FABRICATION AND EXPERIMENTAL ANALYSIS OF MECHANICAL PROPERTIES OF ALUMINIUM-SILICON CARBIDE COMPOSITE

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by

MELESE BUTUNA BEDANE

ID No: GSR/0108/09

Advisor: Dr. Venkatesh Chenrayan

Co-Advisor: Dr. Desalegn Wogaso

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "Fabrication and Experimental Analysis of Mechanical Properties of Aluminium Silicon Carbide Composite" is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Melese Butuna Bedane ____________________ ________________

Name Signature Date

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

Dr. Venkatesh Chenrayan ________________ _______________

Name of Major Advisor Signature Date

Dr. Desalegn Wogaso ___________________ ________________

Name of Co-Advisor Signature Date

ADVISOR'S APPROVAL SHEET

To: Mechanical Design and Manufacturing Engineering department

Subject: Thesis Submission

This is to certify that the thesis entitled "Fabrication and Experimental Analysis of Mechanical Properties of Aluminium Silicon Carbide Composite" submitted in partial fulfillment of the requirements for the degree of Master's in Manufacturing Engineering, the Graduate program of the department of Mechanical Design and Manufacturing Engineering, and has been carried out by Melese Butuna Bedane, Id. No GSR/0108/09, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Dr. VenkateshChenrayan	____________________	__________________
Name of Major Advisor	Signature	Date
Dr. Desalegn Wogaso	___________________	_________________
Name of Co-Advisor	Signature	Date

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ABSTRACT

Aluminium based composites with silicon carbide as particle reinforcement find their wider requirement in aerospace industries because of their excellent mechanical and physical properties. The enhanced mechanical and physical properties of the materials are the direct result of influence between the aluminium matrix and silicon carbide reinforcement. In the present study Aluminium (99.5%) and SiC (50 μm) has been chosen as matrix and reinforcement material, respectively. The benefits of using SiC as reinforcement are expected to be improved stiffness, strength, wear resistance, fatigue resistance, and reduced thermal expansion. Additionally, SiC reinforcements are typically low-cost and are relatively low-density. This research study focused on the influence of SiC particles over the improvement of mechanical properties of aluminium metal matrix composite. The different compositions of SiC (0%, 2.5%, 5%, and 7.5%), were followed to develop the composite using stir casting route, while keeping all other parameters constant. The distribution of SiC particulate reinforcement in Al metal matrix was studied by using optical microscope. Various mechanical properties like tensile strength, hardness and compressive strength, were evaluated for three different composition specimens. The optical micrographs of the Al-SiC indicate that the SiC reinforcing particles were uniformly distributed in the matrix alloy. The experimental results showed that the tensile strength, hardness and compression strength of pure aluminium were improved by 71%, 36%, and 20% respectively. A result of tensile test shows that, tensile strength of pure aluminium raised from 88.22 MPa to 151.60MPa, when 7.5% of SiC was added. Also the result of hardness and compression tests shows that, the hardness and compression strength of aluminium were increased from 29.18 VH to 39.74 VH, and 348.32 MPa to 418.24 MPa respectively with the increasing in weight percentage of silicon carbide to 7.5 percent.

Keywords:-Aluminum silicon carbide; metal matrix composite; stir casting; mechanical properties.

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ABBREVIATIONS AND SYMBOLS

Abbreviations	**Descriptions**
Al	- Aluminium
Al_2O_3	- Aluminium Oxide

Al-SiC	- Aluminium Silicon carbide
AMMCs	- Aluminium Metal Matrix Composites
ANSI	- American National Standards Institute
APA	- American psychological Association
ASTM	- American Society for Testing and Materials
B_4C	- Boron Carbide
BHN	- Bernal Hardness Number
CMC	- Ceramic Matrix Composite
DEFORM	- Design Environment for Forming
HSS	- High-Speed Steel Stirrer
Kgf	- Kilogram Force
L/D	- Length to Diameter (Aspect Ratio)
MMC	- Metal Matrix Composite
PMC	- Polymer Matrix Composite
PP	- paper page
RHN	- Rockwell Hardness Number
ROM	- Rule of Mixture
RPM	- Rotational per minute
SEM	- Electron scanning microscope
Si	- Silicon
SiC	- Silicon carbide
SiO	- Silicon Oxide
SiO_2	- Silicon Dioxide

UTM	- Universal Testing Machine
UTS	- Ultimate Tensile Strength
VHN	- Vickers Hardiness Number

Symbols	Descriptions
%	- Percent
% W	- Weight percentage
^{0}C	- Degree of Celsius
A_i	- Instantaneous cross section area
A	- Cross section area
d	- Mean diameter of indentation
d_i	- Diameter of indentation
D	- Diameter of indenter
D_{av}	- Average diameter of sample
F	- Load applied,
ε_z	- True axial strain
σ_z	- True axial stress
K	- Strength coefficient
L	- Length of Sample
n	- Strain hardening exponent
P	- Applied load
R	- Radius of Sample

CHAPTER 1

INTRODUCTION

1.1. Background of the Study

Scientists are continuously trying to improve various properties of engineering materials; several super alloys and heat resistance materials have been developed for various industrial applications, especially aerospace/aircraft and defense, automotive, medical and sport equipment industries. Advancement in materials have been introduced new generation materials particularly having low density and very light weight with high strength, hardness and stiffness [1]. One of the important of these advanced materials is composites. They are composed of a combination of distinctly different two or more micro or macro constituents that differ in the form of composition and it is insoluble in each other [2]. Properties of the composites depend on the properties of the constituent phases, their relative amount, and dispersed phase geometry including particle size, shape and orientation in the matrix. Composite materials have a continuous phase called the matrix, and non-continuous, phase called the reinforcement. Reinforcements are used in different amount with the composite based on the specification required in order to improve mechanical and physical properties of metal matrix alloy [1]. Such types of material are developed to satisfy proper mechanical properties which cannot be derived from conventional materials.

In the composite, matrix material has several functions, the important ones being, binds reinforcements together, transfers loads, and protects the composite from incursion of external agents. While the roles of reinforcements are to carry the load, provide stiffness, strength, thermal stability, and other structural properties in the composites [1, 2]. In terms of shape, the reinforcement material may be sub-divided into Fibers, Whiskers and Particles categories. Among various reinforcements, particles are the most common and cheapest reinforcement [3]. According to matrix constituent, composites are classified into Polymeric matrix composites, metal matrix composites and ceramic matrix composites. Among these composites [4], metal matrix composite is engineered combination of the metal (Matrix) and hard particle (Reinforcement) to get tailored properties.

1.2. Metal Matrix Composites (MMCs)

The processing and developments of metal-matrix composites have emerged as a class of materials capable of advanced structural, aerospace, automotive, electronic, thermal management and wear applications. The performance advantages of metal matrix composites are their tailored mechanical, physical and thermal properties that include low density, high specific strength, high specific modulus, high thermal conductivity, and high abrasion and wear resistance [3, 4]. For the fabrication of metallic matrix composites several type of manufacturing methods were employed. The choice of appropriate manufacturing method highly alters the resulting composite microstructure, dispersion of reinforcement, interfacial bonding between the matrix phase and reinforcement particle and mechanical performances [5]. The manufacturing method to be employed is greatly based upon the type of reinforcement and metallic matrix material. The economical and easy technique for production of composite materials is very important for elaborating their applications and properties. Several processing techniques which have shown to be comparatively expensive and complex in operation like in-situ casting, powder metallurgy and squeeze casting are also available [6]. Stir casting techniques are attracting researchers due to economical and easy method of processing.

Metal matrix composite provide significantly enhanced properties such as higher strength, higher hardness, good wear resistance and weight savings. Among various matrix materials, aluminum metal matrix materials possess high strength to weight ratio, good corrosion resistance, high thermal conductivity etc. Similarly, among various reinforcements silicon carbide reinforcements are inexpensive; improve yield strength and elastic modulus. Silicon carbide as such, because of its high hardness, has got a number of applications such as in cutting tools, jeweler, automobile parts, electronic circuits, structural materials, nuclear fuel particles, etc. [3, 7]. Aluminum is the most abundant metal in nature around 8% by weight in the earth's crust [8]. Aluminium had been at the center of a variety of engineering applications since long. It was first of all produced in the laboratory long back in 1825 by reducing aluminum chloride.

The ore from which most aluminum is presently extracted is *Bauxite* (Hydrate Aluminum Oxide). Aluminum is capable of mixing with other metals in liquid state, and no element is completely soluble in aluminum in the solid state [3, 9].

Like all composites, aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The major disadvantage behind producing aluminum matrix composites generally rests on the cost of production and reinforcement material. AMMCs can be manufactured by liquid state processing (stir casting, infiltration, squeeze casting etc.), semisolid processing and powder metallurgical route. Among these methods stir casting is simple, inexpensive and used for uniform distribution of reinforcement in composite [4]. Usually metallic and ceramic particles like silicon carbide (SiC), alumina (Al_2O_3), boron carbide (B_4C), graphite etc. are used as reinforcements in AMC [10]. When loads are applied externally to the composites, metal matrix transmits loads to reinforcements and then loads are carried by dispersed reinforcements bonded with the matrix. Strong interface bond between reinforcements and matrix is required to obtain high strength of composites. Therefore, good wetting of the reinforcements is necessary during casting [10]. Metals have a useful combination of properties such as ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong, though brittle.

The Aluminium-silicon carbide MMC possess wide range of physical and mechanical properties such as high strength, stiffness, low density, high corrosion and wear resistance, and low thermal shock [11]. Aluminium-silicon carbide MMC's are used in various fields like aerospace, fuselage skins of high performance aircrafts, underwater, automobile, substrate in electronics, sport instrument, turbine blades, brake pads etc. This study gives the production of Al-SiC metal matrix composite from *pure aluminum* (99.5% C.P) metal matrix and silicon carbide reinforcement, by varying weight fraction of SiC (0%, 2.5%, 5%, and 7.5%). Stir casting method which is less cost, mass production, and very effective for uniform distribution of reinforcement, was used for fabrication of composite. Finally some essential mechanical properties of Al-SiC metal matrix composite, like tensile strength, hardness and compression strength, were experimentally analyzed. The experimental results show that the mechanical properties of aluminium silicon carbide composite such as compression strength, hardness and tensile strength were improve with increasing weight percentage of silicon carbide.

1.3. Statements of the Problem

In modern manufacturing scenario, there is huge demand for the material with high specific strength with low weight. Particularly, in the development of aircraft, satellite and automobile industries, the materials should have light weight with excellent strength. The conventional monolithic alloys have got their own merits and demerits. It is utmost urgency in material development to develop the material with good mechanical and thermal property with less weight. To overcome the difficulties in conventional metals and monolithic alloys, this research works deals with development of novel material like aluminium metal matrix reinforced with silicon carbide particles with good mechanical properties with low specific weight. The present work extends to investigate the influence of composition of silicon carbide particles over the improvement of mechanical properties.

1.4. Objectives of Study

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

1.4.1. General Objective

The general objective of research is to analyze the mechanical properties of aluminum-silicon carbide metal matrix composite with different weight percentage of silicon carbide reinforcement.

1.4.2. Specific Objectives

In line with above major objectives, the study aims at achieving the following specific objectives.

- To fabricate the experimental samples of Al-SiC metal matrix composite with different weight composition of SiC by using stir casting method.
- To evaluate the mechanical properties like tensile strength, compression strength and hardness of the prepared samples by using appropriate equipment.
- To examine the distribution of homogeneity of the reinforcement of SiC throughout the composite by using optical microscope.

1.5. Scope of the Study

Composites are increasingly being used in a wide range of applications such as aerospace, marine, transportation, automotive industry, architectural, building products and military system. Matrix materials commercially pure aluminium (99.5%) was selected for this work, because of its excellent properties such as low density, ductility, good corrosion resistance, and good formability. In order to reduce the cost and improve the final properties of the composites, a wide range of reinforcements are being used. Silicon carbide particle was selected as reinforcements, due to its good strength, stiffness, low cost, and high thermal stability. Stir casting was preferred for the fabrication of Al- SiC metal matrix composite for its low cost, simple, uniformity distribution of reinforcements, mass product, etc. Reinforcement of silicon carbide in various proportions alters the mechanical properties to the significant extent. The modern material development engineering mostly relies on this kind of investigation to develop low cost, low weight high strength material. Scope of this project can also be extended to know the influence of weight percentage of Silicon carbide particle over the improvement of mechanical properties.

1.6. Significance of the Study

A significant part of the work consists of the fabrication of aluminium silicon carbide metal matrix composite by using simple and inexpensive method known as stir casting for uniform distribution of the reinforcement. Mainly, this thesis deals with the possibility to achieve the combination of mechanical properties, not attainable with metal or ceramic alone. The research findings can help researchers and industries for developing a robust, reliable and knowledge base processes for fabrication and experimental analysis of Al-SiC composites.

1.7. Limitation

The absence of appropriate machines in fabrication of aluminium silicon carbide composite material and the absence of appropriate laboratory for testing its mechanical properties are the limitations, for the lag of this work. The limitation in internet access also the other problem that make this research work too late.

1.8. Organization of the Study

The thesis consists of five chapters, as follows:

Chapter 1 consists, the introduction which includes, Background of the study, Statement of problem, Significance of the study, Objectives of study, General objective of study, Specific objectives, Scope of study, and Organization of the study.

Chapter 2 provides a detailed survey of all literatures used in these study- books, journals and information collated from various websites.

Chapter 3 deals with the materials and methodology adopted in the current research work, experimental plan on the preparation of the test material and the experimental techniques used in the current work. Analysis and discussion of the result of microstructure and mechanical properties of the Al-SiC composites have been discussed in the Chapter 4.

Chapter 5 contains the conclusion drawn from the current thesis work and the recommendation for future research work.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Composite materials appear everywhere in life, both man-made (such as fiberglass) and biologically produced (like mammalian bones). The purpose of a composite man-made material is to improve the properties of the matrix material, by the addition of some second material with different chemical and structural properties. An example of an important area of composite research is metal-matrix composites, in which a metallic host material is modified through the addition of reinforcement [1, 12]. The reinforcement may be in the form of particles or fibers. The goal is to supplement the desirable properties of the metal, such as, hardness, compression and tensile strength by the addition of reinforcement.

Aluminum, both in pure and alloy form are a suitable material for many engineering and industrial applications. In aluminum matrix composites, the extensively used reinforcement is in particulate form and is widely employed in automotive and aerospace industries [13]. Therefore, there is a highly demand for utilization of aluminum matrix composites in all sectors because of its better performance, economic and environmental benefits. Furthermore, aluminum metal matrix composites are considered as the most popular among all metal matrix composites and are required for many engineering applications. According to [14] aluminum or its alloy matrix composites have the following major advantages as compared to unreinforced materials;

- Improved abrasion and wear resistance
- Improved high temperature properties
- Higher strength
- Reduced density (less weight)
- Controlled coefficient of thermal expansion
- Enhanced and tailored electrical performance

2.2. Composite Materials

The composite material can be defined as the system of material consisting of a mixture of combination of two or more micro constituents insoluble in each other and differing in form and or in material composition. These materials can be prepared by putting two or more dissimilar materials in such way that they function mechanically as a single unit. The properties of such materials differ from those of their constituents. Normally the composite materials have a hard phase that act as a reinforcing agent and soft phase that act as matrix material. According to [1, 15], the requirements for satisfying the above mentioned condition are:

- The composite material has to be man-made
- The composite material must be a combination of at least two chemically distinct materials with an interface separating the components.

2.3. Types of Composite Materials

Composite materials can be classified based on its matrix or reinforcement materials.

2.3.1. Based on Matrix Materials

Polymer-Matrix Composites (PMC): The most common matrix materials for composites are polymeric. According to [14, 16], these matrix materials are basically used for fiber reinforced composites. The epoxies are the common matrix materials in PMC. Because of its less in weight and high strength Polymer-Matrix Composites are used widely for aerospace applications. The main disadvantages of PMC are their low working temperature, high coefficients of thermal expansion and hence dimensional instability and sensitivity to radiation and moisture [16].

Metal-Matrix Composites (MMC): According to [12], metal matrix composites can be used at higher service temperature than their base metal counterparts. The matrix in these composites is a ductile metal. So, the reinforcement in these composite materials improves strength, hardness and dimensional stability. The metal matrix composites are light in weight with high strength and resist wear and thermal distortion, so it mainly used in automobile industry.

Ceramic-Matrix Composites (CMC): According to [17], Ceramics materials are inherent resistant' to oxidation and deterioration at elevated temperatures; were it not for their disposition to brittle fracture, these materials would be used in higher temperature and serve-stress applications, specifically for components in automobile and air craft gas turbine engines. The developments of CMCs have lagged behind, because of most processing route involve higher temperature and only employed with high temperature reinforcements [17]. Table 2.1 shows the summary properties and production methods of composites.

Table 2. 1. Properties and Processing Methods of the Composites [12, 14, 17]

Property	Polymer Matrix Composite	Metal Matrix Composite	Ceramic Matrix Composite
Strength	High tension and High compression	High tension High compression	Medium tension High compression
Density	Low	Medium	Medium
Fracture toughness	High	Medium	Low
Fabrication methods	Sheet molding Injection molding Resin transfer Tape lay-up Pultrusion	**Solid state** Powder metallurgy Diffusion bonding **Liquid state** Squeeze casting Stir casting	Cold pressing and sintering Chemical vapor deposition Reactive liquid infiltration
Ease of Fabrication	Easy	Medium	Medium
Cost	Low	Medium	High

2.3.2. Based on Reinforcement Materials

Composite materials can classify as fiber, whisker and particulate reinforced composite, based on its reinforcements. A fibrous reinforcement is characterized by its length being much greater than its cross-sectional dimension. Composites of long fibers with high aspect ratios are called continuous fiber reinforced composites, whereas discontinuous fiber reinforced composites are fabricated using short fibers of low aspect ratio [18]. According to [19] Particulate reinforcements have dimensions that are approximately equal in all directions. The shape of the reinforcing particles may be spherical, cubic or any regular or irregular geometry. Table 2.2 shows the properties of reinforcements by its size.

Table 2. 2. Characteristics of the Reinforcements by Its Size [18, 19]

Relative Size	**Advantages**	**Limitations**
Particulate Reinforcement		
Fine	Greatest strength Highest fatigue resistance. Lowest coefficient of thermal expansion.	Tendency to agglomerate. High cost Segregation during casting. Lower hardiness
Medium	Excellent balance between properties (high strength and good ductility) Ease of manufacturing	Moderate hardness High cost
Coarse	Good wear resistance High ductility and ease of Manufacturing	Lower tensile strength
Fibers		
Continuous /Non-continuous	Highest properties in the fiber direction lowers density	High anisotropic properties High cost and difficult to process

2.4. Aluminium Alloy and Its Designation

Aluminium is relatively unique in being highly economic to recycle. Aluminum and its alloys offer an extremely wide range of capability and applicability, with a unique combination of advantages that make it the material of choice for numerous products and markets [20]. The high strength to weight ratio of aluminium, favors the selection of aluminium alloys in critical weight applications. Aluminium alloys are the prime choice for fuselages, wings and support structure of commercial airlines and military cargo [21]. There are a wide range of opportunities for using aluminium in automotive power trains and body structures. According to Jawalkar et al. [22] the car bodies contributes to 20% of total weight of the car, so a promising way to reduce car weight is to use aluminium alloys.

The aluminum association alloy and temper designation system is recognized by the American National Standards Institute (ANSI) as the United States National Standard [20, 23]. Generally, a four-digit numerical designation is used to specify aluminum and its alloys, where the first digit denotes the principal alloying element except AA1XXX series, which stands for purity of aluminum. The second digit stands for the changes to impurity limits or variations of initial alloy, third and fourth digits for individual alloy variations. Table 2.3 shows the designation of wrought aluminium and its major alloys.

Table 2. 3. Designation of Wrought Aluminum and Its Alloys [20, 22, 23]

Series Designation	Major Alloying Elements
AA1xxx	Pure Aluminium ($\geq$ 99. 00%)
AA2xxx	Cupper (Cu)
AA3xxx	Manganese (Mn)
AA4xxx	Silicon (Si)
AA5xxx	Magnesium (Mg)
AA6xxx	Magnesium and silicon (Mg and Si)
AA7xxx	Zink (Zn)
AA8xxx	Lithium (Sn)

The 1xxx series represents the commercially pure aluminum, ranging from the 99.00% minimum Al to 99.99% maximum Al [20]. In this series, the most common alloys consumed were the AA1050 and AA1100 used for electrical applications and food trays, respectively [21]. Aluminum AA1050 is available in a wide range of structural shapes, as well as sheet and wire products. These series would not be used where strength is a prime consideration [20 to 23], because of their lower strength. Rather the emphasis would be on those applications where extremely high corrosion resistance, formability and/or electrical and thermal conductivity are required. Table 2.4, 2.5 and 2.6 shows the chemical composition, mechanical properties and Physical properties of AA1050 respectively.

Table 2. 4. Chemical Composition of Aluminium AA1050 in Weight Percentage [20, 23]

Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Pb
99.5	0.25	0.04	0.05	0.05	0.05	0.07	0.05	0.01	0.009

Table 2. 5. Mechanical Properties for Aluminium AA1050 [20, 23]

Property	Value
Tensile Strength	80-100 MPa
Compression strength	350 MPa
Hardness Vickers	30 VH
Elongation	4 Min %

Table 2. 6. Physical Properties for Aluminium AA1050 [20, 23]

Property	Value
Density	2.71 g/cc
Melting Point	650 °C
Modulus of Elasticity	71 GPa
Electrical Resistivity	0.0282x10 Ω.m
Electrical conductivity	61.4 IACS(min)
Thermal Expansion	24x10 /K

2.5. Reinforcements

The principal purpose of the reinforcement is to provide superior levels of strength and stiffness to the composite. The typical reinforcing materials (graphite, glass, SiC, alumina) provide thermal and electrical conductivity, controlled thermal expansion and wear resistance [24]. Silicon carbide is an important non-oxide ceramic which has diverse industrial applications. A lot of works were reported on SiC synthesis since the manufacturing process initiated by *Acheson* in 1892 [25]. However, Acheson was the first to recognize its potential industrial importance. Silicon carbide is produced industrially from silicon dioxide and carbon, which reacts as follows [25, 26]:

$$SiO_2 + 3C \rightarrow SiO + 2CO \qquad (2.1)$$

The reaction is strongly endothermic, and it takes place in several stages:

$$SiO_2 + C \rightarrow SiO + CO \qquad (2.2)$$

$$SiO + C \rightarrow Si + CO \qquad (2.3)$$

$$Si + CO \rightarrow SiC + O_2 \qquad (2.4)$$

According to [25] the yield and quality of the SiC are seriously affected by any impurities present in the raw materials. Therefore, high-purity raw materials must be used. Properties of silicon carbide are low density, high strength, low thermal expansion, high hardness, high elastic modulus, excellent thermal shock resistance and superior chemical inertness [26]. All of these qualities make SiC a perfect candidate for high power and high temperature electronic devices, as well as abrasion and cutting applications [25, 26].

Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800 °C [10]. In air, SiC forms a protective silicon oxide coating at 1200 °C and is able to be used up to 1600 °C. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant [10]. The benefits of using SiC as reinforcement are improved hardness, strength, wear resistance, and reduced thermal expansion. Additionally, SiC reinforcements are typically low- cost and are relatively low-density [27]. The properties of silicon carbide material are shown in table 2.7.

Table 2. 7. Properties of Silicon Carbide [24-27]

Property	**Value**
Density	3.1 g/ml
Hardiness Barnill	2800 HB(Kg/mm^2)
Melting Point	1650 ^{0}c
Tensile Strength	550 MPa
Poisons Ratio	0.33
Elastic Modulus	410 GPa
Coefficient of Thermal Expansion	4.0*10^{-6}/°C
Oder	Non

2.6. Aluminium-Silicon Carbide MMC

Aluminium metal matrix composites are the competent material in the industrial world. Due to its excellent mechanical properties like high strength to weight ratio and thermal stability; it is widely used in aerospace, automobiles, marine etc. [28, 29]. Aluminum is a ubiquitous element and one of the trace element with moderate toxic effect on living organisms [30]. The aluminum matrix is getting strengthened when it is reinforced with the hard ceramic particles like B_4C, SiC and Al_2O_3 etc.

According to [31] the SiC particles are the most common discontinuous reinforcements in aluminium matrix composites. Although the density of SiC is slightly higher than that of Al. This is because it is inexpensive and readily available but still gives the composite high strength and elastic modulus. In the same way as in the case of continuous SiC fibers the possibility of chemical reactions limits the high temperature applications and may cause problems in production. Aluminium silicon carbide composites are potential materials for various applications due to their good physical and mechanical properties. Krishna et al [32], investigated that the weight of the actuating cylinder can be reduced by replacing the cylinder material with Al-SiC matrix composite. Aluminium silicon carbide composite possess a density of 2.69 g/cm^3 compared to 7.85 g/cm^3 of stainless steel and when replaced, reduces the weight of actuator cylinder by 65.73 %. From the cost analysis, total fabrication cost and time consumed can also be reduced by replacing the existing design with Al-SiC composite in addition to weight saving attributes.

2.7. Fabrication Techniques for AMMCs

Manufacturing methods used for production of AMMCs should ensure uniform distribution of reinforcement in matrix and proper wet-ability of reinforcement in matrix. The manufacturing methods available for Al-SiC metal matrix composite can be broadly classified into three types. They are solid phase processes, liquid phase processes and in-situ processes [33, 34]. Solid phase process such as powder metallurgy, diffusion bonding, are expensive because it needs expensive starting materials such as powder or foil matrix etc. According to [34], among various manufacturing methods, stir casting is generally accepted as a promising route, because of low cost, little damage to reinforcement and stir cast components are not restricted by its size and shape. The processing methods of metal matrix composites are shown in figure 2.1.

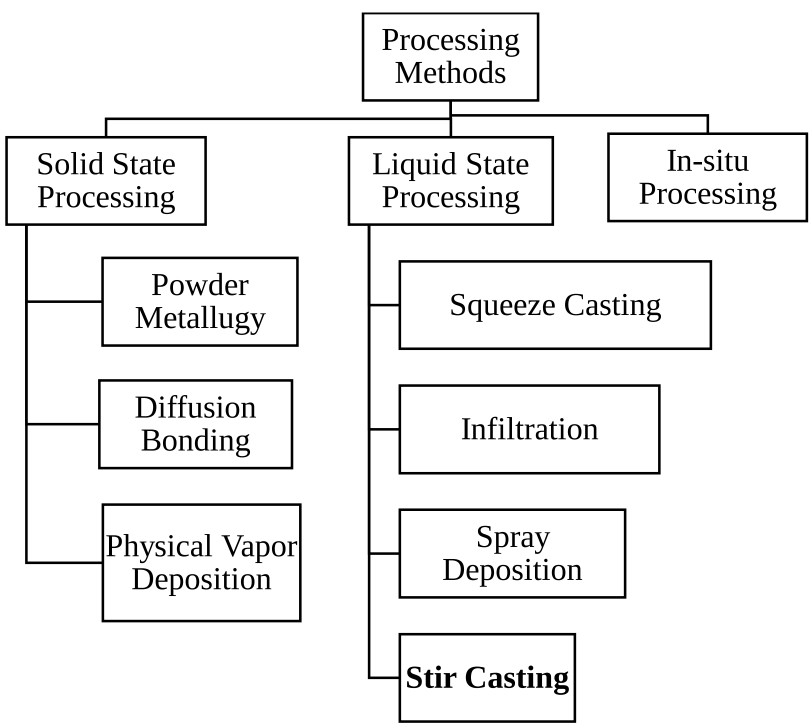


Figure 2. 1. Processing Methods of Metal Matrix Composites [33,34]

2.7.1. Solid State Processing

The solid state processing methods used for fabrication of metal matrix composite are use low temperature and the result is less interaction between matrix and reinforcement materials. By minimizing undesirable interfacial reactions, improved mechanical properties are obtained [35]. Powder blending is one of the solid state processing methods, and followed by consolidation, diffusion bonding and vapor deposition techniques [35]. In some cases, solid state techniques will permit the preparation of composites that cannot be prepared by the liquid metallurgy. However solid state techniques remain expensive compared to liquid metallurgy techniques. In addition, only small and simple shape can be produced by these techniques.

2.7.2. Liquid State Processing

The liquid metallurgy techniques include unidirectional solidifications to produce directionally aligned MMCs, and suspension of reinforcements in melts followed by stir casting, squeeze casting, spray casting and infiltration [5, 36]. The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of micro structural integrity desired. The liquid metallurgy techniques are the least expensive of all, and the multi-step diffusion bonding techniques may be the most expensive [36]. According to [5], the major advantages of these techniques are elimination of porosity and shrinkage, good surface finish, good dimensional accuracy, high strength to weight ratio, improved wear resistance, and higher hardness. Among the liquid state processing methods, the simplest and most commercially used technique is known as vortex or stir-casting technique [5, 36].

2.7.3. Stir Casting

Surappa et al. [37] has reports that vortex-mixing technique for the preparation of ceramic particle dispersed aluminum matrix composites was originally developed by Surappa & Rohatgi (1999) at the Indian Institute of Science, Bangalore. Subsequently several aluminum companies further refined and modified the process which are currently employed to manufacture a variety of aluminum metal matrix composites on commercial scale.

To ensure the uniform distribution of particles, stirring of the melt are suggested. This is why the distribution of particles of the cast particulate composite was not satisfactory uniform when it is prepared by injection technique or pallet method without stirring [38]. In this method molten metal in a crucible is stirred with an available impeller to form a vortex in the melt. The particles get entrapped in the melt and distribute uniformly in it during stirring. Here, the crucial things are to gate uniform distribution of reinforcements and to create good wetting between the particulate reinforcement and the liquid aluminum alloy melt [5, 36, and 38]. The schematic view of stir casting set up is shown in figure 2.2.

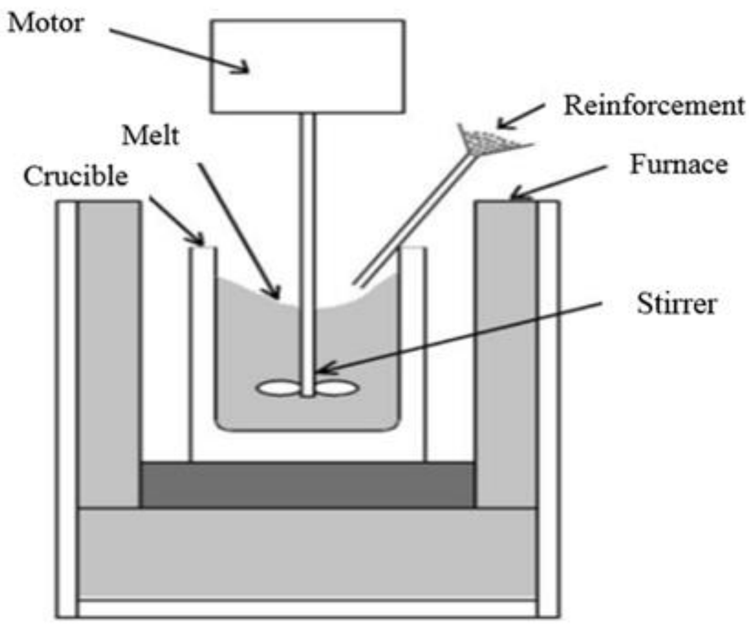


Figure 2. 2. Schematic View of Stir Casting Setup [20]

In preparing metal matrix composites by stir casting process, some of the factors that need considerable attention, which are [5, 36, and 38]:

- To achieve uniform distribution of the reinforcement material.
- To obtain sufficient wet-ability between the two main substances.
- To reduce porosity in the cast metal matrix composite.
- Stirring of the melt to minimize the settling of particles due to density difference.

Process parameters of stir casting such as Stirrer design, Stirrer speed, Stirring temperature, Stirring time (Holding time), Preheat temperature of reinforcement and Reinforcement Feed Rate, should be properly controlled to obtain good metallurgical properties of AMMC's [39 - 44].

Stirrer design: Stirrer is one of the fundamental equipment of stir casting process. According to Paul et al. [40], who investigated the effect of stirrer parameter on aluminium alloy, reinforced SiC MMC produced by stir casting method; stirrer design can affect the distribution and wet-ability of reinforcement. Results indicated that composite fabricated using four blade stirrer shows better properties than two blades [40].

Stirring speed: Stirring speed is one of the most important process parameters as wet-ability is promoted by stirring, such that bonding between matrix and reinforcement. According to [40, 41], the stirring action should be slow to prevent the formation of vortex at the surface of the melt, and care must be taken not to break the surface too often, which could contaminate the bath with dross. When induction melting, the furnace's natural eddy current stirring action usually is sufficient to disperse the particles, although supplementary hand stirring (with the power off) is also recommended to ensure that no particles have congregated in potential "dead" zones [41].

Stirring time: Uniform distribution of the particles in the liquid and perfect interface bond between reinforcement and matrix is promoted by stirring time [42]. In the processing of composite, the stirring time between matrix and reinforcement is considered as important factor. Less stirring leads to non-uniform distribution of particles and excess stirring forms clustering of particles at some places [42]. It is revealed that string time influences the viscosity of liquid metal, particles distribution and also induces some chemical reaction between matrix and reinforcement. And stirring time 5-10 minutes is recommended in aluminium silicon carbide composites [40 - 42].

Stirring temperature: Processing temperature influence on the viscosity of liquid metal and particles distribution. And also induce some chemical reaction between matrix and reinforcements; this varies depending on the type of constituents [43]. According to the study of [44], the results showed that the particles were distributed uniformly in the processing temperature 750 °C and 800 °C. Particles agglomerations were found in the processing temperature of 700 °C, 850 °C and 900 °C because of the changes of viscosity in liquid Al matrix. The viscosity of Al matrix decreases with increased processing temperatures.

Reinforcement pre-heat temperature: According to the research work in order to remove moisture or any other gases present within reinforcement, the reinforcement was preheated at a specified temperature for an hour. The wet-ability of reinforcement with matrix is promoted by preheating [41].

The summary of some fabrication techniques of metal matrix composite are shown in table 2.8.

Table 2. 8. Fabrication Techniques of MMC [35- 44]

Method	**Range of shape and size**	**Metal yield**	**Damage to Reinforcement**	**Cost**
Stir casting	wide range of shapes; no limited by size	Medium	No damage	Least expensive
Squeeze casting	limited by perform shape up to 2 cm height	Low	Severe damage	Moderately expensive
Spray casting	Limited shape; large size	Medium	-----------	Expensive
Powder Metallurgy	wide range of shapes Restricted size	High	Reinforcement fracture	Expensive

2.8. Mechanical Properties of AMMC

Due to its excellent mechanical properties AMMC are widely used in aerospace, automobiles, marine etc. The aluminum matrix is getting strengthened when it is reinforced with the hard ceramic particles and mechanical properties (hardness, compression and tensile strength) of composites are increased with increasing weight percentage of reinforcements [45]. Tensile strength, Hardness, and Compression strength are some essential mechanical properties of AMMC.

2.8.1. Tensile Strength

The tensile test is the most widely used test to determine the mechanical properties of materials [46]. Tensile strength is the stress at which a force applied causes the material to lengthen and then break. During the test, the specimen elongation and applied force are measured. The highest load in the tensile test gives the ultimate strength. Engineering stress and strain are calculated from the experimental values of applied force and specimen elongation. The true stress and strain that used to construct a stress-strain curve are deriving from engineering stress and strain. The following formulas are used to determine engineering and true stress and strain [46].

$$\text{Engineering strain } (\varepsilon_e) = \frac{L - Lo}{Lo} \qquad (2.5)$$

Where; L is final length after fracture; and Lo is Gauge length

$$\text{True strain} = \ln(1 + \varepsilon_e) \qquad (2.6)$$

$$\text{Engineering stress } (\delta_e) = \frac{\text{Maximum load}}{\text{Orginal cross sectional area}} \qquad (2.7)$$

$$\text{True stress} = \delta_e (1 + \varepsilon_e) \qquad (2.8)$$

2.8.2. Compression strength

Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to tensile strength, which withstands loads tending to elongate [32, 46]. Since the compression strength essentially depends up on height to diameter ratio of the specimen, the lateral instability due to buckling action can be avoided by keeping the ratio of height to diameter less than 2. Hence higher is height to diameter ratio; lower is compressive strength [46].

2.8.3. Hardness

Hardness is the property of a material to resist permanent indentation. The hardness test was done, in order to determine the hardness of materials, by Rockwell Hardness Number, the Brinell hardness number and the Vickers Hardness Number [47-49].

Rockwell Hardness (RHN) Test: The Rockwell hardness test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload [47]. The advantage of Rockwell hardness is its ability to display hardness values directly, thus avoid calculations involved in other hardness measurement techniques. Materials such as hardened bearing steels have small grain size and can be measured using the Rockwell scale due to the use of diamond indenters and high load.

Brinell hardness number (BHN) Test: The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a work piece for 30 seconds [48]. Materials such as cast irons and powder metals will need a much larger indenter such as used with Brinell scales. The value of the Brinell Hardness Number (BHN) is obtained by performing calculations using the following formula [48].

$$HB = \frac{2F}{\pi D - \sqrt{(D^2 - d^2)}} \qquad (2.9)$$

Where F is load applied, D is diameter of indenter and d is diameter of indentation

Vicker's Hardness (VHN) Test: The Vickers hardness test uses square-based pyramid diamond indenter with an angle of 136^0 between the opposite faces at the vertex, which is pressed in to the surface of the test piece as a prescribed force. Small parts or sections may need to be measured by using VHN. The hardness number is calculated by dividing the force by the surface area of the indentation. The square base pyramidal indenter is forced under a predetermined load ranging from 1 to 129 kgf into the material for a specific time (10 to 15 seconds for normal test times) and is then removed [49]. The resulting indentation diagonals are measured and averaged to give the value in micrometer. Mathematically the VHN is obtained by the following formula [48, 49].

HV= Constant × Test force/ Surface area of indentation

$$HV=0.102 \times \frac{2F\sin(\frac{136^0}{2})}{d^2} \tag{2.10}$$

Where F is the applied load in kgf and d is the mean diagonal of indentation in mm.

2.8.4. Microstructure Study of Aluminium Metal Matrix Composite

The mechanical and tribological properties of various Al metal matrix composites depend on the microstructure that is obtained after reinforcement with the various ceramic, organic etc. reinforcements [50]. The microstructure evolution depends upon the fabrication techniques, rate of solidification and composition of the composite. It reveals the distribution of the reinforcements in the aluminium matrix. It is also used to detect the micro defects such as porosity, micro cracks etc. that are formed during fabrication process due to the clustering of reinforcements [34, 50].

2.9. Factors Affecting the Properties of AMMC

Although the previous section briefly discussed some of the properties of AMMC, the composites exact set of properties depend on a number of factors. From the existing literatures, three factors that could affect the properties of AMMC are identified. These are:

- Reactivity of the matrix and the reinforcing material
- Volume fraction of the reinforcing material
- Distribution of the reinforcing material

Reactivity of the Matrix and the Reinforcing Material: This is the important factor which contributes largely to the overall working and behavior of the composite. According to [51] the reaction between matrix and reinforcement materials can be prevented by preheating of reinforcement and cleaning the surface of both phases before mechanical stirring. In the case of Al-SiC the primary reaction at the interface is [51]:

$$4Al + 3SiC \rightarrow Al_4C_3 + 3Si \tag{2.11}$$

However, increased reaction between Al and SiC due to a long exposure time or a very high casting temperature can lead to the formation of a thicker layer of Al_4C_3 which might make the AMMC brittle [51, 52]. The melting of aluminum is evident from about 650 ^{0}C and just after this, an exothermic trend could be observed, which corresponds to the occurrence of a reaction between Al and SiC, leading to a large release of heat. That means, Al and SiC mainly reacts with each other just after the melting of aluminum [53].

Volume Fraction of the Reinforcing Material: Since the reinforcing material carry a major portion of stress in the MMC (because it's stiffer) [42], the composite volume fraction, determine the final properties of the material. The mechanical properties of AMMCs, such as tensile strength, compressive strength, hardness, impact strength and wear resistance, all of which increase/improve with an increase in SiC [54]. The reasons for this increase in these properties are attributed to the number of SiC particles that are directly proportional to the stress needed to initiate and propagate the cracks in the composite and due to fact that more load is transferred to the reinforcement which results in higher ultimate strength [54, 55]. The improvement in mechanical properties of AMMCs is only up some weight percentage of reinforcement. According to [56] the tensile strength and hardness increases with the SiC content up to 15% after which it drops. The authors say this happens because the increasing quantities of SiC particles react with each other (clustering) and void nucleation which leading to failure at lower stresses.

Distribution of the Reinforcement Material: When fabricating MMCs through casting or similar liquid phase techniques, the distribution of the reinforcement material is an important factor to be considered as it affects the properties of the material. According to [5] the particle distribution is affected at three stages of the fabrication process i.e., during mixing, after mixing but before solidification (holding) and during solidification. He suggests the use of *stir casting* as it not only helps in the transfer of the particles to the melt but also retains them in a state of suspension. The solidification/cooling rate of the composite is important because it influences the distribution of the SiC in the final ingot. when the material is cooled rapidly, there is a more homogenous distribution of SiC particles compared to a more slower rate which results in a more clustered distribution (because of more particle pushing) [57].

2.10. Application of Al-SiC Composites

The Metal matrix composite materials are widely used in automotive engineering applications. The most important property of aluminium-silicon carbide with reference to the aerospace industry is its strength to weight ratio, which is three times more than mild steel [32]. In addition, Al-SiC composites have high strength, wear resistance, high thermal stability, less weight and a more effective load carrying capacity [9, 16]. Therefore, Al-SiC composite offers considerable advantages to the aerospace industry especially in applications that require good thermal and tensile properties. According to [59, 60] aluminum-silicon carbide composite material is one of the option as a material for power transmission gears and connecting rod. Krishna et al [32], investigated that the weight of the actuating cylinder can be reduced by replacing the cylinder material with Al-SiC matrix composite. Al-SiC composite possess a density of 2.69 g/cm^3 compared to 7.85 g/cm^3 of stainless steel and when replaced, reduces the weight of actuator cylinder by 65.73 %. From the cost analysis, total fabrication cost and time consumed can also be reduced by replacing the existing design with Al-SiC composite in addition to weight saving attributes.

Conclusion: According to different literatures, the SiC reinforcement in the Al-MMCs is more fracture resistant compared to $A1_2O_3$ and Si. The wet-ability results of different literatures showed that, aluminium and silicon carbide developed good wettability at interface of metal matrix composite. Non-uniform distribution is due to the difference in density. So particulate silicon carbide is slightly greater density than aluminium matrix, and the high melting point of silicon carbide, not promote the chemical reaction between the aluminium and silicon carbide. The studies show that an increase in weight fraction of reinforcement results in improvements of mechanical properties of composite.

The major limitations in the existing literatures on fabrication of AMMCs are: Not many studies have been reported on the fabrication of Al-SiC metal matrix composite by using pure aluminium as matrix material. And also no or very limited studies have been reported on the effect of content of SiC over the improvement of hardiness, tensile and compression strength of pure aluminium silicon carbide composite.

CHAPTER 3

MATERIALS AND METHODOLOGY

This chapter describes details of experiments conducted for the present work which include material selection, sample preparation, hardiness test, compressive test and tensile strength test.

3.1. Materials Used

Aluminum: Aluminium of commercial grade with 99.5% purity was used for the casting. For this work, unalloyed aluminium, with 99.5% aluminium composition was changed in to scrap form and melted by using stir casting. The reason for selecting this material is its vast applications in major industrial areas such as aerospace and automotive industries. Figure 3.1 shows the scrap form of pure aluminium. The compositions of aluminium alloy was analyzed using glow discharge spectrometer (serial NO. 10008619) and are shown in Table 3.1. For detail see appendix V.

Table 3. 1. Chemical Composition of Aluminium Used in this Work

Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Sn	Cr	Ga
99.5	0.17	0.21	0.002	0.002	0.0035	0.008	0.031	0.0078	0.018	0.0079	0.014

Figure 3. 1. Pure Aluminum in Scrap Form

Silicon Carbide: Silicon Carbide is the chemical compound of carbon and silicon. Its low in cost and the unique properties like, high hardness, chemical inertness, high thermal conductivity, low coefficient of thermal expansion and strength at high temperature ranges, make the SiC more selective reinforcements for this work. In this paper SiC of average 50 μm grain size was used for casting the composite. Figure 3.2 shows the silicon carbide in powder form.

Figure 3. 2. Silicon Carbide in Powder Form

3.2. The Equipment Used for Fabrication of Al-SiC Composite

- Analytical balance for measuring weight of materials;
- Muffle furnace for preheating of SiC;
- Stir casting set-up for formation of composite;
- Sand casting for molding processes;
- Conventional lath machine for secondary processing;
- Universal material tester for tensile strength and compression strength testing processes;
- Computerized Vickers Hardness tester for micro-hardness test;
- Optical microscopic for micro-structure study.

3.3. Methodology for Developing of Al-SiC Composite

The commercially pure aluminium used in this work as a matrix material was changed to the scrap form, to make it suitable for measuring its weight gram and also the scrap form is easy to add in to the crucible for melting. The scrap of pure aluminium and powder of silicon carbide were ready as required for composition development in weight gram and weight percentage. The samples were prepared for tensile test, hardness test, compression test and microstructure studies according to their standards. It was by considering the standard dimension of the samples for experimental test. The weight of the materials required for the preparation of samples according to their standard dimension was calculated by using the following formula (see Appendix I).

$$\text{Weight (g)} = \text{Volume (cm}^3\text{)} \times \text{Percentage (\%)} \times \text{Density (g/cm}^3\text{)} \tag{3.1}$$

The amount of both aluminium and silicon carbide required was measured by using analytical balance (model FA2104). The analytical balance that have been used in measuring the amount of Al and SiC as required for spacemen preparation is shown in Figure 3.3 (Appendix I).

Figure 3. 3. Analytical Balance

Table 3.2 shows weight percentages and weight gram of aluminium and silicon carbide that required for the preparation of composite.

Table 3. 2. Percentage Composition of Al and SiC for Composition Preparation (Appendix I)

Samples	Aluminium (Al)		Silicon-Carbide (SiC)	
	Weight (g)	Weight (%)	Weight (g)	Weight (%)
1	978.56	100	0	0
2	954	97.5	24.45	2.5
3	929.6	95	48.93	5
4	905.1	92.5	73.40	7.5
Total	3,769.8		146.78	

3.3.1. Production of the Composite by Stir Casting

Stir casting process is the most economical, simple, flexible and applicable to large volume production, among all the available routes for AMMCs production. However, considerations for achieving AMMC, such as; no adverse chemical reaction between the two phases, no or very low porosity content in the cast AMMCs, wet-ability between the two main phases and a uniform distribution of the reinforcement material, make the stir casting more selective.

3.3.2. Steps Involved in Stir Casting

Figure 3.5 shows the procedures followed during the stir casting process of aluminum silicon carbide metal matrix materials.

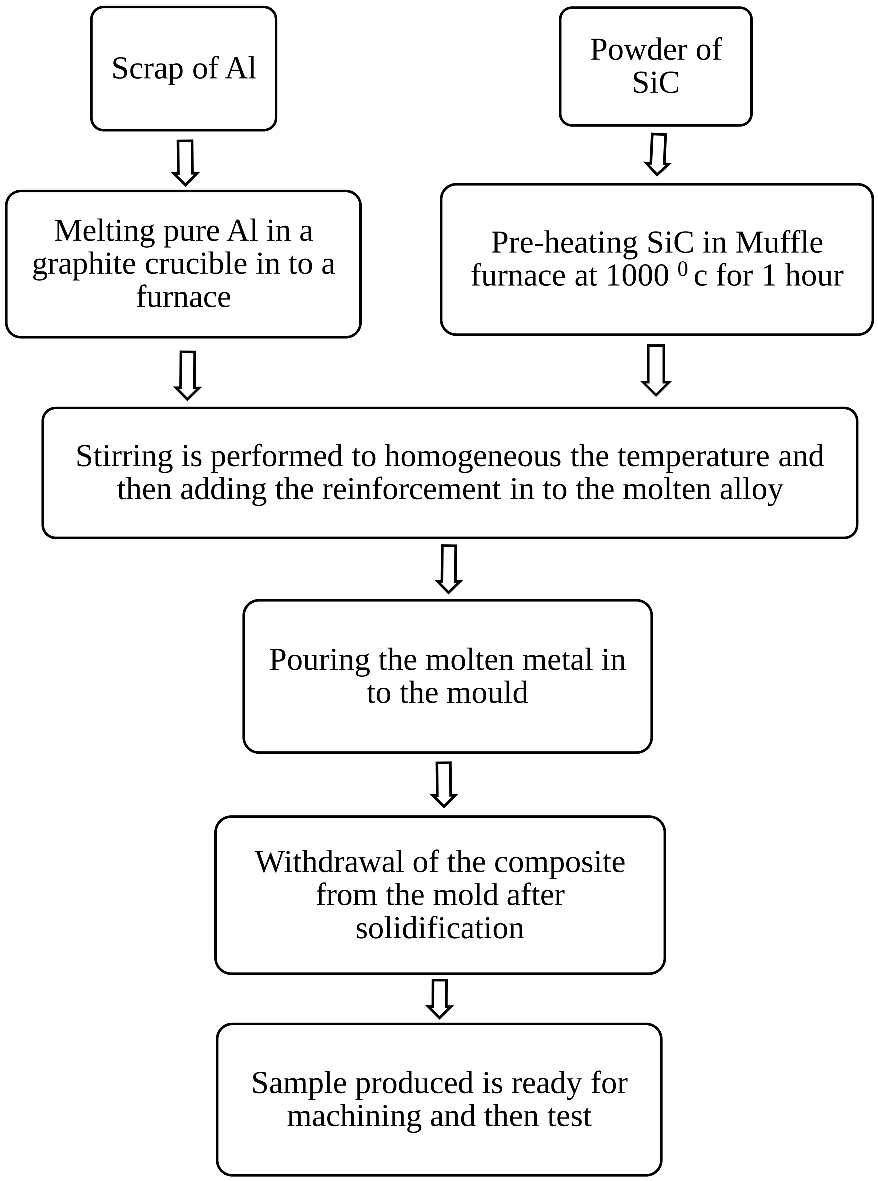


Figure 3. 4. Flow Chart Showing Steps Involved in Stir casting-Casting

3.3.3. Process Parameters

Controlled parameters:

- Weight percentage of SiC

Fixed parameters:

- Grain size of SiC [grade]
- Pre heating temperature of SiC
- Melting temperature of Al,
- stirring time and stirring speed

First of all stirring system has been developed by coupling motor with gearbox and a high-speed steel (HSS) stirrer. All the melting was carried out in a graphite crucible in an oil-fired furnace. The furnace temperature was first raised at the melting point of pure alumunium to melt the alloy scraps completely and was then cooled down just below the liquids to keep the slurry in a semi-solid state. At this stage, the preheated SiC particles were added proportionately by weight in the ratio of 0%, 2.5%, 5%, and 7.5% and mixed manually. The percentage of alloying element to be used was determined by literature reviews and history for development of this work. Manual mixing was used because it was very difficult to mix using automatic device when the alloy was in a semi-solid state. After sufficient manual mixing was done, the composite slurry was reheated to a fully liquid state and automatic stirring was carried out with the help of radial drilling machine and HSS stirrer for10 minutes at stirring rate of 290 RPM. In the final mixing process the furnace temperature was controlled within 700 $\pm$10 ^{0}C. After stirring process the pouring of the composite slurry has been carried out in the sand mould prepared according to the specifications for hardness, microstructure and tensile strength test specimens.

3.3.4. Mould Preparation

The non-metallic group molding, sands, graphite, silicon carbide and ceramics are included. But, out of all, the sand molding is the most common utilized non-metallic molding material because of its inherent properties like, chemical and thermal stability at higher temperature. Moreover, it is also highly cheap and easily available. In this work the mold cavities were prepared for the preparation of different size spacemen for hardiness and tensile strength tests. Figure 3.6 and 3.7 shows the sand mold boxes have been used for fabrication of tensile and hardiness test specimens respectively.

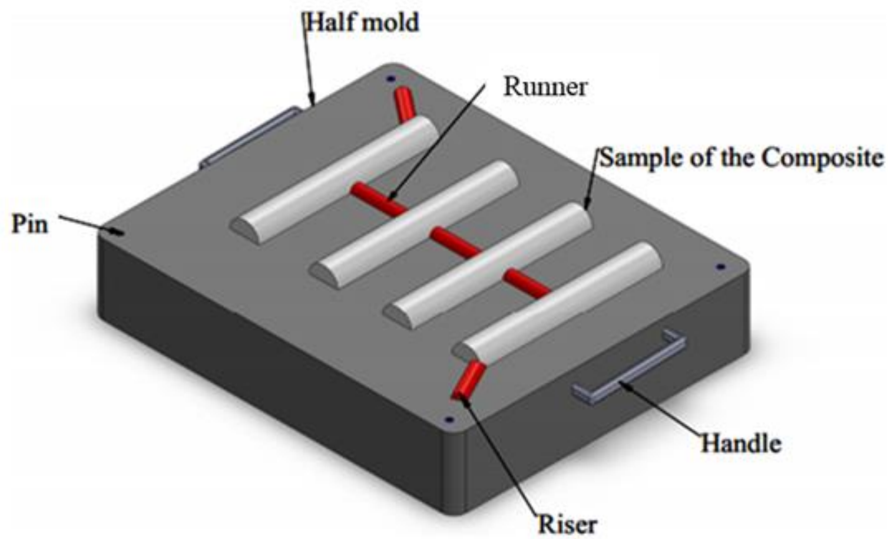


Figure 3. 5. Sand Mold Box Used for Making Tensile Test Samples

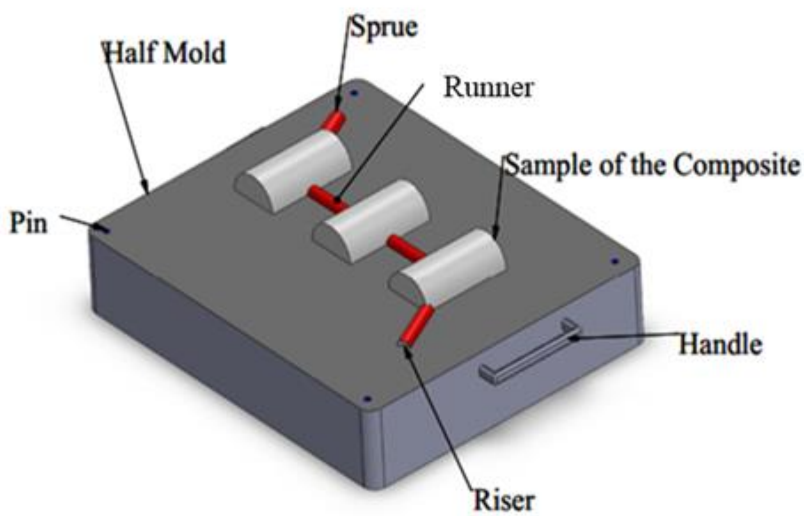


Figure 3. 6. Sand Mould Box for Making Hardness Specimens

3.3.5. Sample Size and Sampling

The samples of the composite were prepared according to their standard dimension required for tensile, hardness and compression strength test and also for microstructure study.

Samples for Tensile Test: The tensile test was performed to determine various mechanical properties such as tensile strength and % of elongation. The rod form of specimens in the dimension of (24 mm diameter and 150 mm length) were prepared by pouring the molten composite in to sand mold, that have prepared for tensile test sample preparation. Figure 3.8 shows the samples have been fabricated for tensile test.

Figure 3. 7. Samples Prepared for Tensile Test before Machining

The prepared rod samples were brought down to final dimensions as per ASTM E8 Standard by machining the samples using conventional lathe machine. The machined samples were nominated to test for mechanical properties like tensile strength and percent of elongation. Three samples were prepared for each composition for tensile strength test. The specimens used in compression test were cut from the tensile test sample during machining process. Tensile test samples and its geometry are shown in Figure 3.9 and 3.10 respectively.

Figure 3. 8. The Tensile Test Specimens

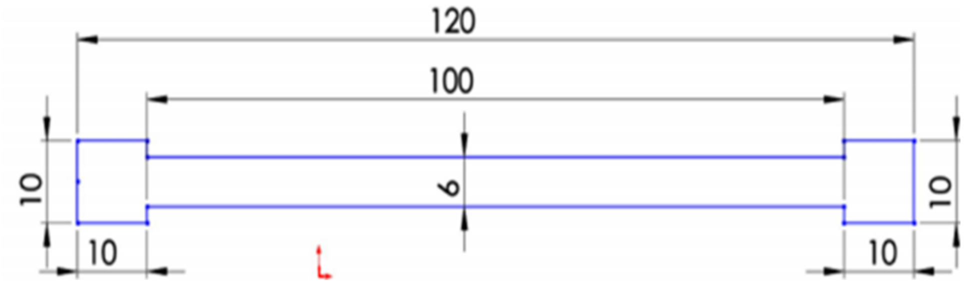


Figure 3. 9. The Final Dimension of Tensile Test Specimen 2D Drawing

Samples for Hardness Test: The rod form of specimens in the dimension of (40 mm diameter and 72 mm length) were prepared by pouring the molten composite in to sand mold, that have prepared for hardness test sample preparation. Hardness test specimens are shown in Figure 3.11.

Figure 3. 10. Samples Perpared for Hardness Test befor Machining

The prepared rod samples were came down to final dimensions (diameter 20mm and length 24mm) for micro hardness test by machining the samples using conventional lathe machine. The samples were polished by 400, 600, 800 and 1200 grit paper, to clean by removing any irregularity and get fine surface before testing their hardness. The specimens used for hardiness tests and its final dimension are shown in figure 3.12.

a b

Figure 3. 11. (a) Hardness Test Specimens, (b) final Dimension of Hardiness Test Samples

Sample Preparation for Optical Microscopy: Casting composites samples used for microstructure observation was cut into circular bars with dimensions of 20 mm in diameter and 20 mm height using a low-speed abrasive cutting saw. The samples were prepared for micro structural study as per ASTM E3-11 standard. To gate mirrored surface, the specimens of composites were polished with six different emery papers of 200 grit to 1200 grit size. The polished and cleaned specimens were mounted by using hot mounting press (compression mounting) machine. This system consists of upper ram, lower ram, cylinder, heating part, cooling part and mold. It is automatic mounting press that automatically operates pressure, heat and cooling by water. To obtain mirror like smooth surface, super finishing is carried out on velvet cloth or silicon carbide paper embedded disc polisher using diamond suspension.

Finally the polished specimens were cleaned with acetone and etched with (Methanol (25 ml) + Hydrochloric (25 ml) + Nitric Acid (25 ml) + Hydrofluoric acid 1 drop) and ready for microstructure study. The treatments of mirrored surfaces by etchants are used for avoid chemical attack on the phases and to make the secondary phases visible in the microscope at higher magnification. The specimens have been prepared in final dimension for microstructure studies are shown in figure 3.13.

Figure 3. 12. Specimens for Microstructure Study with SiC Content; (a) 0%, (b) 2.5%, (c) 5%, (d) 7.5%

3.3.6. Testing of the Specimen

Checking Hardness over Vickers Hardness Tester: Hardness measurements have been carried out on the Al-SiC composite samples by using standard Vickers hardness test machine (model HVS-50, serial NO. 0009) shown in figure 3.14 (a). Vickers hardness measurements were carried out in order to investigate the influence of SiC weight fraction on the matrix metal (aluminium). For indentation a 136° pyramidal diamond indenter is used. The hardness values were measured in four different locations over the surface of the samples and average value was calculated. For hardiness test the specimens were loaded onto the machine and the test was carried on as follows:

- The indenter was pressed into the sample by an accurately controlled test force.
- The force of 10 kgf is maintained for a specific dwell time, normally for 15 sec.
- After the dwell time was completed, the indenter was removed leaving an indent in the sample that appears square shaped on the surface.
- The size of the indent was determined optically by measuring the two diagonals of the square indent.
- The Vickers hardness number is a function of the test force divided by the surface area of the indent. The average of the two diagonals is used in the following formula to calculate the Vickers hardness. HV = Constant X Test force / (Indent diagonal)^2 [48].

$$HV = 0.102 * 2F\ [\sin\frac{136^0}{2}]/d^2 \qquad (3.2)$$

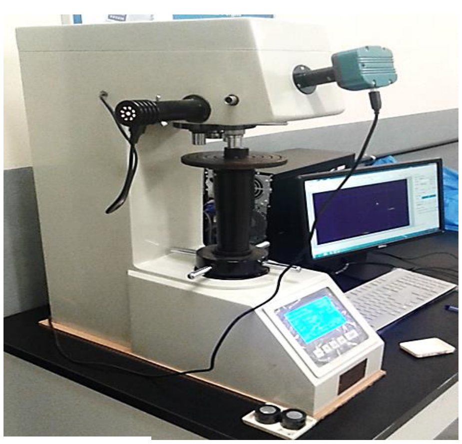
Where F is test force, d is the mean diagonal of indentation and the constant is a function of the indenter geometry and the units of force and diagonal (see from appendix II).

Checking Tensile Strength: The tensile test was carried out at room temperature in the computerized universal testing machine model-WP 310, Sr. No. 49553-40387, maximum load 50 KN, shown in figure 3.14 (b). The specimen was gripped by the holding jaws. The grips are two small round shape hollow structures in which the specimen can be held in between with the help of a ring over it. On fixing the specimen and ensuring that all the electrical connections are made on the tensometer, the computer that controls the system is switched on. Software controls all the operations. All the data regarding the specimen was fed in the system. The Tensile load was applied gradually from initial value of 0.5 KN till failure load. The tensometer stretches the specimen by incrementing the force it applies until the specimen breaks. After the specimen breaks, a message of termination of the function appears. The applied load and displacement are recorded for every displacement of 0.01mm. After the readings have been saved, the specimen is removed from the tensometer and is set to be used for another specimen. Three samples were tested for each composition for the tensile strength and the average has taken. The engineering stress (δ_e) and engineering strain (ε_e) are calculated from force and displacement, have recorded during tensile test (see appendix III).

$$\delta_e = \frac{F}{A} \tag{3.3}$$

$$\varepsilon_e = \frac{\Delta L}{L} \tag{3.4}$$

Where, F if applied load, A is cross sectional area, L gauge length and ΔL is change in length.



(a)

(b)

Figure 3. 13. (a) Vickers Hardness Tester, (b) Universal Material Tester

Compression Strength Testing: Compression test specimens were prepared according to ASTM E9 standard for the testing of materials, maintaining the L/D ratio of 1.5. In this work cylindrical specimens with 8 mm diameter and 12 mm length were used for compression testing. The testing took place also using the universal testing machine. During the conduction of the tests, the specimens were compressed between two flat plates, one being movable and the other being stationary, and their deformations at various loads were recorded.

In this study, the compressive strength of the pure Al as well as the developed composite (Al-SiC) at room temperature were measured using universal testing machine shown in Figure 3.14 (b) and corresponding test specimens after testing are shown in Figure 3.15. The two ends of samples surface were polished using SiC grinding paper, before starting the compression test. This was in order to reduce the friction between the specimens and die surfaces during compression and in order to make sure of flatness at both sides. The dimensions of the sample (initial diameter and height) were recorded before testing. This information was used for the calculation to get the compression strength and strain of the sample. The stress and strain values were calculated for the three materials of similar geometry, for each percentage of SiC content. And the compression test results are based on an average of three independent test values of each material. To measure the stress and strain of the samples with the compression range, the sample were loaded with the load measurement. The samples were then unloaded, and then again measure the displacement and diameter repeat again up to fracture. The true strain (ε_t) can be calculated as:

$$\varepsilon_e = \frac{\Delta L}{L} \tag{3.5}$$

$$\varepsilon_t = \ln(1 + \varepsilon_e) \tag{3.6}$$

Where, ΔL is the change in length, L is initial sample length and ε_e is the engineering strain.

$$\delta_t = \frac{F}{Ai} \tag{3.7}$$

Where δ_t is true compressive stress, F is applied load and A_i is the instantaneous cross sectional area of sample normal to the loading direction.

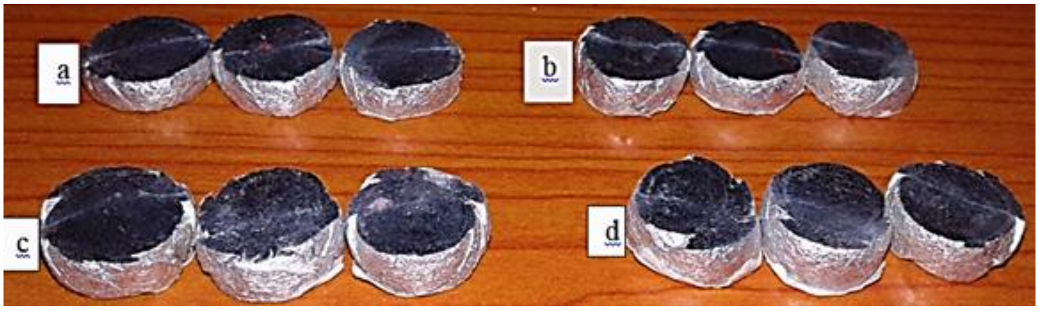


Figure 3. 14. Specimens of Compression Test, After Testing, with SiC Content; (a) 0%, (b) 2.5%, (c) 5%, (d) 7.5%

Checking Microstructure over Optical Microscope: Microscopic analyses of the composite samples were performed by optical microscopy of model: Huvitz HR-300 series, shown in figure 3.16. An image was seen by 1000 magnification (x1000) and an image analyzer was used to examine the distribution of the reinforcement particles within the aluminum matrix.

Figure 3. 15. Optical Microscope for Microstructure Study

CHAPTER 4

ANALYSIS

In this chapter the data recorded during experimental tests and microstructure study will be analyzed and the effects of weight percentage of SiC particles over the improvement of mechanical properties of Al-SiC will be discussed.

4.1. Mechanical Properties of Al-SiC Composite

The effects of changes in contents of SiC in Al-SiC composite can be analyzed by determining the mechanical properties of these composite samples under different tests. In this work tensile, compression and Vickers micro hardness tests were conducted in order to evaluate the effects of composition of SiC over the improvement of the mechanical properties of Al-SiC composite.

4.1.1. Hardness of Aluminium-Silicon Carbide composite

The resistance to indentation is termed as hardness strength. Analysis of hardness of materials is important, since hardness measurements are used for the quality control of materials. The main aim of hardness analysis was to quantify the effects of weight percentage of silicon carbide on the hardness of aluminium-silicon carbide composite.

In this work hardness test was carried out at room temperature using a load of 10 Kgf Vickers hardness testers with at least four indentations of each sample and then the average values were utilized to calculate hardness number. Results of micro hardness of the samples are shown in Table 4.1. The results show that the added amount of SiC particles enhances hardness, as these particles are harder than aluminium alloy, which render their inherent property of hardness to soft matrix. The variation of the hardness values in the composite, possibly being caused by the uniform distribution of the SiC in the molten. This was, because of the pouring and string methods used during fabrication of the composite. The increasing of hardness was observed as well as weight percentage of SiC increase from 0 percent to 7.5 percent. However, gradually increasing in hardness was slow as weight percentage increase. The increasing in hardness become slowly might be due to increasing in particles agglomeration [1, 2]. Grain boundary is one of defects that lead to increase the value of free energy of materials. Thus, in order to reduce free energy in materials, particle size should be large enough to shrink the grain boundaries. Nevertheless, increasing in grain size will lead lack of resistance and allowed dislocation to occurred which is primary reinforcement mechanism [1, 58]. Variation of hardness of Al-SiC composites with the contents of SiC was shown in figure 4.1. It is observed that with increase in composition of SiC, hardness of composites increases.

Table 4. 1. Vickers Hardness Testing Results in Al-SiC Composites

Composition	Vickers hardness by 10 kgf				Average VHN
Non reinforced Al	29.6	30.3	27.4	29.4	29.18
Al + 2.5% of SiC	36.6	32.3	34.7	31.4	33.75
Al + 5% of SiC	37.8	38.3	40.4	38.7	38.80
Al + 7.5% of SiC	39.4	38.8	41.3	39.6	39.76

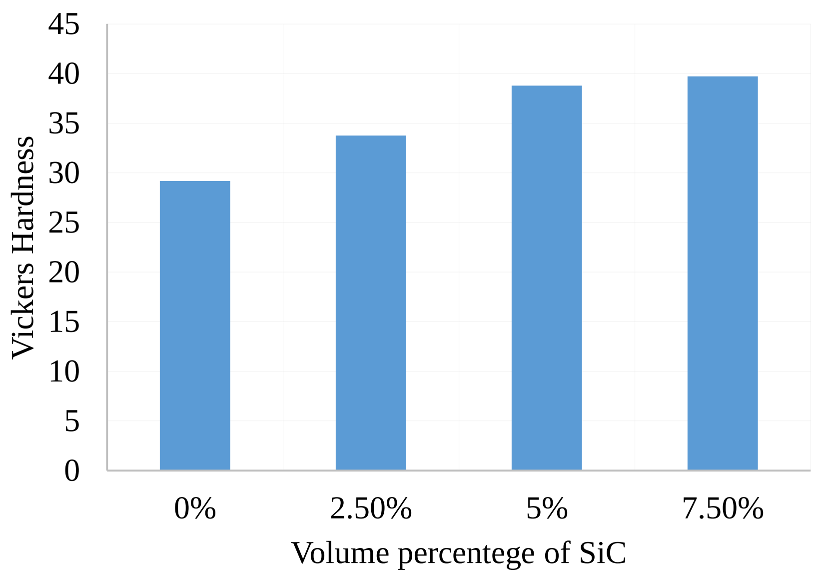


Figure 4. 1. Hardness Distribution in the Al-SiC Composites

As the results indicated in Figures 4.1, there is rapidly increasing trend of hardness strength with increase in contents of SiC up to 5 percent. Beyond this percent of SiC the rate of increasing in hardness strength started decreasing as SiC particles interact with each other leading to clustering of particles and consequently settling down. Eventually the density of SiC particles in the melt started decreasing thereby lowering the hardness [1, 32]. Since the weight percentage of SiC is very small there is no appreciable increase in hardness as the weight percentage of reinforcement increases. The increasing rate of hardness of Al-SiC composites from 2.5% to 5% SiC by weight percentage is higher compared to 5% to 7.5% SiC. This implies the requirement of an optimum weight percentage of reinforcement in the matrix for better hardness. As shown in table 4.1 the hardness of sample 1 (un-reinforced alloy) is 29.18 VHN, it increase with increase in weight percentage of Silicon carbide and it reaches to a maximum value of 39.74 VHN for sample 4, which has maximum value of SiC (7.5%). It is observed that the hardness of the composites is higher than that of the un-reinforced alloy. Figures 4.2 indicate that Sample 4 has the highest amount of ceramic particles, followed by Samples 3, 2 and 1 in turn.

According to [7, 55], the composites hardness increase along with mass per weight content of SiC. The value was increase drastically at early reinforcement volume. However, rate of increasing hardness value decrease after 5% of SiC. He also found that increasing in hardness of AMMC not only caused by increasing volume of reinforcement, but also from uniform distribution of silicon carbide particles. As the indenter moves downward during the hardness test, the pressure has been accompanied by no uniform matrix flow along with localized increase in particle concentration, which tends to increase the resistance to deformation [20]. Consequently, the hardness value increases due to local increase in particle concentration associated with indentation.

The hardness of Al reinforced by 7.5% of SiC is higher than Al reinforced by 5% of SiC as shown in Figure 4.2. It was believed that the difference in silicon carbide content in composites influence the hardness properties. Silicon carbide is a material having a higher strength than aluminum. Thus, the increase in the quantity of silicon carbide in the composites increases the strength of the Al-SiC composites. Hardness of aluminium reinforced by 5% SiC was also higher than non-reinforced aluminium. These results also supported by report from [1, 2, 7] which found that the hardness of the composites of aluminum reinforced with silicon carbide increase with increasing the silicon carbide content. The hardness reading of Al reinforced by 7.5% SiC was increased by almost 36.2% more than non-reinforce one. It was concluded that the higher percentage of silicon carbide, the higher hardness of composites. The hardness strength results obtained in this study are comparable to results from other researchers. This is summarized in Table 4.2.

Table 4. 2. Average Hardness Value of Al-SiC Composite of Different Works

Samples	Average VH	Process used	Authors
Al (99.5%)	29.18 VH	Stir casting	Current work
Al + 2.5%SiC	33.75 VH		
Al + 5%SiC	38.80 VH		
Al + 7.5%SiC	39.74 VH		
Al (99.7%)	28.5 BHN	Stir casing	M. Singla et al [1]
Al + 5%SiC	38.2 BHN		
AA1050	24.50 VH	Stir casting	R. Krishna et al. [32]
Al + 3%SiC	31.24 VH		
Al + 9%SiC	38.67 VH		
Al (98.5%)	30.8 BHN	Stir casting	Hassan et al [2]
Al + 3%SiC	32.4 BHN		

All researchers conclude that the hardness of aluminium silicon carbide increases as the contents of SiC increased. But, the rate of increasing in hardiness is decreased as the volume of the SiC increased and when, the volume is above the optimum value the hardness strength of composite gate decreased. Such that all are agree with the current work.

4.1.2. Tensile Strength of Al-SiC Composite

The tensile strength of material is the stress that a material can withstand while being stretched, before breaking. Tensile test is fundamental test of mechanical where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of specimen over some distance. The cross sectional area of work peace will change when load is applied. But in engineering stress-strain curve it is not possible to measure accurate area at the time when the load is applied. Since the stress of materials found during tension from the applied force is engineering stress, the true stress of the materials was calculated by using the following formulas. Since the true stress based on the instantaneous cross-sectional area of work peace and the true strain is based on instantaneous length measurement, the curve is called as true stress-strain curve.

$$\text{True stress } (\delta_t) = \delta e\,(1 + \varepsilon_e) \qquad (4.1)$$

$$\text{True strain } (\varepsilon_t) = \ln\,(1 + \varepsilon_e) \qquad (4.2)$$

Where, δ_e is engineering stress, ε_e is engineering strain, ε_t is true strain and δ_t is true stress.

Tensile testing of Al-SiC composite was carried out at room temperature using a computerized universal testing machine, maximum load 50 KN. Standard specimens with 100 mm gauge length and 6 mm in diameter were used to evaluate ultimate tensile strength, and percent of elongation. In this work three trial tests for each reading were taken. Average was taken that of three reading. Table 4.3 show the results of tensile strength with the percentage of silicon carbide. The experimental results show that in general, the tensile strength of the AMMC's produced are somewhat higher than that obtained for the non-reinforced alloy. It can be noted that the addition of silicon carbide particles improved the tensile strength of the composites. Figure 4.2 shows the effect of volume fraction of SiC on the tensile strength Al-SiC composite. The tensile strength of the sample1, in non-reinforced condition is 88.22 MPa, and this value increases to a maximum of 151.60 MPa, for sample 4 (Al + 7.5%SiC), which is about 43% improvement on that of the non-reinforced matrix material. Figure 4.2 shows the variation of tensile stress of Al-SiC composite for various percentage of reinforcement (SiC). It is observed that ultimate tensile strength of Al-SiC composite increases with the increase of weight percentage of silicon carbide; while it is reverse for the total elongation, as shown in figure 4.3. This may be due to the presence of hard silicon carbide precipitates which increase the strength of Al-SiC composite [35].

Table 4. 3. Tensile Strength Testing Results of Al-SiC Composite (see appendix III)

Composition	Average True Stress (MPa)
Pure Al (99.5)	88.22
Al + 2.5%SiC	110.081
Al + 5%SiC	144.12
Al + 7.5%SiC	151.60

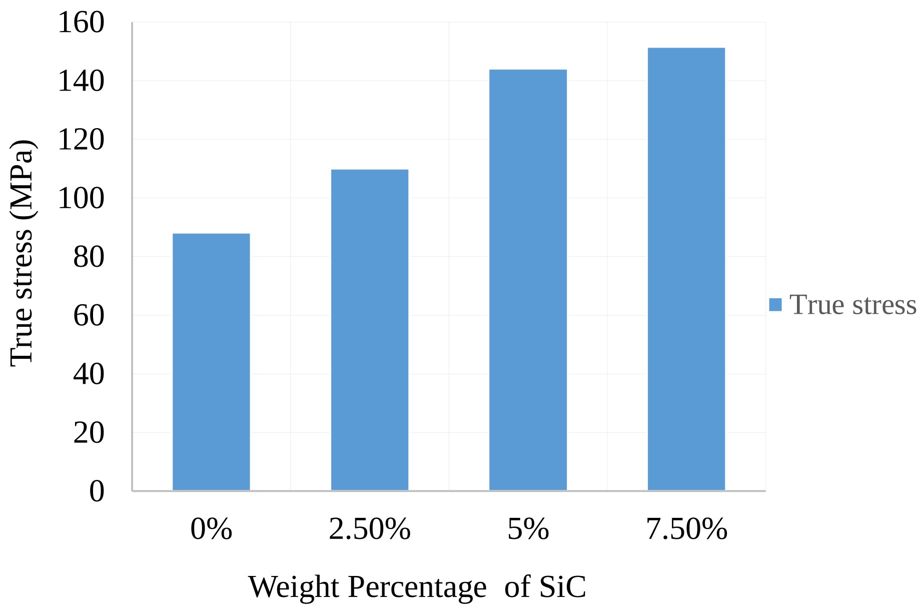


Figure 4. 2. Tensile Strength of Al-SiC as a Function of Weight Percentage of SiC Particles

The ductility of a material is a measure of the elongation to which a material will deform before fracture. It also provides an indication of how visible overload damage to a component might become before the component fractures. Ductility is also used a quality control measure to assess the level of impurities and proper processing of a material [7]. In tensile test the increasing in length of specimen before fracture is usually expressed as a percentage of elongation. Table 4.4 and figure 4.3 shows the reduction in percentage of elongation of aluminium-silicon carbide metal matrix composite as the percentage of SiC particle gate increased.

Table 4. 4. Elongation of Al-SiC Composite

Elongation per samples	
samples	Elongation (%)
1	4.71
2	3.40
3	2.46
4	1.95

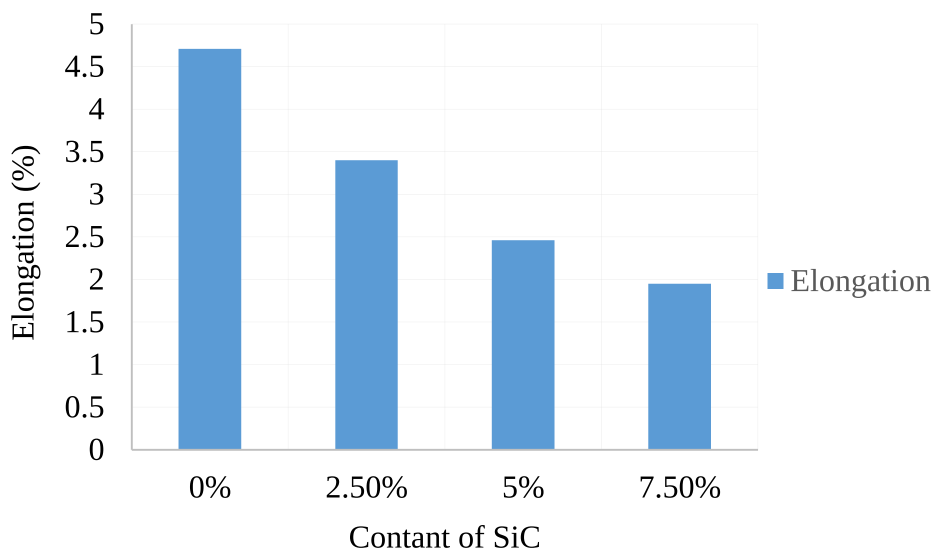


Figure 4. 3. Effects of SiC Weight Percentage on Elongation of AMMC

It can be seen that the introduction of SiC particles into A1 alloy results in a significant reduction in their ductility. Ozben et al. [7] relate such a reduction in ductility to a distribution of SiC particles and void initiation at the reinforcement matrix interface. The percentage elongation is the measure of ductility. The break elongation decreases with increase in weight percentage of the reinforcement. From the figure 4.3 it is clear that, the break displacement was maximum;

for non-reinforcement alloy and reduced as the weight percentages were further increased. From figure 4.3 it is observed that as percentage of reinforcement increases the ductility of composite material decreases from 4.71% to 1.95%. The combined effect of tensile strength and ductility is the indication of toughness. From the results of tensile strength and ductility, the indication of ductility of the material decreases in higher percentage levels of reinforcement and material become brittle as the weight percentage of reinforcement's further increased. Figure 4.5, 4.6 and 4.7 shows the increasing in tensile strength and decreasing in strain with the rise of weight percentage of silicon carbide reinforcement.

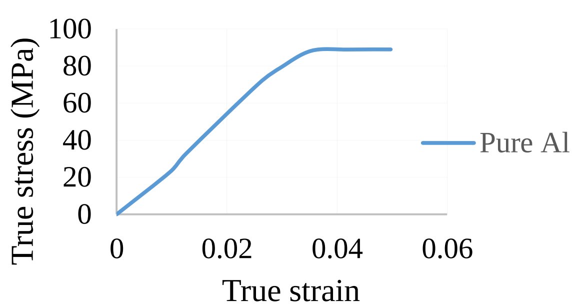


Figure 4. 4. True Stress-Strain Graph of Non-reinforced Al

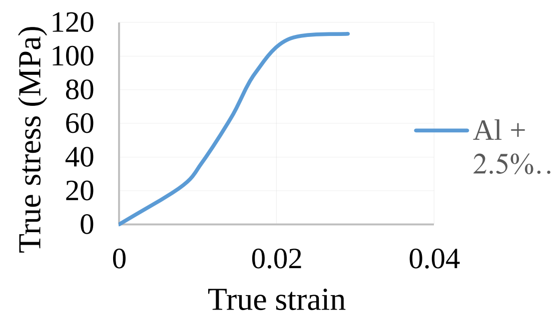


Figure 4. 6. True Stress-Strain Graph of Al Reinforced by 2.5% of SiC

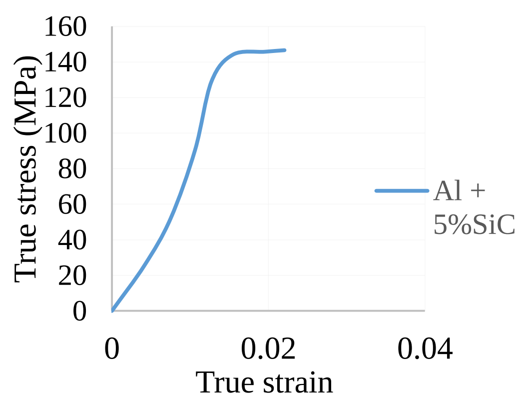


Figure 4. 5. True Stress-Strain Graph of Al Reinforced by 5% of SiC

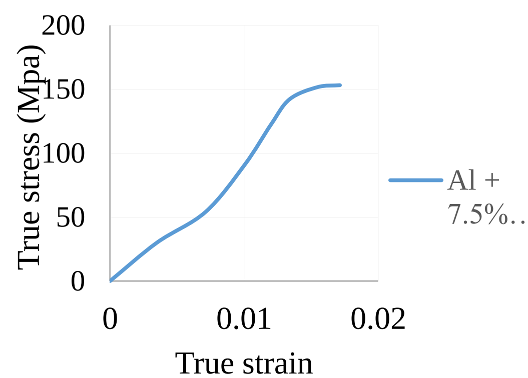


Figure 4. 7. True Stress-Strain Graph of Al Reinforced by 7.5% of SiC

Figure 4.8 show the stress-strain graphs of aluminium and aluminium-silicon carbide composite with different weight percentage of silicon carbide reinforcement.

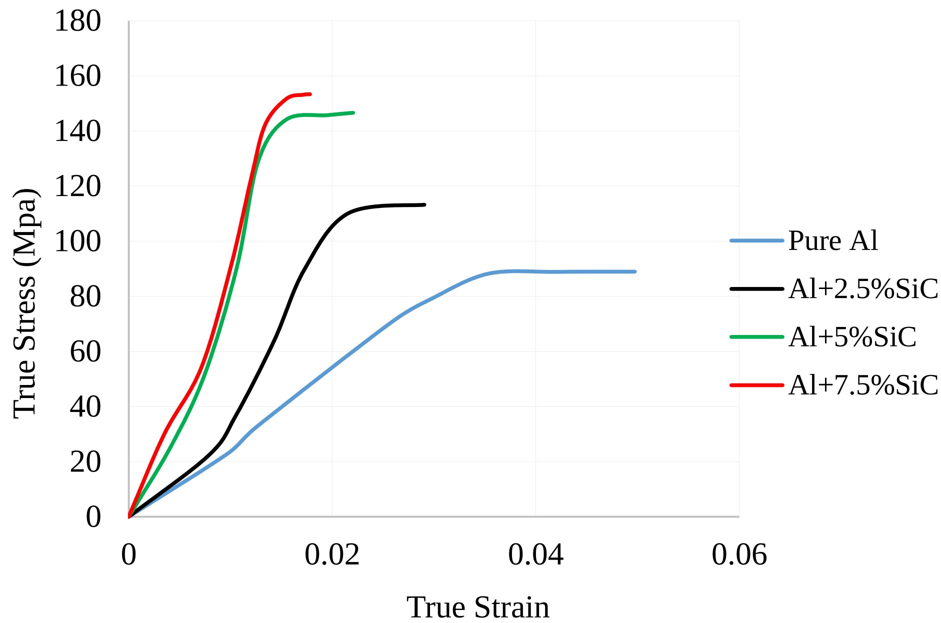


Figure 4. 8. Stress-Strain Graph of Al Reinforced by 0%, 2.5%, 5% and 7.5% of SiC

Since the reinforcing material bears a major portion of stress in the MMC (because it's stiffer) [42], in the composite, its weight percentage determine the final properties of the material. Figure 4.8 shows the tensile properties, such as the ultimate tensile strength and elongation, of composites having different weight fractions of reinforcement particles. As shown in this figure (4.8), the tensile strength increased with increasing content of SiC reinforcement, whereas the elongation decreased with increasing weight percentage of SiC. In this work, because the spatial distribution of the reinforcement particles was close to a uniformly distribution for all the samples, the weight percentage of SiC particulates had a significant effect on the tensile properties of the composites, and the strength increased with increasing weight percentage. However, the rate of increase of the tensile strength slightly decreased with increasing volume fraction of the SiC particles. This is due mainly to an associated effect on particle clustering which form voids. Myriounis et al. [52] demonstrated that the tensile strength of AMMC decreases with increasing percentage of reinforcement beyond the optimum, and they attributed this result to an increase in particle clustering of SiC.

As it is observed from figure 4.4, pure aluminium has low strength of resisting the tension load. But because of it has high elongation rate, it was not easily braked. This is why the commercially pure aluminium is soft and very ductile [20]. As the silicon carbide was introduced in to aluminium matrix in figure 4.6, the composite was formed with the improved strength. In figure 4.6 the composite contains 2.5% of SiC and the strength of pure aluminium was increased from 88.22 MPa to 110.10 MPa. This is due to the presence of hard particle of silicon carbide particles that are directly proportional to the stress needed to initiate and propagate the cracks in the composite which improve the mechanical properties of metal matrix composite [7, 24]. As the volume percentage of silicon carbide increased from 2.5% to 5% and 7.5% in figure 4.5 and figure 4.7 respectively, the strength of the composite was increased. However, the elongation percentage reduces as the SiC content grows. Figure 4.8 shows that, the rate of increasing in tensile strength was decreased as the volume fraction of SiC increased. This is probably because of the increased area of the interface i.e., number of interfaces which, could result in void nucleation and coalescence leading to failure at lower stresses. Nevertheless, the work of Singla et al. [1] shows that, the reduction in increasing rate of properties such as hardness and tensile strength with the increasing in weight percentage of SiC, was happens because the increasing quantities of SiC particles react with each other (clustering) and settle down, thereby contributing to a local reduction in density (of SiC particles) and lower hardness and tensile strength.

Neelima Devi et al. [56] it was found that in the SiC particle reinforced Al alloy, containing beyond approximately 15 volume fraction of SiC, the rate of increase in strength decreases with volume fraction increases. Moreover, when the reinforcements cluster, the matrix material between individual reinforcement does not bond well. During subsequent deformation these interface are likely to separate. The embedded hard particles in the matrix act as a barrier that resists the plastic flow of composites when it is subjected to low strain. The low ductility of the investigated composites could be attributed to the susceptibility to the effect of stress- raiser. This can explain the improvements of the tensile properties in Al-SiC composites, and others mechanical properties such as compression strength and hardness [32]. A homogeneous distribution of silicon carbide particles in the matrix is always associated with the formation of particle cluster; such cluster region promotes damage due to increased reaction of the matrix within the cluster, resulting in low ductility. Krishna et al. [32] found that cluster regions were preferred sites for damage initiation and that damage accumulation ahead of a propagation crack also tended to occur in cluster region. As the volume fraction of silicon carbide increases the clustering of the reinforcements also increase, which result for the reduction in strength of composite. Present experimental results agree well with these facts. The tensile strength obtained in this study is comparable to results from other researcher. This is summarized in table 4.5.

Table 4. 5. Tensile Strength and Elongation of Al-SiC MMC

Composition	Tensile Strength (MPa)	Elongation (%)	Authors
Al (99.5%)	88.22	4.71	My work
Al + 2.5%SiC	110.08	3.40	
Al + 5%SiC	144.12	2.46	
Al + 7.5%SiC	151.60	1.95	
Al 1050	86.63	5.13	Neelima et al. [56]
Al + 3%SiC	117.38	2.71	
Al + 5%SiC	137.23		Rajesh et al. [35]

4.1.3. Compressive Strength of Al-SiC Composite

The above discussion is concerned primarily with simple tension, i.e. uniaxial loading that increases the inter-atomic spacing. Compressive strength or compression strength is the capacity of a material to withstand loads tending to reduce size, as opposite to tensile strength, which withstands loads tending to elongate. A Compression tests were used to assess the mechanical behavior of the composites and matrix alloy under pressing load. The load was compressed and deformation at different load was noted. Compressive stress and strain was calculated and plotted as stress-strain diagram, as shown in figure 4.9. When compression load was applied on spacemen the deformation may take place: for brittle materials it may be crushing or fracture and for ductile material it may be due to elastic or plastic deformation [36].

In this work the compressive strength testing of Al-SiC composite was carried out at room temperature using a computerized universal testing machine. Standard specimens with 8 mm diameter and 12 mm in length were used to evaluate compression strength. The stress and strain of the samples were calculated from recorded data of change in diameter and change in length of samples respectively under compression load (see appendix IV). Table 4.6 shows the experimental results of compressive strength of AMMC composite reinforced with different percentages SiC (0%, 2.5%, 5% and 7.5%).

Table 4. 6. Compression Strength Results for Al-SiC Composite (see appendix IV)

Spacemen	SiC mixture (%)	Compression strength (MPa)
1	0%	348.32
2	2.5%	367.56
3	5%	409.61
4	7.5%	418.24

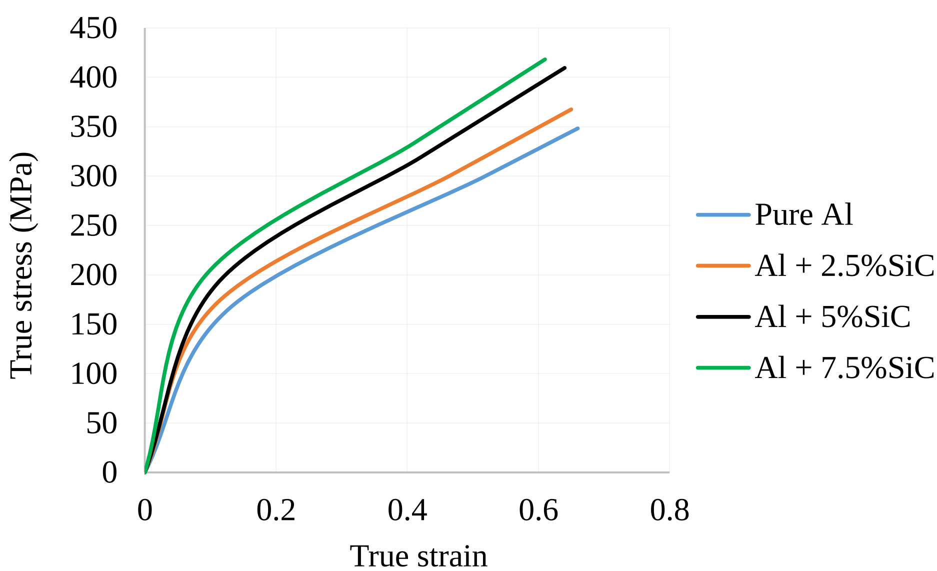


Figure 4. 9. Compressive Strength of Composite

The experimental results of this study show that, the compressive strength of the metal matrix composite produced was higher than that the non-reinforced alloy. It can be noted that the addition of silicon carbide particles improved the compressive strength of the composites. In compression loading the fracture of the specimen take place due to bulging action. And the properties of a material to bulge under compression loading, define its malleability. From the experimental results, it can be seen that, as weight percentage of SiC in Al-SiC composite increases the compressive strength of the composite was increased, but its malleability was decreased. This is due to the presence of hard particle SiC, which make the composite hard and brittle [1]. Figure 4.9 shows the effect of volume fraction of SiC on the compressive strength Al-SiC composite. The compressive strength of the sample1, in non-reinforced condition is 348.32 MPa, and this value increases to 418.24 MPa, for sample 4 (Al+ 7.5%SiC). This was due to the proper dispersions of SiC into the matrix or strong interfacial bonding in between the Al and SiC interfaces [32].

In this experiments, because the uniformly distribution of reinforcement particles for all the samples, increasing in volume fraction of SiC particulates had a significant effect on the compression properties of the composites, and the strength increased with increasing percentage of SiC. One of the reasons of increasing in compressive strength may be that the use of stir casting, that hence proper mixing of the particle of the filler material. Thus, the binding capacity increased and hence compressive strength increased [7]. The ultimate compressive strength of pure aluminium was 348.32 MPa, but when 2.5% of SiC was added its compressive strength was improved by 5.5% and increased to 367.56 MPa. When 5% of SiC was added, the compressive strength was improve by 17.5% and increased to 409.6 MPa. And also when 7.5% of SiC was added the compressive strength of pure aluminum was improved by 20% and increased to 418.24 MPa. However, the rate of increase of the compressive strength slightly decreased with increasing volume fraction of the SiC particles. This is due to, an associated effect on particle clustering which form voids [7, 58]. The compressive strength of the Al-SiC increased with increasing the percentage of SiC up to (5%) rapidly, but after 5% of SiC, the rate of increasing in compressive strength of Al-SiC composite was decreased. Therefore, increasing SiC particle volume fraction apparently contributes to the decreasing the increasing rate of ultimate compression strength.

On compression, the specimen will shorten. The material will tend to spread in the lateral direction and hence increase the cross sectional area. Compressive strain is that which produce in the body when two opposite or equal forces try to compress the body. In this cases length of body decreases as compressive stress try to compress the body. The sample height decrease and diameter increases when the load was increased. Hence the sample was fractured at the maximum load which gives as the result maximum compressive stress. Figure 4.10 shows the decreasing in length and increasing in diameter of samples with increasing of applied load.

Figure 4. 10. Change of Spacemen in Length and Diameter With Respect to Load

The decreasing in the length and increasing in the diameter during compression where decreased with the increasing the percentage of SiC. This is due to the presence of hard particle SiC which improve the compressive properties of alumunium metal matrix composite [24]. The rigidity and crushing strength of particles is much higher than that of matrix material hence the strength increases. The compressive strengths obtained in this study are comparable to results from other researcher. These were summarized in table 4.7.

Table 4. 7. Compressive Strength of Al-SiC

Materials	Compressive strength (MPa)	Authors
Al + 7.5%SiC	418	My work
AA1050 + 9%SiC	423	[36]
Al + 5%SiC	409	My work
AA1050 + 5%SiC	400	[58]
Al(99.5% C.P)	348	My work
AA1050	347	[36]

4.2. Microstructure Study

The properties of composites depend on the microstructure, interface characteristics between reinforcements and matrix. In order to maximize the mechanical properties, it is essential to achieve the uniform distribution of reinforcement within the matrix. It is necessary to conduct a microscopic analysis on a composite material in order to gain better understanding of its microstructure characteristic. The distribution of SiC particles in Al matrix were one of the factors influencing the properties of the aluminium silicon carbide composite. When the SiC particles are added in to the molten aluminium, it was observed that the segregation of particles in molten metal. This is because of the difference in specific density of matrix and reinforcement materials [48]. Therefore stirring system was applied for 10 minute at 290 RPM, using drilling machine setup to achieve a good homogeneous distribution of a particle in the matrix.

The optical microstructure of Al cast composites with 0%, 2.5%, 5% and 7.5% SiC have been taken at X1000 magnification in the optical microscope and are shown in figures 4.11 (a), (b), (c) and (d) respectively. It was observed that there is better dispersion of reinforcement in the matrix as there are no more visible porosity and inclusions in the interfacial regions. As the weight percentage of SiC increases in the matrix, the reinforcement particles increases and the inter particle space decreases. Figure 4.11 (b), (c), (d) shows the optical microstructures of AMMC reinforced by 2.5, 5 and 7.5 percent of SiC respectively. Figure 4.11(a) show that, it is pure aluminium and no SiC distribution in it. In pure Al microstructure there is only white surface is visible. It is because of the pure aluminium (Al 99.5%) has no major alloy elements. Figure 4.11 (b) shows an optical micrograph of AMMC reinforced by 2.5% SiC and is observed that more rounded white particles and less dark areas. In microstructure of Al-SiC composite, the white areas are indicating the aluminium particle and the dark areas are the silicon carbide [48, 50]. Figure 4.11 (b), reveal good distribution of particles and very low agglomeration in the composite reinforced with 2.5% of SiC, fabricated by stir-casting process. Moreover, the figures indicate that the SiC particles have tendency to segregate and cluster at inter-dendrite regions (Figure 4.11(b – d)).

Figure 4.11 (c) shows an optical micrograph of AMMC reinforced by 5% SiC. Here, the number of SiC was increased and the uniformly distribution silicon carbide with networked structure was observed. There was good distribution of SiC particles in aluminium as well as very low agglomeration of SiC in low percentage (less than 5%). As the SiC particles content increases up to 7.5 percent (figure 4.11 (d)), the microstructure became dense and darker, and this is good agreement with earlier work [41, 52]. From optical micrographs, non-homogenization of SiC particles in Al matrix were observed in the microstructure of 7.5% SiC reinforced AMMC, as shown in Figure 4.11 (d).

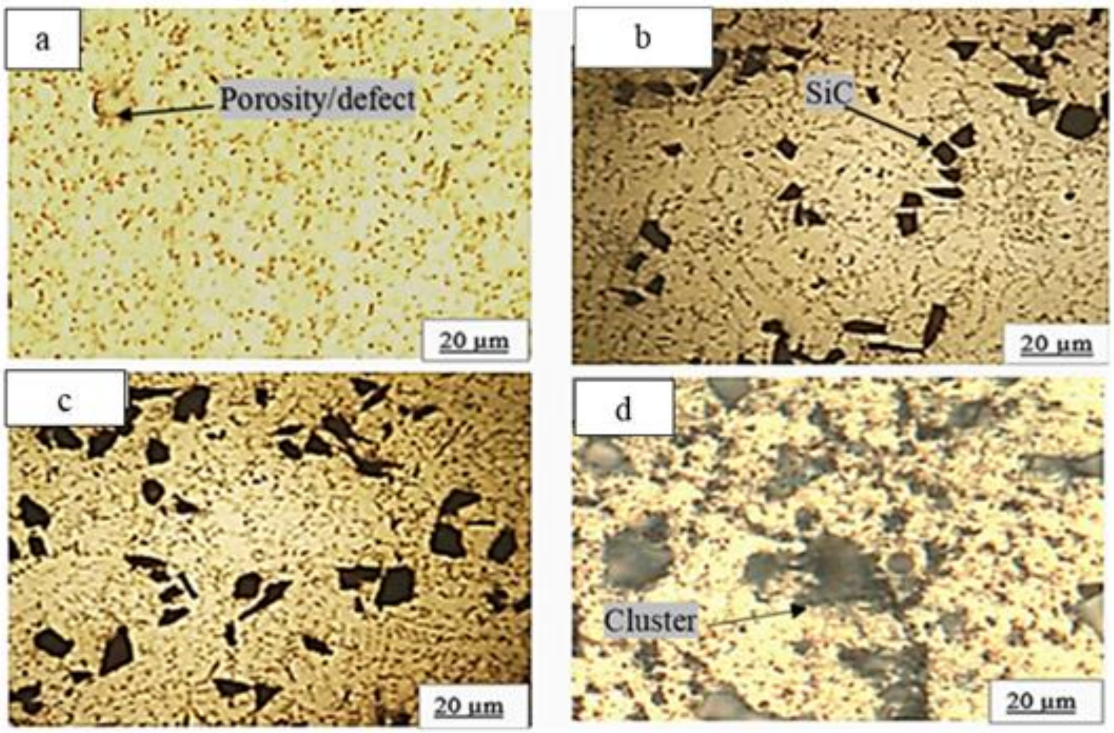


Figure 4. 11. Optical Micrograph of AMMC with SiC Content; (a) 0%, (b) 2.5%, (c) 5%, (d) 7.5%

From Al-SiC composites micro structural analysis, some places in Al matrix can be identified without SiC reinforcing particles. And result in formation of porosity and create more defects in composite. Porosities were observed in all microstructures. This was because when SiC particles were added in the melt during casting, it introduced air/gas in the melt entrapped between the particles. Therefore increasing weight percentage of SiC particles increased entrapped air resulted in higher amount of porosity [56]. The existence of porosity and SiC particle clustering in the Al matrix were attributed to the low viscosity of the melt. Viscosity decrease when increasing process temperature [44]. During high sting time at high temperature, the geometries of capturing SiC particles do not restrict their movement inside the liquid metal and solidification [41, 43]. Also the presence of low viscosity of liquid metal tends to physically not restrict growth of porosity. The clustering of particles results in the partial ductile and brittle which result in lower mechanical properties of Al-SiC composite. When the reinforcement weight percentage was increased, the more closely spaced brittle reinforcements imposed greater constraints on the plastic flow in the ductile matrix thereby generating higher stresses throughout the composite microstructure [52, 54].

Another importance of micro structural observation in the case of non-reinforced and reinforced samples, investigated in the present study, was to quantify particle distribution in-homogeneities. Some researchers have attempted to do this by visual inspection [48]. In this study, visual inspection method was used to quantify the rate of distribution of Silicon carbide particles in the matrix alloy. It can be seen that the composite materials made by the investigated processing technique had a cast microstructure of the matrix present with particles, distributed homogeneously throughout the casting. Relatively uniform distribution was observed in almost all the composites produced. However, there are some particles-free zones due to particle pushing effects during solidification.

Generally, in present experiments, the uniformity of the microstructures also observed to be disrupted by the presence of silicon carbide particles. It is apparent from the microstructure that the distribution of reinforcement particles becomes more uniform in the matrix as their contents increases. Figure 4.11 (d), shows the distribution of silicon carbide particles in matrix alloy with 7.5% of silicon carbide particles. Comparing to the distribution of silicon carbide particles in aluminium, from Figure 4.11 (b) and the figure 4.11 (d) that contain 2.5% and 7.5% of SiC respectively, shows that the aluminium metal matrix composite that contain 7.5% of SiC give a more uniform dispersion. However, the tendency for particle to clump together also increases when the weight percentage of the silicon carbide increased. The results show that the amount of porosity increases with increasing contents of SiC. The presence of silicon carbide particles in the microstructures could impede the movement of dislocations, thereby improving the strength of composite.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Composite materials are characterized by their good mechanical and development properties over a wide range of temperatures and high strength to weight ratio. In this work, detailed literature review was done for fabrication and selecting the composition of composite material. In this experimental study, the aluminium metal matrix composite specimens were fabricated successfully by stir casting method by varying SiC as 2.5%, 5% and 7.5% in weight percentage. The mechanical properties such as tensile strength, compressive strength and hardness of various composition of reinforcement were found. All the specimens were tested in universal testing machine for tensile and compressive strength and Vickers hardness testing machine for hardness. Based on the obtained results the following conclusions can be made:

- Aluminum (99.5%) based metal matrix composite reinforced with particles of silicon carbide were successfully fabricated by stir casting method.
- Stir casting is very efficient, simple and cost effective method of manufacturing of aluminum matrix composites and also it is most suitable for mass production.
- Composite samples show a higher strength and low ductility than the samples commercial pure Al, which may result from improved bonding between the reinforcement and matrix materials.
- The test result shows that as the weight percentage of reinforcement increases the tensile strength, compression strength and hardness also increases.
- But the rapidly increasing trend of hardness, tensile and compressive strength with increase in weight percentage of SiC was up to 5% weight fraction. Beyond this weight fraction of SiC, the rate of increasing in these mechanical properties was decreased. This is due to, the interaction of SiC particles with each other, that leading to clustering and consequently settling down of particles, which contributing to a reduction of mechanical properties of Al-SiC composite.

- Optical Microscopic studies revealed a distribution of reinforcement in formed composition of Al-SiC MMC. From the result, a uniformly distribution of reinforcement in metal matrix is achieved.

Stir casting is recommended as the most viable process because of its simplicity and its ability to ensure the uniform distribution of reinforcement particles. The research findings can help researchers and industries for developing a robust, reliable and knowledge base processes for fabrication and experimental analysis of Al-SiC composites. Since Al-SiC composites have high tensile strength, high hardness values, and less weight, it is recommended that the Al-SiC composite materials are a good replacement for stainless steel, for fuselage skins, actuating cylinder and connecting rod in automotive engineering applications.

5.2. Recommendations for Future Work.

Research areas in fabrication of MMC are broad several areas regarding the proposed fabrication methods which merit study, or development in more detail, include:

- The effect of different size of stirrer and stirring speeds. It may be feasible to reduce particle fracture, further improve wetting, and minimize porosity through improved understanding of the process of mechanical stirring
- This study used sand casting, however other available casting techniques like die casting, could be tried and analyzed, so that a final conclusion can be drawn there from. The effect of mold design, riser design in the production of metal matrix composites can be an interesting field of investigations.
- Fabrication of AMMCs by other advance processes like powder metallurgy, diffusion, deposition, etc. may be done to achieve different set of mechanical properties.
- The study can be extended, by considering the effects of shape and size of reinforcement particles and the distribution and properties of constituents on the mechanical properties of Al-SiC composite.

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APPENDIX I: WEIGHT PERCENTAGE CALCULATIONS for SAMPLE PREPARATION

The value of **tensile test samples** weight before machining was obtained by performing the following formula.

Weight of sample = Volume X Percentage X Density

Density of A99.5 alloy= 2.7g/cm^3

Density of silicon carbide = 3.1g/cm^3

Volume (area X length) = ((πr^2) X L)

When L is the length of sample, R is the radius of the cylindrical sample and π is constant.

Volume of sample for tensile test =68 cm^3

Since L=15cm, and R=1.2cm

<u>Addition of 0% silicon carbide</u>

Weight of aluminium alloy = 68 X 2.7= 183.6 grams

<u>Addition of 2.5% silicon carbide</u>

Weight of aluminium alloy = 68 X (97.5/100) X 2.7= 179 grams

Silicon carbide = 68 X (2.5/100) X 3.1 = 5.27 grams

<u>Addition of 5% silicon carbide</u>

Weight of aluminium alloy = 68 X (95/100) X 2.7= 174.4 grams

Weight of silicon carbide = 68 X (5/100) X 3.1 = 10.54 grams

<u>Addition of 7.5% silicon carbide</u>

Weight of aluminium alloy = 68 X (92.5/100) X 2.7= 169.8 grams

Weight of silicon carbide = 68 X (7.5/100) X 3.1 = 15.8 grams

The tensile test samples may failure during casting or machining process. Therefore, four samples were prepared for each aluminium alloy-silicon carbide composition. The total aluminum alloy and silicon carbide weight needed for casting tensile test samples were:

Total weight of aluminum alloy = (183.6 + 179 + 174.4 +169.8) X 4 = 2,830 grams = 2.83 kg

Total weight of silicon carbide = (5.27 + 10.54 + 15.8) X 4 = 126.44 grams

Hardness test samples weight calculations

The value of hardness test samples weight before machining also obtained by performing the same formula to tensile test samples.

Density of pure aluminium= 2.7 g/cm^3

Density of silicon carbide = 3.1 g/cm^3

Volume (area X length) = ((πr^2) X L) = 90.43 cm^3

Since L=7.2cm, and R=2cm

<u>Addition of 0% silicon carbide</u>

Weight of pure alumunium = 90.43 X 2.7= 244.16 grams

<u>Addition of 2.5% silicon carbide</u>

Weight of pure aluminum = 90.43 X (97.5/100) X 2.7= 238 grams

Weight of silicon carbide = 90.43 X (2.5/100) X 3.1 = 7 grams

<u>Addition of 5% silicon carbide</u>

Weight of pure aluminum = 90.43 X (95/100) X 2.7= 232 grams

Weight of silicon carbide = 90.43 X (5/100) X 3.1 = 14 grams

<u>Addition of 7.5% silicon carbide</u>

Weight of pure aluminum = 90.43 X (92.5/100) X 2.7= 225.85 grams

Weight of silicon carbide = 90.43 X (7.5/100) X 3.1 = 21 grams

The total aluminum alloy and silicon carbide weight needed for casting hardness test samples were:

Total weight of pure aluminum = 244.16 + 238 + 232 +225.85 = 940 grams

Total weight of silicon carbide = 7 + 14 + 21 = 42 grams

Finally, the total pure aluminum and silicon carbide needed for casting process were 3.77 kg and 0.165 kg respectively. The total raw materials required for the sample preparation was 3.94 kg.

The other samples used for compression strength test and microstructure study were from tensile strength and hardness test samples during machining process.

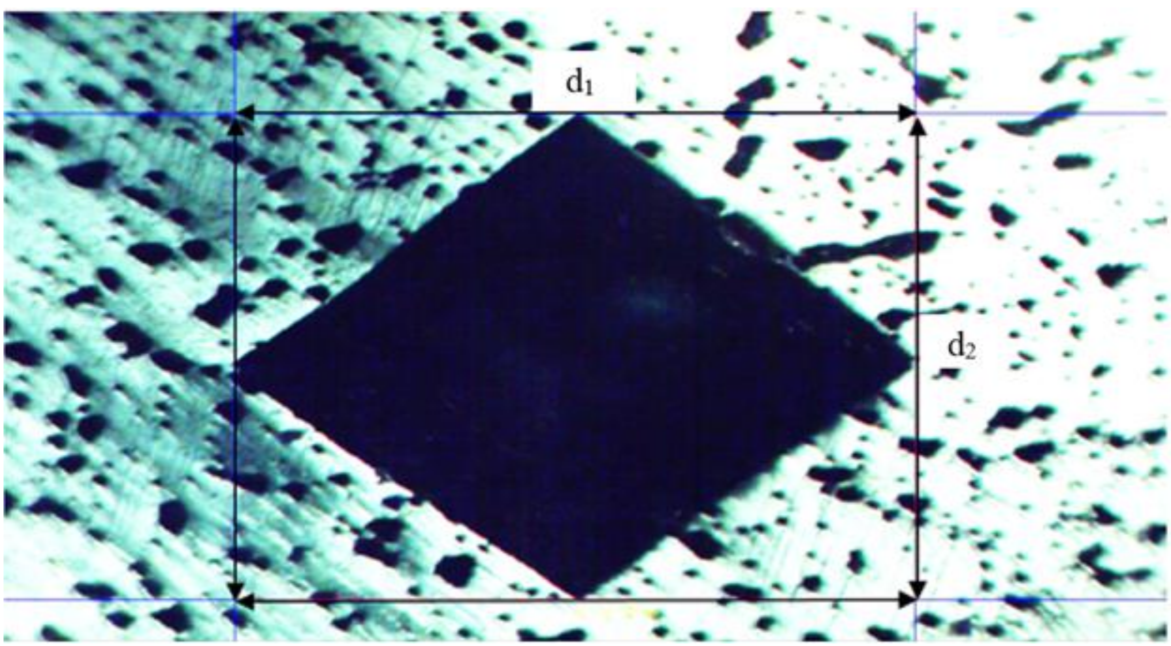
APPENDIX II: MATHEMATICAL CALCULATION of VICKERS HARDNESS

$$HV = 0.102 \times \frac{2F\sin(\frac{136^0}{2})}{d^2} \quad (a)$$

$$d = \frac{d1+d2}{2} \quad (b)$$

Where, F is the indentation load in Kgf, d_1 and d_2 are diagonals of indentation in mm, as shown in figure below.

<u>Note</u>: 1Kgf =9.807 N



APPENDIX III: EXPERIMENTAL RESULTS OF TENSILE TESTS

Force-Elongation table for non-reinforced aluminium (99.5% C.P)

Tests/ trails	Force/load (KN)									
1	0.00	0.53	0.82	1.21	2.06	2.65	2.34	1.63	0.84	0.01
2	0.00	0.72	0.97	1.05	1.62	1.78	1.75	1.37	0.68	0.03
3	0.00	0.59	0.93	1.25	1.68	2.81	2.18	2.02	1.59	1.01
Average	0.00	0.61	0.91	1.71	1.79	2.41	2.09	1.67	1.04	0.35
Tests/ trails	Elongation (%)									
1	0.00	1.41	1.70	2.89	3.17	3.23	3.44	3.78	4.23	4.32
2	0.00	1.82	2.13	2.31	2.48	2.39	3.14	3.41	3.52	3.57
3	0.00	2.43	2.74	3.64	4.20	4.74	5.20	5.63	6.13	6.24
average	0.00	1.89	2.19	2.95	3.28	3.45	3.93	4.27	4.63	4.71

Force-Elongation table for Al-SiC composite with 2.5%SiC

Tests/trails	Force/load (KN)								
1	0.00	0.38	0.81	1.56	2.31	2.97	0.90	0.57	0.09
2	0.00	0.58	0.94	1.74	2.54	3.25	1.25	0.82	0.09
3	0.00	0.24	1.24	2.03	2.62	2.92	1.71	1.07	0.61
Average	0.00	0.40	1.03	1.78	2.49	3.05	1.29	0.82	0.26
Tests/trails	Elongation (%)								
1	0.00	1.24	1.49	1.73	1.74	2.19	2.58	3.14	3.35
2	0.00	0.26	0.25	0.87	1.22	1.71	2.42	3.23	3.69
3	0.00	1.16	1.44	2.00	2,26	2.64	2.93	3.12	3.16
average	0.00	0.89	1.06	1.54	1.74	2.18	2.64	3.16	3.40

Force-Elongation table for Al-SiC composite with 5%SiC

Tests/trails	Force/load (KN)								
1	0.00	0.83	0.88	2.02	3.32	4.52	1.93	0.26	0.00
2	0.00	0.84	1.94	2.77	3.55	3.55	2.78	0.38	0.03
3	0.00	0.77	1.55	2.83	3.92	3.96	2.24	1.40	0.21
Average	0.00	0.81	1.46	2.54	3.60	4.01	2.32	0.68	0.08
Tests/trails	Elongation (%)								
1	0.00	0.73	1.25	1.52	1.79	2.05	2.60	2.89	3.00
2	0.00	0.26	0.53	0.79	1.04	1.36	1.57	1.88	2.07
3	0.00	0.28	0.49	0.71	0.96	1.27	1.86	1.91	2.31
Average	0.00	0.16	0.76	1.01	1.26	1.56	2.01	2.23	2.46

Force-Elongation table for Al-SiC composite with 7.5%SiC

Tests/trails	Force/load (KN)								
1	0.00	0.70	0.89	1.43	2.20	3.39	4.52	1.94	0.01
2	0.00	0.65	1.04	1.75	2.49	3.19	3.80	3.61	0.10
3	0.00	0.85	1.01	1.32	2.20	3.71	4.35	0.64	0.04
Average	0.00	0.73	0.98	1.50	2.30	3.43	4.22	2.06	0.05
Tests/trails	Elongation (%)								
1	0.00	0.80	1.00	1.30	1.45	1.68	1.90	1.95	2.12
2	0.00	0.40	0.69	0.72	0.97	1.06	1.24	1.52	1.76
3	0.00	0.44	0.64	0.85	1.10	1.31	1.53	1.71	1.96
Average	0.00	0.55	0.78	0.96	1.17	1.35	1.56	1.73	1.95

From force–Elongation results, the engineering stress and engineering strain were calculate, by using the following formulas:

$$\delta_e = \frac{F}{A} \qquad \text{(i)}$$

$$\varepsilon_e = \frac{\Delta L}{L} \qquad \text{(ii)}$$

Where, δ_e is engineering stress, ε_e is engineering strain, F is load applied on specimen, A is the cross sectional area of specimen, L is the gauge length, and ΔL is change in length of specimen under tension. And also the true stress (δ_t) and true strain (ε_t) were calculated from engineering stress and engineering stain by using the following formulas:

$$\delta_t = \delta_e (1 + \varepsilon_e) \qquad \text{(iii)}$$

$$\varepsilon_t = \ln (1 + \varepsilon_e) \qquad \text{(iv)}$$

The table below shows the maximum load, ultimate tensile strength, maximum elongation of samples and their average values.

Composition	Tests (trials)	Maximum load (KN)	Ultimate tensile strength (N/mm^2)	Elongation(mm)
Pure Al	1	2.65	93.72	4.32
	2	1.78	62.95	3.57
	3	2.81	99.38	6.24
	Average	2.41	85.35	4.71
Al+2.5% SiC	1	2.97	105.04	3.35
	2	3.25	114.95	3.69
	3	2.92	103.27	3.16
	Average	3.05	107.75	3.4
Al+5% SiC	1	4.52	159.86	3.01
	2	3.55	125.56	2.07
	3	3.72	134.14	2.31
	Average	3.93	138.99	2.46
Al+7.5% SiC	1	4.52	159.86	2.12
	2	3.80	134.98	1.76
	3	4.35	153.85	1.96
	Average	4.22	149.37	1.95

APPENDIX IV: RESULTS of COMPRESSION TESTS

$$\delta_t = \frac{F}{Ai} \qquad \text{(i)}$$

When, δ_t is true compressive stress, F is applied load and A_i is instantaneous area

$$A_i = \pi \frac{Dav^2}{4} \qquad \text{(ii)}$$

$$D_{av} = \frac{Dt+Db}{2} \qquad \text{(iii)}$$

When, Dt is top contact diameter of specimen and Db is bottom contact diameter of specimen under compression test.

$$\varepsilon_e = \frac{\Delta L}{L0} \qquad \text{(iv)}$$

$$\varepsilon_t = \ln(1 + \varepsilon_e) \qquad \text{(V)}$$

Where ε_e is engineering strain, ε_t is true strain, Lo is initial length of specimen and ΔL is change in length of specimen under compression. The compression test results shown in table I, II, III and IV were the average of three trials for each composition.

Table I. Compression Results for Pure Aluminium (99.5%)

Load (KN)	D_{av}(mm)	L_o(mm)	ΔL (mm)
0	8.00	12.0	0.00
10	8.80	10.4	1.60
20	9.20	5.76	6.24
30	10.64	4.44	7.56
40	12.10	4.1	7.92

Table II. Compression Results for Al reinforced by 2.5 percent of SiC

Load (KN)	D_{av} (mm)	L_o (mm)	ΔL (mm)
0	8.00	12	0
10	8.62	10.68	1.32
20	9.18	6.36	5.64
30	10.40	4.68	7.32
40	11.77	4.20	7.80

Table III. Compression Results for Al reinforced by 5 percent of SiC

Load (KN)	D_{av} (mm)	L_o (mm)	ΔL (mm)
0	8.00	12	0
10	8.17	10.68	1.32
20	8.94	6.96	5.04
30	10.02	5.16	6.84
40	11.15	4.32	7.68

Table IV. Compression Results for Al reinforced by 7.5 percent of SiC

Load (KN)	D_{av} (mm)	L_o (mm)	ΔL (mm)
0	8.00	12	0
10	8.03	10.92	1.08
20	8.74	7.08	4.92
30	9.86	5.40	6.60
40	11.04	4.68	7.32

APPENDIX V: CHEMICAL COMPOSITION RESULT of ALUMINIUM

	HIBRET MANUFACTURING AND MACHINE BUILDING INDUSTRY	DOC. No.HMMBI HMMBI/ / SPI/LB/-02	
	Chemical composition Laboratory Test Result Form	Issue No. 01	Page 1 of 1

Date: 14/09/10

Requested by: MELESE BUTUNA

Sample type: ALUMNIUM

Purpose: IDENTIFICATION

S/N	Sample Name	Chemical composition													
		Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Sn	Ti	Ga	Al	CSN
1	Round Pin Φ20	0.17	0.21	0.002	0.002	0.0035	0.008	0.0078	0.0079	0.005	0.018	0.031	0.014	99.5	Al

Prepared by: Saba
Sign: [illegible]
Date: 14/09/10

Checked by: Diviko
Sign: [illegible]
Date: 14/09/10

Approved by: SEADA
Sign: [illegible]
Date: 14/09/10