, M.T and Jayadevan K.R. (2016) Analysis of Stir Cast Aluminium Silicon Carbide Metal Matrix Composite: A Comprehensive Review Procedia Technol. 24 379–85.

[83] Singh, G., Goyal, K., & Goyal, D. K. (2015). Fabrication and Investigation of Mechanical Properties of Al-flyash-SiC Composites. *Journal of Mechanical Engineering, 3(5)*: 173-184.

[84] Singh, K.K., Singh, S., and Shrivastava, A.K. (2017). Comparison of Wear and Friction Behavior of Aluminum Matrix Alloy (Al 7075) and Silicon Carbide based Aluminum Metal Matrix Composite under Dry Condition at Different Sliding Distance Mater. Today Proc. 4 8960–70.

[85] Sirvancı, M., (2011). *Kalite Için Deney Tasarımı*, 2nd ed.; Literatür Yayınları: Istanbul, Türkiye pp. 13–18.

[86] Sivapragash, M., Kumaradhas, P., Stanly Jones Retnam, B., X. Felix Joseph, U.T.S. Pillai (2.16). "Taguchi based genetic approach for optimizing the PVD process parameter for coating ZrN on AZ91D magnesium alloy" Materials and Design 90, 713–722.

[87] Stojanović, B., Ivanović L., (2015). Application of aluminium hybrid composites in automotive industry. Technical Gazette. 22:247-51.

[88] Straffelini, G., Bonollo, F., Tiziani, A., (1997). Influence of matrix hardness on the sliding behaviour of 20 vol% Al2O3-particulatereinforced 6061 Al metal matrix composite. Wear, 211, 192-197.

[89] Suresh, R. and Ravikumar, M., Reddappa, H.N. (2018). Aluminium Composites Fabrication Technique and Effect of Improvement in Their Mechanical Properties - A Review Mater. Today Proc. 5 23796–805.

[90] Toptan, F., Kerti, I., Rocha, LA. (2012). Reciprocal dry sliding wear behavior of B4C reinforced aluminum alloy matrix composites. Wear 290–291:74–85.

[91] Toptan, F., Kilicarslan, A., and Kertil, I., (2010). The Effect of Ti Addition on the Properties of Al-B4C Interface: A Microstructural Study. Materials Science Forum, 636-637, 192-197.

[92] Umasankar, V., M.A. Xavior, S., Karthikeyan, (2014). Experimental evaluation of the influence of processing parameters on the mechanical properties of SiC particle reinforced AA6061 aluminum alloy matrix composite by powder processing, J. Alloy. Compd. 582, 380–386.

[93] Van Agterveld, D. T. L., Palasantzas, G., and De Hosson, J. Th. M., (1999). "Magnesium surface segregation and oxidation in Al-Mg alloys studied with local probe scanning Auger-scanning electron microscopy," *Applied Surface Science*, vol. 152, no. 3, pp. 250–258, 1999.

[94] Beck A.F, Heine M.A, Caule E.J. and Pryor M.J. (1967). "The kinetics of the oxidation of Al in oxygen at high temperature," *Corrosion Science*, vol. 7, no. 1, pp. 1-22.

[95] Velikokhatnyi, O.I., Kumta, P.N., Acta Biomater. 6 (2010) 1698–1704.

[96] Venkatesan, Kb., Kuppan,Pc., Ramanujam,Rd. (2014). Hybrid Aluminium Metal Matrix Composite Reinforced with SiC and TiB2, *12th Global congress on manufacturing and management*, 1018 – 1026.

[97] Vijayakumar, S., Soundarrajan, M., Palanisamy, P., & Pasupathi, K. (2013). Studies on Mechanical Properties of Al-SiC Metal Matrix Composite. *SSRG-IJMSE Volume 2.*

[98] WANG Zhao-hui, WANG Xu-dong, ZHAO Yu-xin, DU Wen. (2010). "SiC particles reinforced magnesium matrix composites fabricated by ultrasonic method" Trans. Nonferrous Met. Soc. China 20, s1029-s1032.

[99] Wang, N.L., Z. G., and Sun, L. Z., (1995). Low Cycle Fatigue Behaviour of SiCp Reinforced Aluminium Matrix Composite at Ambient and Elevated Temperature, Scr. Metall. Mater., 32,11, 1739 1745.

[100] Wang, W.J.,Gauthier-Brunet, V., Bei, G.P., Laplanche, G., Bonneville, J., Joulain, A., Dubois, S., (2011). Mater. Sci. Eng. A 530, 168–173.

[101] Wanga, H.Y., Jiang, Q.C., Wang, Y., Ma, B.X., and Zhao, F., (2004). Fabrication of TiB_2 particulate reinforced magnesium matrix composites by powder metallurgy. Materials Letters 58, pp.3509–3513.

[102] XIA Yu-feng, QUAN Guo-zheng, ZHOU Jie,(2010). "Effects of temperature and strain rate on critical damage value of AZ80 magnesium alloy"Trans. Nonferrous Met. Soc. China 20, s580-s583.

[103] Ying, Yu., Hitoshi Ishii, Keiichiro Tohgo, Young Tae Cho, Dongfeng Diao, (1997). Temperature dependence of slidingwear behavior in SiC whisker or SiC particulate reinforced 6061 aluminum alloy composite. Wear, 213, 21-28.

[104] Zhang, Z., Yang, R., Chen, G., Zhao, Y., and Shao, Y., (2012). Correlation between microstructure and tensile behavior in powder metallurgy ZK60 alloys, Mater. Lett. 89, 166–168.

APPENDIX

Table A-1. Hardness value (HV) for each sample with three readings and calculated average value.

	Hardness (HV)			
Sample No.	**Trial-1**	**Trial-2**	**Trial-3**	**Av. Value (HV)**
S1	54.9	51	75.5	60.467
S2	67.8	65.9	59.4	64.367
S3	62	73	67.6	67.533
S4	80.5	75.7	76.2	77.467
S5	87.9	89.7	92.9	90.167
S6	95.9	98.4	89.2	94.5
S7	105	102.8	121.4	109.733
S8	99.2	103.3	112.3	104.933
S9	109.5	102.8	107.6	106.633
S10	128	132	137.9	132.633

Table A-2. Mass of specimens before and after experimental wear at all load applied conditions with ware rate value.

Sample No.	Mass before(g)	Load 10(N)	Mass loss(g)	Wear rate(×10^8kgm$^{1)}$	Load 30(N)	Mass loss(g)	Wear rate(×10^8kgm^1)	Load 50(N)	Mass loss(g)	Wear rate(×10^8kgm^1)
S1	0.7809	0.779	0.0019	1.936	0.7765	0.0025	2.548	0.7726	0.0039	3.974
S2	0.7813	0.7798	0.0015	1.528	0.7775	0.0023	2.344	0.7738	0.0037	3.771
S3	0.7817	0.7802	0.0015	1.528	0.7782	0.002	2.031	0.775	0.0032	3.261
S4	0.8166	0.8154	0.0012	1.223	0.8136	0.0018	1.834	0.8108	0.0028	2.853
S5	0.8177	0.8166	0.0011	1.121	0.815	0.0016	1.631	0.8127	0.0023	2.344
S6	0.8163	0.8153	0.001	1.019	0.8139	0.0014	1.427	0.8119	0.002	2.038
S7	0.8201	0.8197	0.0004	0.408	0.8192	0.0005	0.51	0.8183	0.001	1.019
S8	0.8187	0.818	0.0007	0.713	0.8171	0.0009	0.917	0.8157	0.0014	1.427
S9	0.8196	0.8191	0.0005	0.51	0.8184	0.0007	0.713	0.8172	0.0014	1.426

Appendix Figures

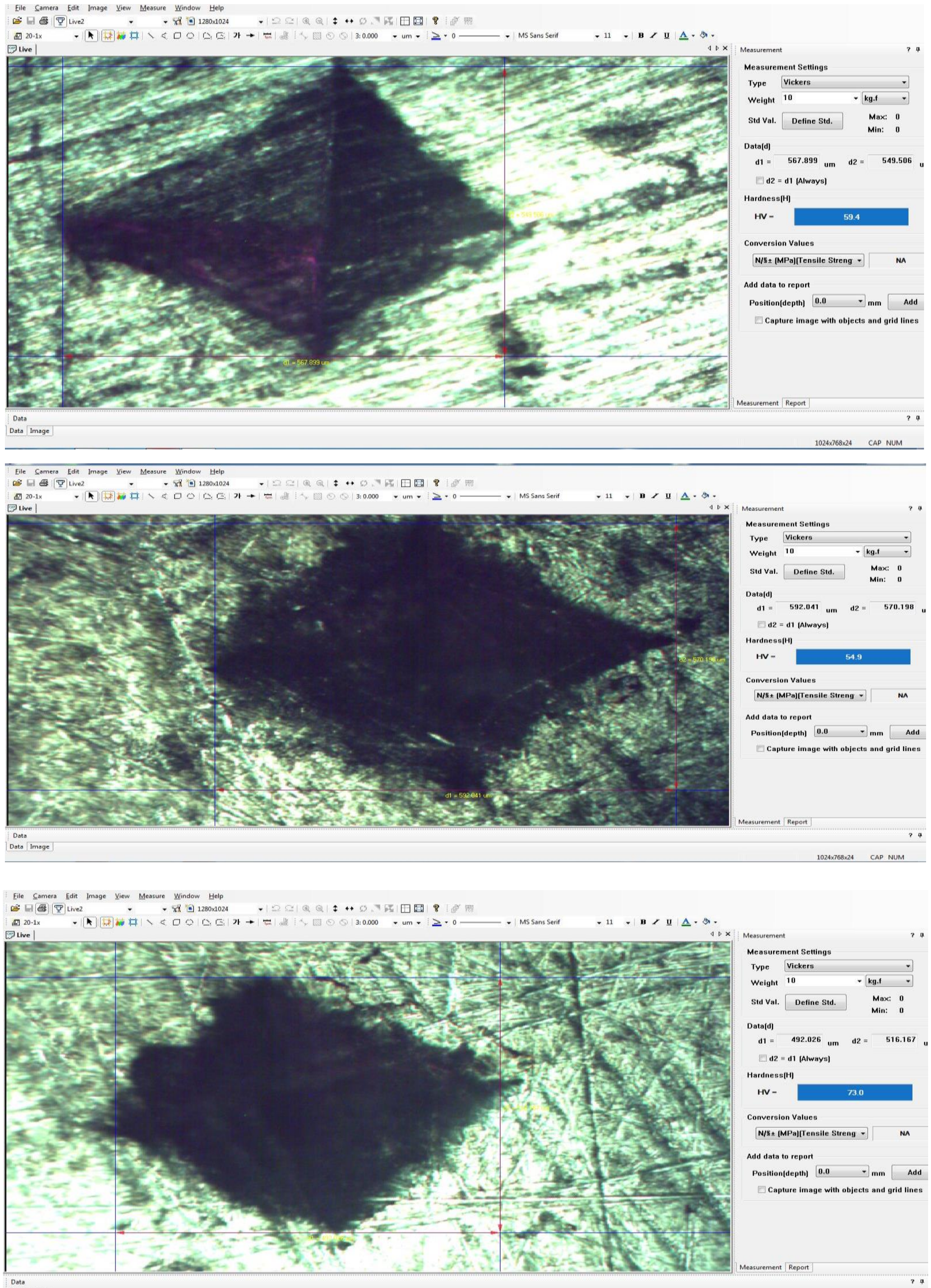
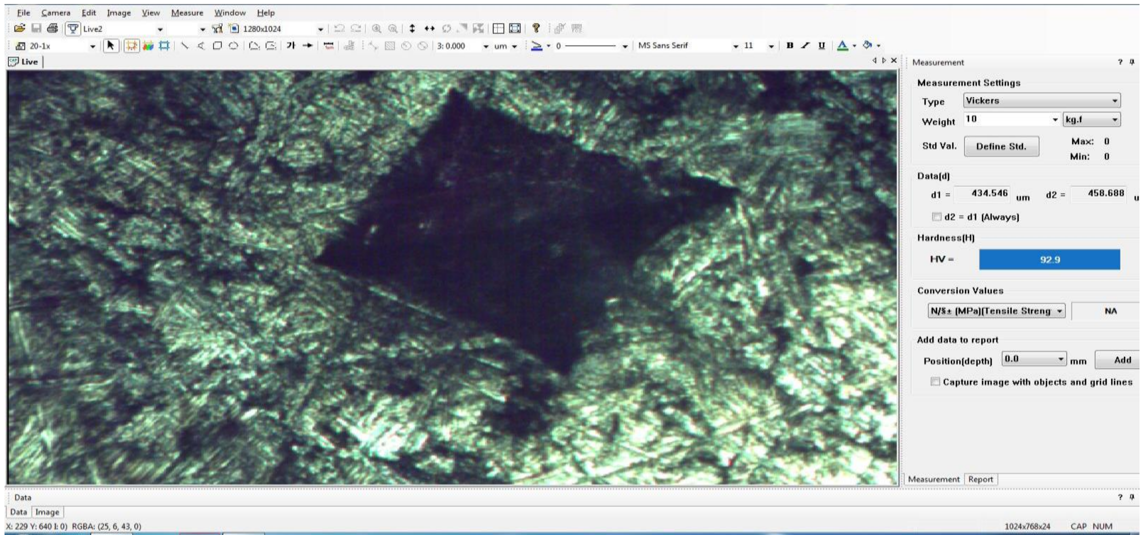
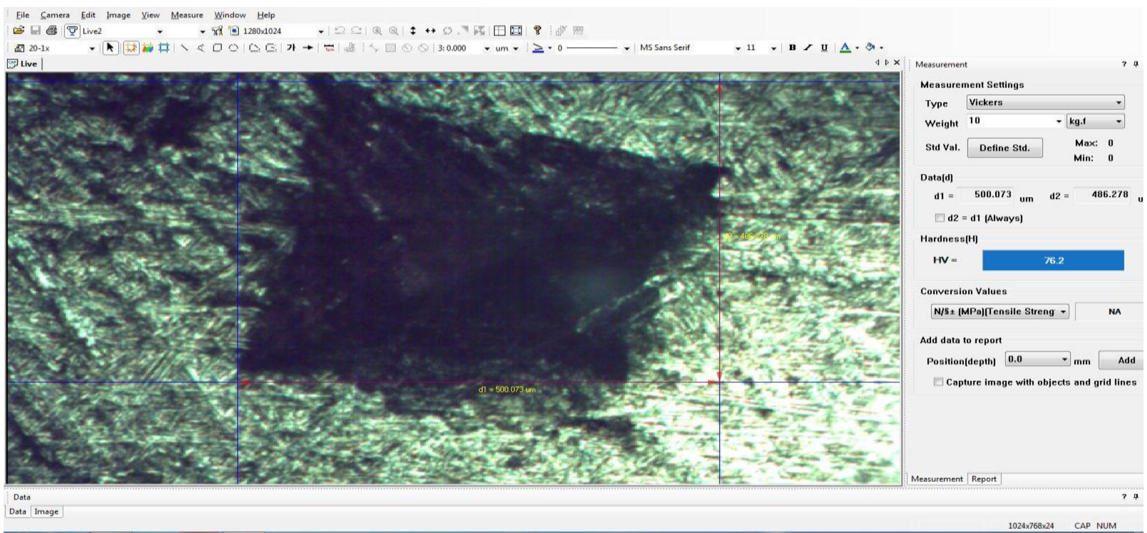


Figure A-1. Vickers hardness value for AlMg alloy matrix samples (S1, S2 and S3).





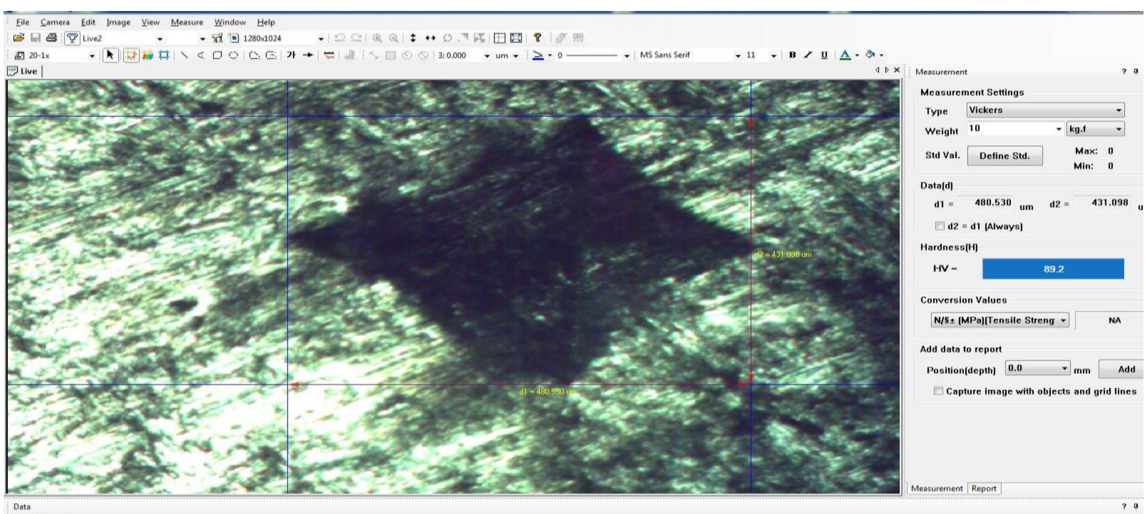


Figure A-2. Vickers hardness value for AlMg-SiC composite samples (S4, S5 and S6).

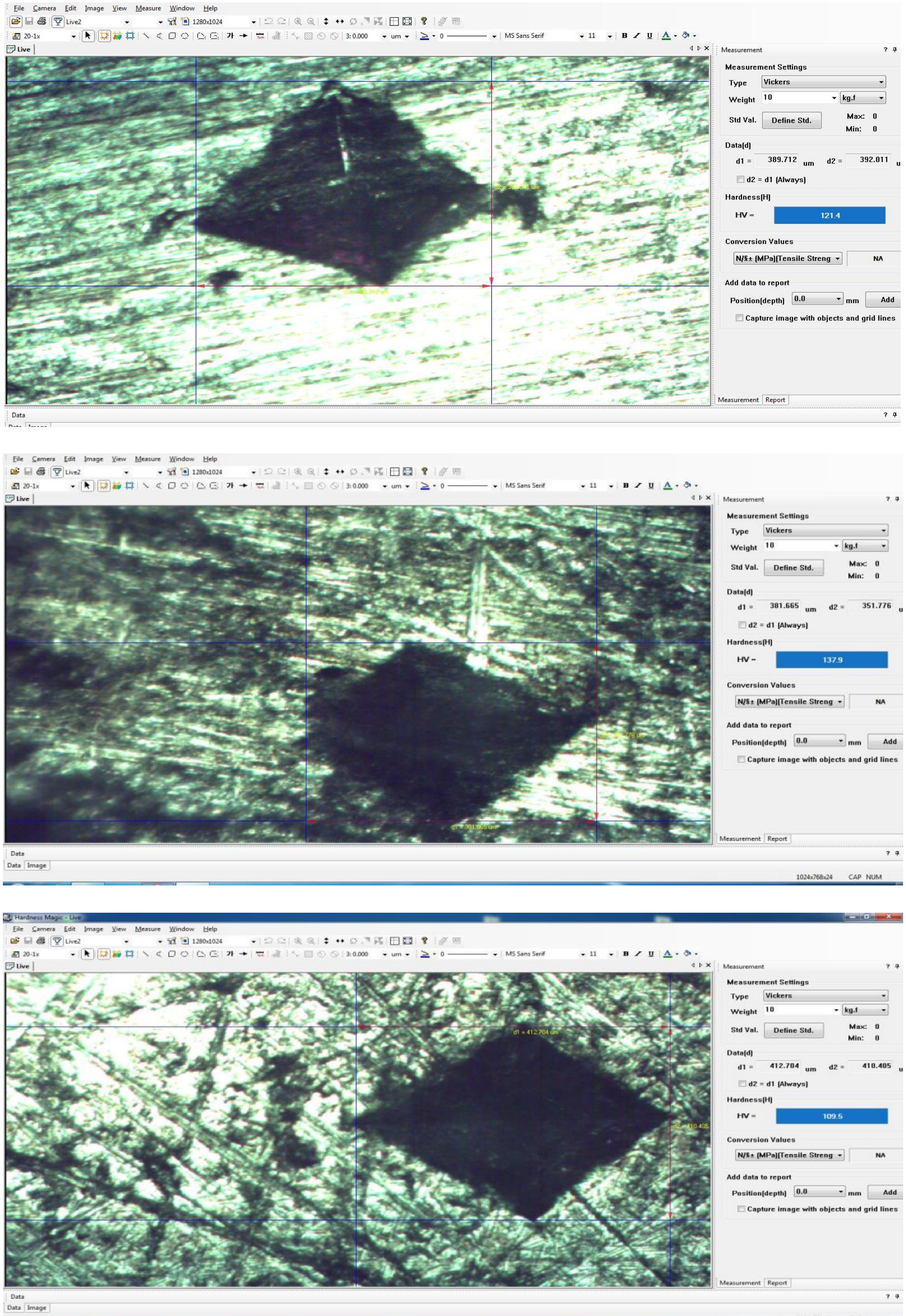


Figure A-3. Vickers hardness value for AlMg-SiC composite samples (S7, S8 and S9).

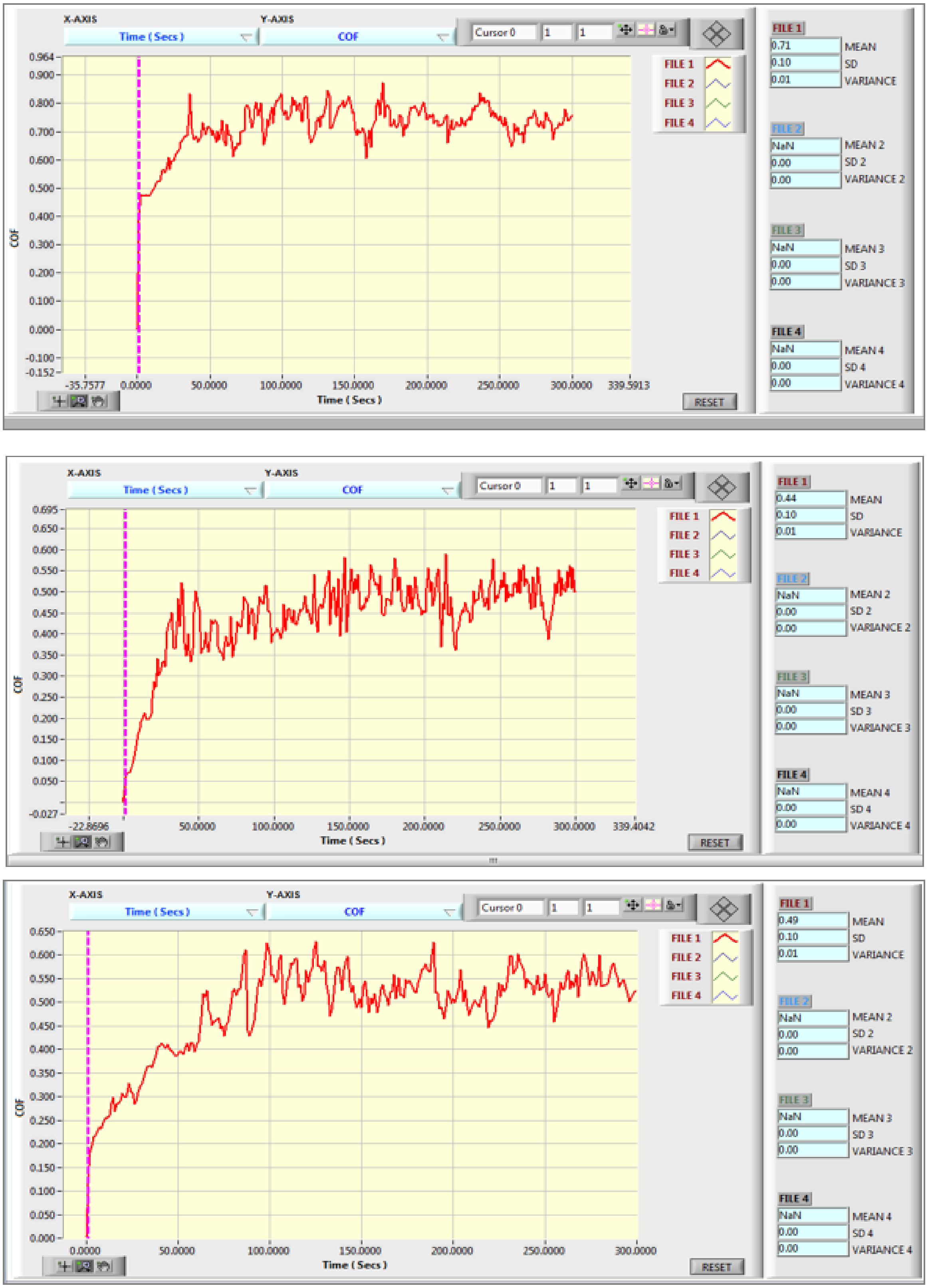


Figure B-1. (COF) Vs time for AlMg-matrix samples (S1, S2 and S3).

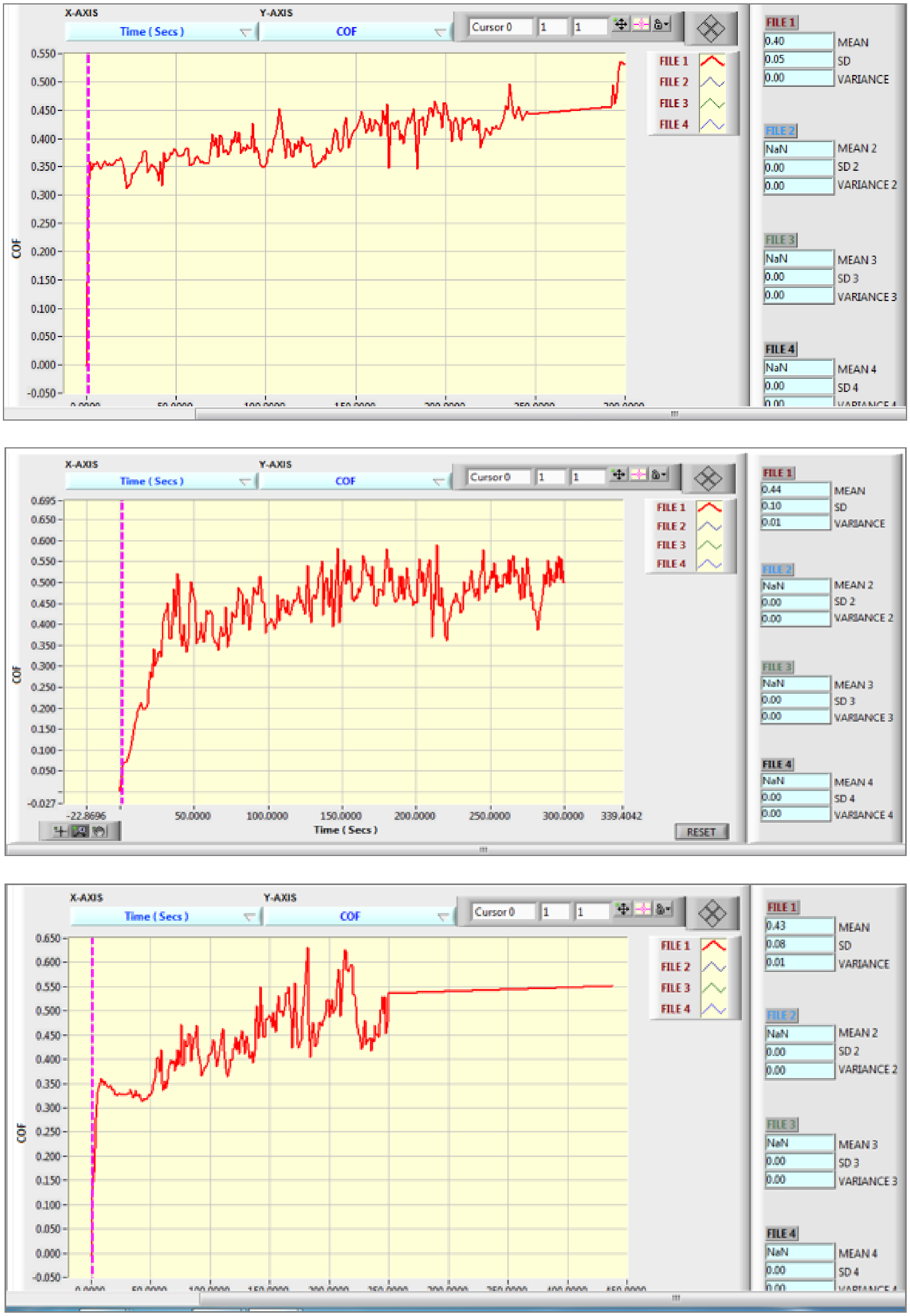


Figure B-2. (COF) Vs time for AlMg-5%SiC composite samples (S4, S5 and S6).

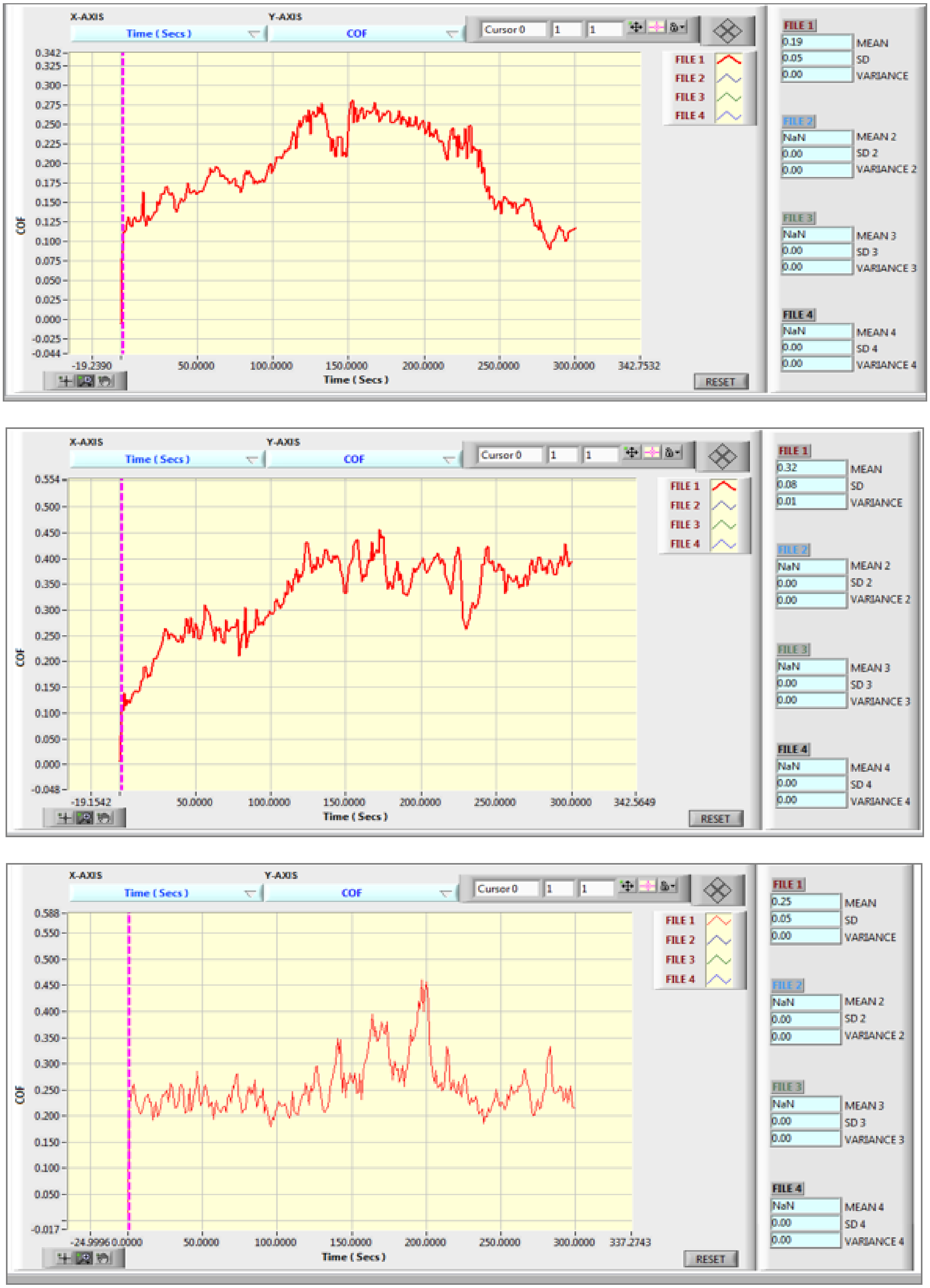


Figure B-3. (COF) Vs time for AlMg-10%SiC composite samples (S7, S8 and S9).