JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING
MANUFACTURING SYSTEM ENGINEERING CHAIR

MASTERS OF SCIENCE PROGRAM IN MANUFACTURING SYSTEM ENGINEERING

PRODUCTION AND CHARACTERIZATION OF ALUMINIUM ALLOY (Al-6063) MATRIX COMPOSITE REINFORCED WITH RICE HUSK ASH USING STIR CASTING

A Thesis submitted to School of Graduate Studies of Jimma, Jimma University,
Jimma Institute of Technology, Faculty of Mechanical Engineering in Partial
Fulfillment of the Requirements for the
Degree Master of Science in Manufacturing Engineering

By: Mekete Desalegn

May, 2022

Jimma Ethiopia

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By: Mekete Desalegn

Advised By
Main Advisor: Dr. Praveen Balakrishnan
Co-Advisor: Mr. Srinivasa R. K (M.Tech)

DECLARATION

I, Mekete Desalegn Fitamo, declare that this thesis entitled “Production and Characterization of Aluminum Alloy (Al-6063) Matrix Composite Reinforced with Rice Husk Ash Using Stir Casting” is my original work and that it has not been presented and will not be presented by me to any other university for similar or any other degree award.

Name Signature Date

As master’s research advisor, we certify that we have read and evaluated this MSc. thesis proposal entitled “Production and Characterization of Aluminum Alloy (Al-6063) Matrix Composite Reinforced with Rice Husk Ash Using Stir Casting” is submitted by Mekete Desalegn our supervisor-ship as a university advisor.

Main advisor name Signature Date

Co-advisor name Signature Date

External Examiner Name Signature Date

Internal Examiner Name Signature Date

Chairperson Name Signature Date

ABSTRACT

Because of their superior mechanical and physical qualities, aluminum-based composites using rice husk ash as particle reinforcement are in high demand in the aerospace industry. The materials' improved mechanical and physical characteristics are a direct result of the interaction between the aluminum matrix and the RHA reinforcement. Most production factories have been facing great challenges or problems due to the customer demand for lightweight and high-strength material, especially used in aerospace, automotive, and marine industries. Therefore, it was essential to develop and study lightweight to obtain high strength capability.

The main objective of this study is to produce aluminum alloy and rice husk ash composite with various percentage compositions and to characterize their mechanical properties. The impact of RHA particles on the enhancement of mechanical characteristics of aluminum metal matrix composites was and also the focus of this research. The different RHA compositions (0, 4%, 8%, 12%, and 16%) were used to develop the composite using the stir casting route, while all other parameters remained constant. Various mechanical properties like tensile strength, hardness and compressive strength, were evaluated for five different composition specimens. The experimental results showed that the tensile strength, hardness and compression strength of aluminum alloy were improved by 49%, 16%, and 6% respectively. A result of tensile test shows that, tensile strength of aluminum alloy (Al6063) raised from 48.19 MPa to 168.35 MPa, when 16% of RHA was added. As the load increases from 10N to 50N in the step of 20N, the coefficient of friction and wear loss increases. At 50N load, the maximum weight loss was 0.0096g for non-reinforced specimen and the minimum weight loss was 0.0115g for reinforced specimen (Al6063/16% RHA) at this load. Also, the result of hardness and compression tests shows that, the hardness and compression strength of aluminum alloy (Al6063) were increased from 76.14 HRF to 88.44 HRF, and 392.75 MPa to 417.31 MPa respectively with the increasing in weight percentage of RHA to 16%.

Keywords; *Composite material, Aluminum alloy (Al-6063), Metal Matrix Composite, Rice Husk Ash and Stir casting.*

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NOMENCLATURE

%	Percent
%Wt	Weight percent
AMMC	Aluminum metal matrix composite
AMCs	Aluminum matrix composites
AMMCs	Aluminum metal matrix composites
ASTM	America society of test material
CM	Composite material
CMCs	Ceramic matrix composites
Dc	Diameter of crucible
Ds	Diameter of stirrer
HMMCs	Hybrid metal matrix composite
HRF	Rockwell hardness F-scale
MMCs	Metal matrix composites
MMC	Metal matrix composite
PMCs	Polymer matrix composites
PAMMCs	Particulate aluminum metal matrix composites
RH	Rice husk
RHA	Rice husk ash
RPM	Revolution per minute
SEM	Scanning electron microscope
UTM	Universal testing machine

CHAPTER ONE

1. INTRODUCTION

The thesis's history, aims, problem statement, scope, and importance are all discussed in this chapter.

1.1. General Background of the Study

At present, metal matrix composites (MMCs) are broadly utilized in industrial sectors, medical sectors, construction sectors and others like Automobile Industries, Aircraft Industries, Marine time Industries, Medical Industries, and Construction equipment are due to desirable properties MMCs, like better strength, high wear resistance, light in weight, good thermal conductivity and low thermal expansion [1]. The development of composite materials had largely affected by changes in manufacturing technology.

A composite material is made up of two or more separate components that are mechanically bonded together. In the composite, each component retains its sense of self, including its structure and features. Stiffness, strength, weight, high-temperature performance, corrosion resistance, hardness, and conductivity are just a few of the qualities that composite materials have. Composites are developed when two or more materials are joined to provide a set of qualities that would have been hard to reach otherwise. In composite materials, especially fiber-reinforced polymers, the characteristics of individual components, numerous distinct phases, and the size, shape, orientation, and distribution of fiber all play a significant impact. Composites are multifunctional material systems with properties that no other material can match [2].

Composite materials are usually classified on the basis of the physical or chemical nature of the matrix, e.g., polymer matrix, metal-matrix and ceramic matrix composites. In addition, there are some reports to indicate the emergence of inter metallic-matrix and carbon-matrix composites. The matrix is a percolating “soft” phase (which in general has excellent ductility, formability and thermal conductivity) in which are embedded the “hard” reinforcements (high stiffness and low thermal expansion). The reinforcements can be continuous or discontinuous, orientated or disorientated [3]. Natural fibers are becoming more popular as reinforcing materials in composites due to several advantages, including their low cost, lightweight, non-toxic nature, high mechanical characteristics, and minimal environmental effect [4]. Steel and plastic are now commonly utilized in the manufacture of a broad range of products, including doors, false ceilings, toys, agricultural boxes, rims, and mobile panels, to name a few. However, none of these materials is cheap or ecologically benign, and their existence has severe repercussions for both the user and the environment. Natural fibers have made their way into composite applications during the last few decades [5].

Metallic base alloy characteristics (such as ductility, conductivity, and toughness) are combined with ceramic reinforcing properties in MMCs (such as superior strength, high wear resistance, high thermal stability, and high modulus) [6]. Greater tensile, shear, and compression strength, improved service temperature potentials, and reduced wear loss can all be gained as a result of hybridization.

Because of their lightweight, excellent corrosion resistance, and superior electrical and thermal conductivity, aluminum alloys are among the most often used materials in the manufacturing of MMC_S as matrix materials. Several aluminum alloys (such as 1xxx, 2xxx, 5xxx, 6xxx, 7xxx, and others) are used in the manufacture of composites. The aluminum alloys of the 6xxx family have high machinability and miscibility, and they are primarily utilized as a matrix material in the manufacture of AMMCs [7]. Aluminum metal matrix composite (AMMC) is effective for a variety of applications due to its low density, high specific strength, high stiffness, improved wear resistance, low thermal coefficient of expansion, and high-temperature application.

Based on the primary manufacturing techniques, metal matrix composites may be categorized as solid, liquid, or semi-solid form production methods. The diverse types of metal matrix composite manufacturing methods include solid-state procedures (powder metallurgy), liquid state processes (such as stir casting, stir squeezed casting), and semi solid-state methods (spray deposition) [8]. Stir casting was utilized to make the composite specimen in this investigation because it is a quick and inexpensive way to make large and small-scale MMC components.

1.2. Aluminum Alloy (Al6063)

The aluminum association has developed a naming system that groups aluminum alloys by alloying elements and material properties, with a four-digit "name" to distinguish them. This term's first digit designates a group of alloys separated mostly by alloying components. 6063 aluminum is one of the 6xxx alloys, which strengthen the basic aluminum by adding magnesium and silicon. Heat treatable, weldable, corrosion-resistant, and simple to manufacture, 6063 aluminum alloy is a popular choice. It is more corrosion resistant than 6061 aluminum because it contains less copper, which increases corrosion susceptibility. One of the most heat-treatable alloys is AA 6063 aluminum plates and rods. Architectural fabrication, window and door frames, pipe and tubing, and aluminum furniture are the most common applications.

Because of its small weight, aluminum is frequently utilized as a structural material, particularly in the aircraft sector. Low strength and melting point, on the other hand, were always an issue. The use of reinforcing elements such as SiO2, SiC particles and whiskers, or other elements or compounds as alloying elements, was a low-cost approach of alleviating these problems. The addition of ceramics and alloying element particles to aluminum allows for increased specific elastic modulus, improved thermal characteristics, and other benefits. Several methods for producing aluminum composites and alloys reinforced with particulates and other alloying elements, such as powder metallurgy, stir-casting method, infiltration casting, direct melt oxidation, hot dipping, and sintering of ball-mill activated mixture of powders, will help to produce a homogeneous distribution of reinforcement in matrix [9, 10].

The better characteristics of aluminum matrix composites over monolithic aluminum alloys have piqued curiosity. Hard reinforcement materials increase a variety of qualities, including strength, stiffness, and wear resistance. To create high performance metal matrix composites, many processing techniques have been documented [10].

1.3. Composite Material, CM

In its most fundamental definition, the term composite means "put together." It is made up of two or more different materials that have been joined together. Composite materials are inhomogeneous and anisotropic. Composite materials offer distinct characteristics, such as a high strength-to-weight ratio [11]. Composite materials have two phases: a continuous "matrix" phase and a discontinuous "reinforcements" phase. The matrix phase of composites is in charge of connecting fibers/reinforcements together, transferring loads and stresses within the composite structure, maintaining the overall structure, and protecting the composite from external agents including humidity, chemicals, and other contaminants [12]. The study would make use of reinforcing and matrix materials. Reinforcing materials might be fibers, particles, or layers. Its main purposes are to sustain the load and improve the mechanical strength of the CM, such as stiffness and flexural strength. The matrix material might be made of polymer, ceramic, or metal. Connecting the reinforcements, transferring stresses within the reinforcements, and preserving the material's shape are all functions they perform [13].

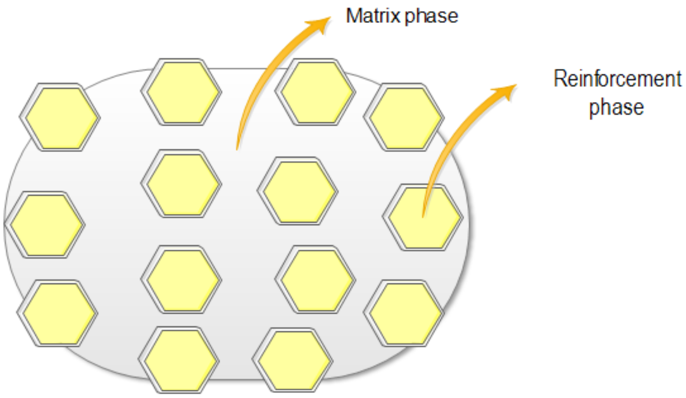


Figure 1.1: Composite material structure (Cheung H et al., 2019)

1.4. Various Considerations in the Fabrication of Metal Matrix Composites

When producing a higher-quality metal matrix composite utilizing a stir casting mechanism, stir process parameters, matrix reinforcement material selection, production method, metal matrix material characteristics, and impediments should all be carefully examined.

Figure 1.2 depicts a cause and effect diagram of the various aspects that should be taken into consideration while manufacturing MMCs.

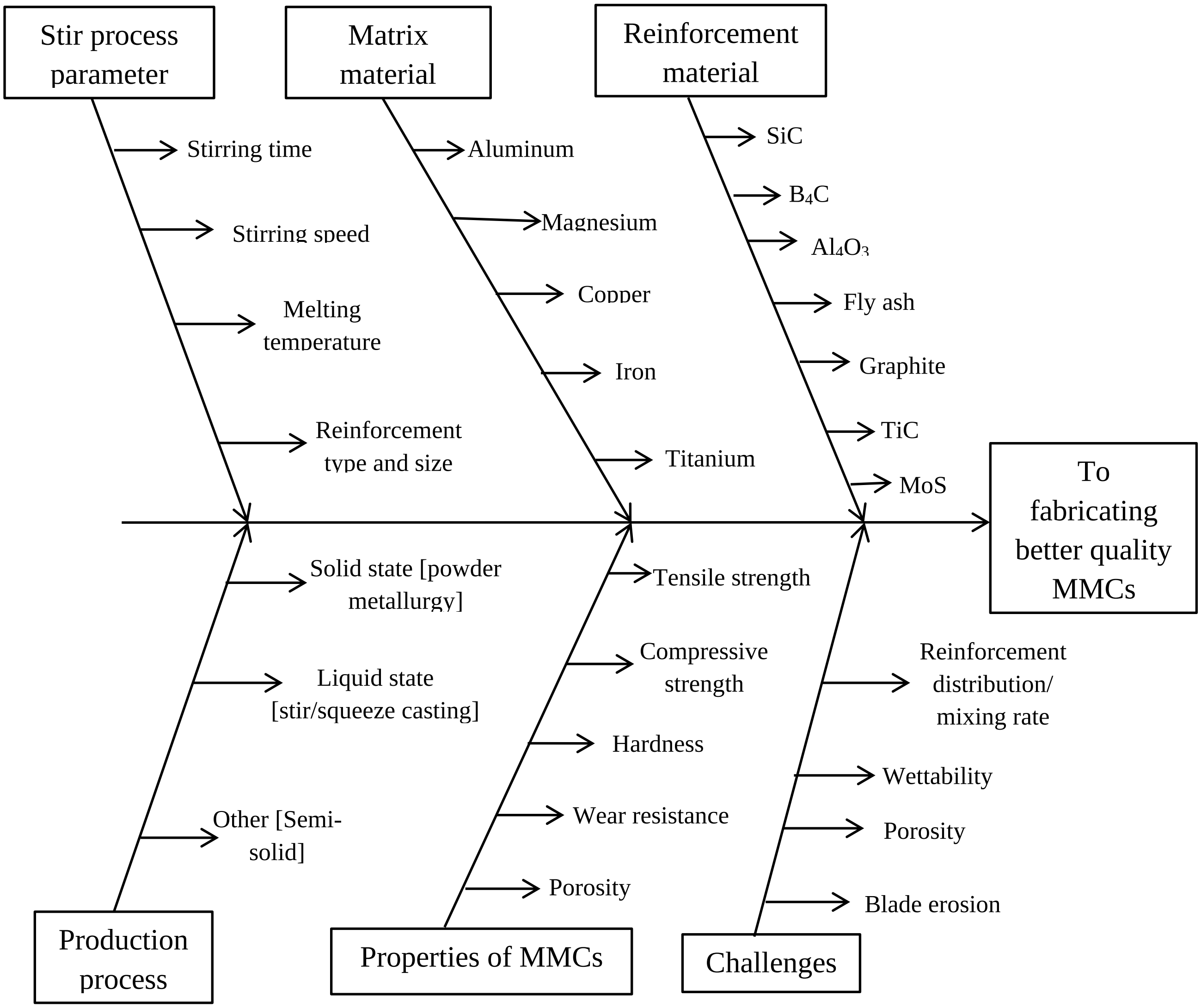


Figure 1.2: Fish bone diagram for producing better MMCS by stir casting process (Ramanathan et al., 2019)

1.5. Problem Statement

Today's major industries, such as automotive, aerospace, and marine, are focusing on the manufacture of lightweight and high-strength components utilizing cost-effective composite materials rather than steel. Aluminum is the third most common element in the earth's crust and is a light metal with a specific weight of 2.7 gm/cm^3 (about one-third that of steel). Aluminum alloy is used in automotive parts such as brake rotors, clutches, engine blocks, connecting rods, vehicle bodies, shafts, gear trains, and other components to minimize dead weight and energy consumption. Aluminum alloy is the most abundant element due to the manufacturing of lightweight and high-strength cost-effective composites. In other words, using heavy metals in automobile components increases the vehicle's total weight and fuel consumption. And also the composite is produced from the waste material (the matrix is scrap Al6063 alloy and the reinforcement is the RH) these also manage the waste material. Because aluminum alloy has low density and availability, it is extensively used for different applications besides automotive use. Even though aluminum alloy attracts the user due to its lightweight and availability in abundance, still it’s mechanical and tribological properties such as tensile strength, compressive strength, hardness, and wear resistance need improvement to encounter the required applications. As a result, the focus of the research is on the production and characterization of an aluminum alloy (Al-6063) matrix composite reinforced with rice husk ash stir casting to overcome mechanical, physical, and tri-biological property limitations.

1.6. Objectives

1.6.1. General Objectives

The general objective is to Synthesis a composite based on aluminum alloy with rice husk ash composite and to study their mechanical properties with various weight percentage compositions.

1.6.2. Specific Objectives

- To prepare aluminum alloy and rice husk ash composite with various weight percentage compositions.
- To characterize the mechanical properties such as tensile strength test, compression strength test and hardness test.
- To investigate tribological properties (wear loss and coefficient of friction) of hybrid composite using Pin-on-Disc tribometer and also investigate wear morphology of the worn samples by SEM.

1.7. Significance of the Study

Because it illustrates how utilizing the rice shell may decrease expenditures and improve waste management, the findings of this study are important for composite and rice producers, as well as waste management in rice processing firms. Individuals, academics, and manufacturers interested in new green composites may find the project's outcome valuable as a resource. Cleanliness can help the country and community while also turning trash into valuable goods.

The elimination of a byproduct, the rice husk, was beneficial to society. This might benefit rice farmers by allowing them to resale rice shells for composite manufacturing. Manufacturing industries such as automotive, aerospace, and others are now focusing on the creation of lightweight components utilizing cost-effective composite materials rather than steel and aluminum alloys. The cost barrier of cars or other equipment can be reduced by selecting the most cost-effective reinforced material. The study focuses on lowering vehicle fuel usage by lowering the vehicle's dead weight.

This research work has the following advantage;

- It will be used as an alternative source of low-cost and lightweight materials.
- It will reduce the weight of the machine, for example, the use of this hybrid composite reduces the weight of the vehicle and decreases fuel consumption.
- Significant improvement in mechanical and tribological properties of the machine component.
- It will substitute the material which is used in some parts of motor vehicles such as connecting roads, valves, shafts, rotor drum/disk, etc. with comparable Properties.
- As teaching aid and reference material for technological education and further research in developing composites.

1.8. Scope of the Study

The scope of this research will include;

- To synthesis of aluminum alloy with rice husk ash composite with various weight percentages.
- To characterize the wear morphology via scanning electron microscopy (SEM) and mechanical properties was also performed.

1.9. Beneficiaries

This effort will help a variety of sectors, including the automobile industry, construction industries, aerospace industries, and other businesses that employ heavy metals to manufacture machine components. Further research into composite materials will also help researchers and students.

1.10. Structure of the Thesis

This research study is divided into five chapters, with the highlights of each part addressed below. The study's first chapter is an introduction. It covers the study's background, the problem description, the objectives, and the scope of the research, the significance of the study, beneficiaries, and the report's arrangement.

The second chapter concentrated on various literary works done by various writers that focused on the research of metal matrix composite materials.

The third chapter discusses the materials and procedures that were utilized to complete this thesis. Matrix and reinforcing materials, Fabrication Equipment, Testing Equipment, Composition preparation for composite fabrication, the composite fabrication method's procedure, and others are all covered in this part.

The experimental result of mechanical, microstructure, and tribological properties of the manufactured specimens Al-6063+ rice husk ash composite has been presented and discussed in Chapter four.

Finally, Chapter five presents the conclusion of experimental results and recommendations for future works.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter examines past research on Rice husk ash, aluminum alloy composites, composite materials, features and categorization of composite materials, and earlier works gathered from journals, books, articles, papers, and websites, among other sources.

2.1. Composite Material

Composite materials, both man-made (such as fiberglass) and biologically generated, may be found in almost every aspect of existence (like mammalian bones). A composite man-made substance's objective is to improve the qualities of the matrix material by adding a second material with different chemical and structural properties. Metal-matrix composites are an important field of composite research in which a metallic host material is transformed by the addition of reinforcement [1, 14]. The reinforcement might be in the form of fibers or particles. The purpose is to give reinforcement to the metal to improve desirable qualities such as hardness, compression, and tensile strength.

Aluminum, in both its pure and alloyed forms, is a versatile material that may be used in a variety of technical and industrial applications. The most often utilized reinforcement in aluminum matrix composites is particulate form, which is widely used in the automotive and aerospace sectors [15]. As a result, there is a significant demand for aluminum matrix composites in all industries due to their superior performance, cost savings, and environmental advantages. Furthermore, of all-metal matrix composites, aluminum metal matrix composites are the most prevalent and are required for numerous technical applications. Aluminum or its alloy matrix composites, according to [16], offer the following main benefits over 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

Composite materials are made up of a variety of different materials that have different physical and chemical characteristics. To make composite materials, the stir casting process was utilized, which is a simple and inexpensive procedure. As a consequence, different percentages of reinforcing material were used to make stir casting samples of Aluminum Al-6063 Rice husk ash (RHA).

Despite the benefits, they bring in terms of performance, structural efficiency, and cost, composite materials are quickly being employed in aerospace, marine, and other industries. Physically joining two or more suitable elements to produce a continuous structure is how composite materials are created. It can also provide materials with unique characteristics that aren't available anywhere else. The matrix and reinforcing material are the two continuous and discrete components, respectively. The distributed or reinforcing elements are tougher and stronger. On the other hand, continuous or matrix components are generally soft and sticky [17]. As reinforcing materials, fiber, particle, or layer might all be used. Some of its major tasks include supporting the load and improving the mechanical strength of CM, such as stiffness and flexural strength. The matrix component might be made of polymer, ceramic, or metal. Its functions include tying the reinforcements together, transmitting stresses among reinforcements, and maintaining the material's shape.

Composite materials are made by physically combining two or more compatible materials to create a continuous structure. It can offer materials with enhanced properties that are not accessible from every source. The materials are multifunctional that include one or more discontinuous or distributed phases within a continuous phase. Discontinuous phases are frequent. The matrix is a discontinuous phase that has superior mechanical properties to the continuous phase.

The matrix phase in composite material has the role of binding fibers/reinforcements together; Transfers loads and stresses within the composite structure; supports the overall structure, protects the composite from the incursion of external agents such as humidity, chemicals, etc. [18]. On the other hand, fibers/reinforcements provide stiffness, strength, thermal stability, and other structural properties in the composites. The discontinuous phase is usually harder and stronger than the continuous phase [19]. Matrix phase provides shear, low density, and toughness.

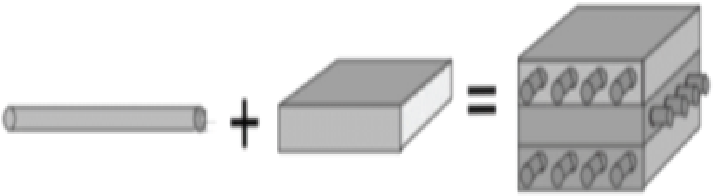


Figure 2.1: Composition of composite (Yadav et al., 2016)

2.2. Characteristics of Composite Materials

The characteristics of composite materials as well as their distribution and interaction, have a significant impact on their properties. The reinforcing constituent's weight percent in the matrix material has an impact on composite properties as well. Apart from the primary material properties, the geometry of the reinforcement (shape, size, and distribution) does have a massive effect on the composite's qualities. The orientation of the reinforcement does have an impact on the composite's properties. The reinforcement phase's design (which can be spherical, cylindrical, or rectangular cross-sectioned prisms or platelets), the size and size distribution (which controls the material's texture), and the volume fraction all play a role in determining the extent of the reinforcement matrix interaction. Concentration, which is generally quantified in volume or weight fraction, determines how much a single ingredient contributes to the overall characteristics of composites [20]. Composite manufacturing methods and manufacturing variables have a significant impact on composite quality.

2.3. Classification of Composite Materials

Composite materials are classified based on their reinforcement and matrix types. Reinforcement categories include fiber composite materials, particle composite materials, and structural composite materials, whereas matrix types include polymer composite materials, metal composite materials, and ceramic materials.

In general, composite materials can be divided into two categories based on the nature of their characteristics, as shown in Figure 2.2. Natural composites are naturally existing or valued composites, whereas synthetic composites are created or synthetically existing composites. Animals and plants both have natural composites. Wood (lignin is a matrix, and hemicellulose is a reinforcement) and bones are well-known examples of natural composites.

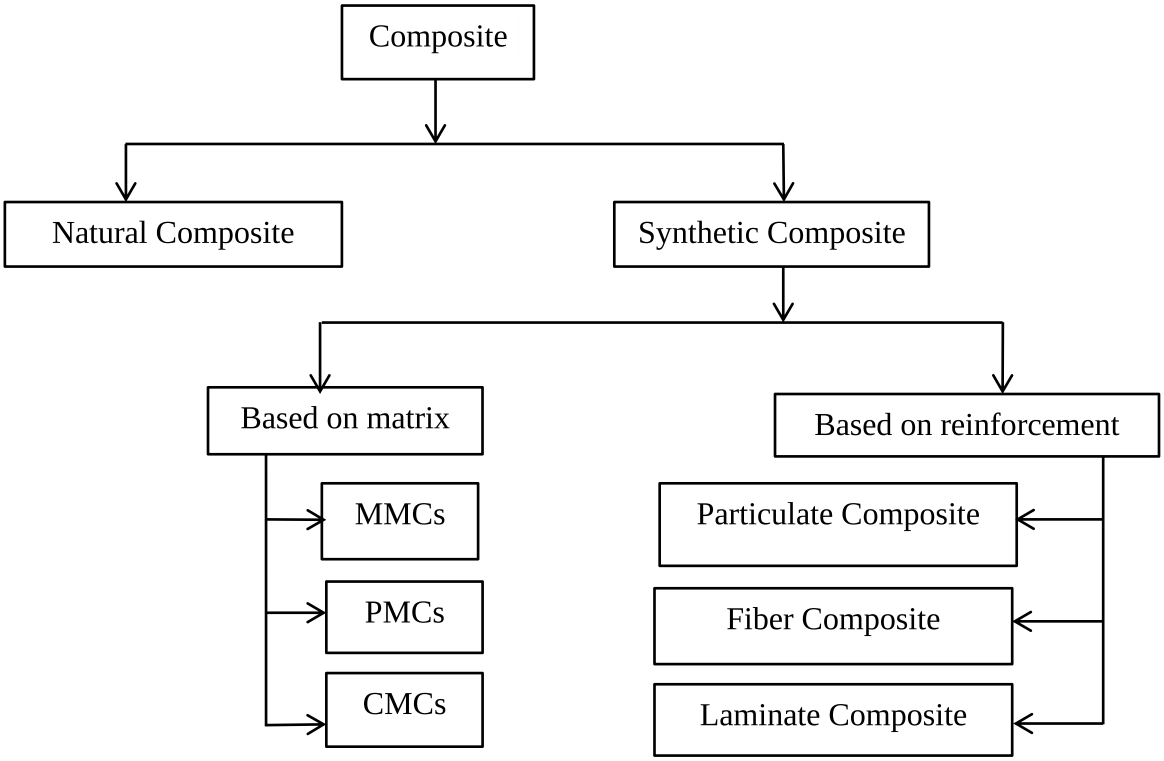


Figure 2.2: Classification of composite material

2.3.1. Based on Matrix Materials

The three forms of synthetically produced composites that may be classified depending on the matrix material used are metal matrix composites (MMCs), polymer matrix composites (PMCs), and ceramic matrix composites (CMCs).

Polymer-Matrix Composites (PMC): Polymeric matrix materials are the most popular matrix materials for composites. These matrix materials are primarily employed in fiber-reinforced composites, according to [16, 21]. The most frequent matrix materials in PMC is epoxies. Polymer-Matrix Composites are frequently employed in aerospace applications because of their low weight and great strength. Low operating temperature, high coefficients of thermal expansion and hence dimensional instability, and susceptibility to radiation and moisture are the primary drawbacks of PMC [21].

Metal-Matrix Composites (MMC): Metal matrix composites, according to [22], maybe employed at higher service temperatures than their base metal equivalents. These composites have a ductile metal matrix. As a result of the reinforcement, the strength, hardness, and dimensional stability of these composite materials are improved. Because metal matrix composites are lightweight, strong, and resistant to wear and thermal deformation, they are commonly employed in the automotive sector.

Ceramic-Matrix Composites (CMC): Ceramic materials are intrinsically resistant to oxidation and deterioration at elevated temperatures, according to [23], and if it weren't for their proclivity for brittle fracture, they would be used in higher temperature and serve-stress applications, specifically for components in automobile and aircraft gas turbine engines. CMCs have lagged in development because most processing routes need higher temperatures and are only used with high-temperature reinforcements [23]. Table 2.1 shows the summary properties and production methods of composites.

Table 2.1: Properties and process methods of the composites

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

Based on the reinforcements, composite materials can be classified as fiber, whisker, or particle reinforced composites. The length of a fibrous reinforcement is significantly higher than the cross-sectional dimension. Continuous fiber-reinforced composites are made up of long fibers with a high aspect ratio, whereas discontinuous fiber-reinforced composites are made up of short fibers with a low aspect ratio [27]. Particulate reinforcements have diameters that are about similar in all directions, according to [26]. Reinforcing particles might be spherical, cubic, or any other regular or irregular form.

Particulate Composites: Figure 2.3 shows a matrix reinforced by a dispersed phase in the form of particles in a Particulate Composite. Because the particles are added at random, they are generally isotropic. Particulate composites offer benefits such as greater strength, higher working temperatures, and oxidation resistance, among others [25]. Ceramics and glasses, metal particles, and amorphous materials are all utilized as reinforcing particles [24].

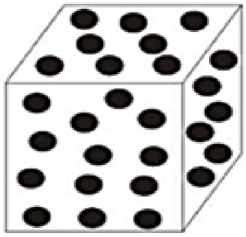


Figure 2.3: Particulate composite matrix in the dispersed phase (Przemysław et al., 2013).

Fibrous Composites: it can be divided into a composite with short and long fiber reinforcement as shown in figure 2.4 and figure 2.5.

A. Composites with short fiber reinforcement. As illustrated in Figure 2.4, the matrix is reinforced by a dispersed phase in the form of discontinuous fibers (length 100*diameter).

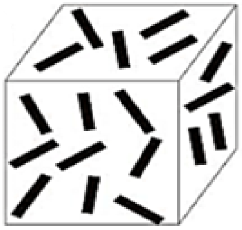


Figure 2.4: Fibrous composite matrix dispersed phase in discontinuous fiber (Przemysław et al., 2013).

B. Composites with long fiber reinforcement. As illustrated in Figure 2.5, the matrix is reinforced by a scattered phase in the form of continuous fibers.

Figure 2.5: Fibrous composite matrix scatters in continuous fiber (Przemysław et al., 2013).

Laminate/ Structural Composites: Multilayer composites, as shown in Figure 2.6, are fiber-reinforced composites that are made up of multiple layers with various fiber orientations.

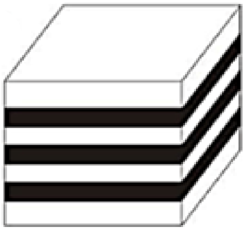


Figure 2.6: Laminated (structural) composite matrix (Przemysław et al., 2013).

2.4. Metal Matrix Composite

Metal Matrix Composites are composites that have metals as their matrix phase. Aluminum, titanium, magnesium, and copper are typical metals utilized as matrix materials. The other material, ceramic, is used to strengthen the metal matrix [26]. They have higher temperature capability, strength, and thermal conductivity than offered by PMCs [27].

Aluminum metal matrix composites (AMMCs) are materials in which aluminum metal is utilized as a matrix material and is reinforced with additional materials such as SiC, Al_2O_3, B_4C, Ti_2B, and other ceramics. AMMCs are used in airframes, pistons, drive shafts, submarines, and other aerospace, ground, and water transportation applications. Because of its lightweight and better strength-to-weight ratio, corrosion resistance, wear resistance, and higher thermal conductivity, demand for AMMCs has been growing [28]. Whiskers, particles, and fibers are examples of continuous and discontinuous reinforcement. Particulate-based reinforcement aluminum metal matrix composites (PAMMCs) are composites that have an aluminum matrix material with particle reinforcement. PAMMCs have several applications in ground transportation like pistons, transmission components, cylinder liners, bearings, brakes, etc. [26]. These composites have isotropic properties. Solid-state (Powder Metallurgy) and liquid-state techniques can be used to make them (Stir casting, Compo-casting, Squeeze Casting, in situ casting routes).

Stir casting is a widely used processing technique for fabricating PAMMCs because of its simplicity, flexibility, and high amount of production application. Among all the options, this is the most cost-effective way [29].

The metal matrix composite (MMC) is made up of a variety of components, which are explained by the metal matrix, shape, and kind of reinforcement [30]. MMCs are metals that have been reinforced with fibers, particles, or monofilaments. It is a lightweight structural material that may be utilized in the aerospace sector [31, 32]. Aluminum-based composites are always by far the most used materials [33]. AMMC has remained the best potential candidate for research in producing viable engineering components [34, 35].

Metal matrix composites (MMCs) are composites in which metals are used as a matrix material. As matrix materials, aluminum, magnesium, titanium, and copper super-alloys and alloys are used. Graphite, silicon carbide, boron carbide, molybdenum disulfide, aluminum oxide, and other common reinforcements are used. Specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability may all benefit from the reinforcement [21].

2.4.1. Applications of Metal Matrix Composites

Metal matrix composites have a variety of applications in engineering today. Due to its excellent properties over alloys and pure metals, the development of MMCs promoted many sectors to embrace metal-based composites over alloys and pure metals. The following are some of the industrial applications of metal matrix composites:

A) In aircraft and aerospace industries

The space shuttle's fuselage frame is supported by boron/aluminum tubes. Because of its low thermal conductivity, this composite decreased the weight of the space shuttle by more than 320 lb (145 kg), as well as the thermal insulation needs. Carbon-reinforced aluminum is used in the

Hubble Telescope on the space shuttle. MMCs are also used to make airline wing and supporting structures, military aircraft components, and cargo [36].

B) In automobile industries

Metal matrix composites, which are lighter than their metal counterparts, are increasingly employed in car engines. Metal matrix composites are also the preferred material for gas turbine engines due to their great strength and low weight.

MMCs are used by automobile manufacturers in their products. For example, engine components made of an aluminum-alloy matrix reinforced with aluminum oxide and carbon fibers have been developed; this MMC is lightweight and resistant to wear and thermal distortion. Drive shafts, extruded stabilizer bars, and forged suspension and transmission components all use metal-matrix composites [21].

Aluminum matrix composites are used to make pistons, connecting rods, engine blocks, brake rotors, current collectors, propeller shafts, and break discs [36]. Connecting rods constructed of aluminum matrix composite reinforced with aluminum oxide are shown in Figure 2.7.

Figure 2.7: Connecting rods made of Al-Al2O3 (Przemyslaw and Aleksander, 2013)

C) In Military industries

Dimensional stability is required for precision components in missile guiding systems so that their geometries do not vary during usage. MMCs with high micro-yield strength, such as SiC/Aluminum composites, meet this criterion [37].

Due to its desired qualities, metal matrix composite is also suitable in the marine industry, sports and recreation sectors, electrical transmission equipment, and rail transportation businesses, among others.

2.4.2. Merits of Composite

Composite materials offer several key characteristics that have led to their widespread acceptance and usage in a variety of applications. It has the following advantages:

- **Lightweight**

Composite materials are lightweight as compared to metal, concrete, or wood. Composite structures are typically one-fourth the weight of steel structures of the same strength [38].

- **High strength**

Composite materials are sufficiently strong, especially when measured in terms of their weight per unit. Composites have four to six times the tensile strength of steel or aluminum, depending on the reinforcements. Composite materials offer better fatigue endurance limits, torsional stiffness, and impact characteristics than traditional materials [39].

- **Corrosion and chemical resistance**

Composites have high chemical resistance and will never rust or degrade. As a result, the maritime industry has adapted it for the construction of boats and ships. Fiberglass boats can withstand the corrosive effects of seawater without rusting [40].

- **Elastic**

Elasticity is a significant characteristic of fiber-reinforced composite materials because they may snap back into place after being bent. Metals, on the other hand, will give or dent if bent. As a result, composite materials may be utilized in automobile leaf springs and archery bow limbs [39].

- **Versatile**

Composite materials are more adaptable than metals, allowing them to be customized to specific performance requirements and complicated design specifications [41].

- **Good thermal insulating properties**

In some applications, the non-conductivity of heat and electricity is a desirable property when choosing a material. As a result, certain composites, such as fiberglass composites or others, can be used in this application [39].

- **Environmentally green**

Aside from its mechanical and physical benefits, composite materials may also be used as an alternative to environmentally friendly materials. Because natural fibers derived from sustainable resources may be used to create composite materials. It is used to reduce the number of greenhouse gases released into the atmosphere [39].

2.5. Aluminum Alloy (Al-6063) Matrix Composites

The strength-to-weight ratio of aluminum matrix composites (AMCs) is greater than that of other metal matrix composites. This section provides an overview of previous research on aluminum matrix composites, particularly Al-6063 matrix composites. The two subsections were single-reinforced aluminum (Al-6063) alloy matrix composite and hybrid-reinforced aluminum (Al-6063) alloy matrix composite. By changing the weight percent, mechanical characteristics (tensile, compression, and hardness tests) and certain investigations were carried out.

Due to their better characteristics over monolithic aluminum alloys, aluminum matrix composites have sparked a lot of attention. Hard reinforcement materials increase a variety of characteristics, including strength, stiffness, and wear resistance. High-performance metal matrix composites have allegedly been made using a variety of processing techniques.

Aluminum 6063 is an aluminum alloy with mechanical characteristics that make it useful in a variety of industries. Some of its characteristics, such as hardness and tensile strength, may not be acceptable for industries, which is why rice husk ash, a biodegradable agricultural waste product, was used to strengthen it (RHA) [42]. RHA particles are utilized because they have a high silica concentration, are inexpensive, and are readily available. AMMCs have a high specific strength, low density, strong damping capacity, high thermal conductivity, low expansion coefficient, and good temperature resistance, to name a few [34]. Aluminum alloy is reinforced with 0, 4, 8, 12, and 16 wt% RHA in this study to improve the mechanical properties of the Al-6063/RHA composite.

2.5.1. Application of Al-6063

- Aerospace
- Automotive
- Military industries due to their high strength to wear ratio, stiffness, lightweight, good wear resistance, and improved thermal and electrical properties

2.6. Rice Husk Ash

Rice husk is a waste product from agriculture that accounts for 20% of the world's annual rice production of 649.7 million tons. RHA is a less costly reinforcing material when compared to SiC, Al_2O_3, and TiC. In small steam power plants, it is used to create steam. During the burning process, the volatile material from the husk is removed, and the remaining husk is converted into ash, which is known as rice husk ash. RHA includes 85% to 90% amorphous silica, according to recent study findings [43]. This RHA poses a serious environmental threat by contaminating the land and the area in which it is deposited. This suggests that the researcher's argument that agricultural waste may be put to good use is correct. Rice husk may be burnt at temperatures below 800°C to create amorphous silica ash, which can be utilized to make composites with low density, hardness, and high-temperature resistance. Rice husk is a low-cost material that may be used to make silicon carbide whiskers, which are then used to strengthen ceramic cutting blades [44].

Stir casting is the most popular commercial process of manufacturing aluminum-based composites. This technique incorporates preheated ceramic particles into the molten matrix vortex produced by a spinning impeller. In theory, it allows for the adoption of a black metal processing approach, lowering the ultimate cost of the product.

2.6.1. Application of rice husk

A) Rice husk as a Fuel

The majority of the RH is used as fuel in power plant boilers to generate steam. Direct combustion or gasification is two methods for obtaining energy in the form of heat. Small-scale enterprises often utilize low-capacity boilers. They used rice husk as an energy source to power the boiler. Because rice husk is practically free and abundant, businesses are concentrating their attention on this type of fuel to improve boiler efficiency [45]. Plants with capacities ranging from 2 to 8 MW are commercially viable. To produce 1MWh of electricity, approximately 1 ton of rice husk is required [46].

B) Rice husk as an Agent of Silica and Silicon Compound

Rice husk is not only recognized for its organic content, but it also contains approximately (15-20%) silica, making it a valuable source of silicon compounds such as SiC, Si_3N_4, $SiCl_4$, complexes such as zeolite, and pure form silicon [47]. These silicon-derived compounds are used in a wide range of applications. Compounds produced as a powder from RH have a high level of purification and fine dispersion.

C) For insulating Fire bricks

One of the most essential variables in the thermal insulation of fire bricks is porosity. When bricks come into touch with RH and are exposed to fire, pores form. The burning of organic materials in the rice husk causes pores to form. Air has been trapped in these holes, which acts as a thermal insulator, allowing less heat to escape into the environment. Because of this porosity, bricks can be used as backup insulation [48].

D) In the making of activated carbon

The RH is mostly made up of hydrocarbons such as lignin and cellulose, which are utilized to make activated carbon. These activated carbons have a complicated porous structure. Activated carbons are made in two different ways, one is known as physical or thermal activation, while the other is known as chemical activation. Carbonization and activation occur independently in physical activation, while in chemical activation, both processes of carbonization and activation occur concurrently utilizing a chemical agent [48, 49]. Physical activation is quite beneficial in the production of activated carbon with a small specific surface area. These types of carbon can be utilized as good adsorbents due to their microporous nature [49].

E) Other applications of Rice husk

RH is a significant raw ingredient in the manufacture of xylitol, ethanol, vinegar, and sulphonic acid. It may also be used as a polishing and cleaning solution for metals and machine components that require a good surface finish and cleaner topography [50]. Rice husk has been used as a raw material in the manufacturing of various industrial components such as plastic fillers, building materials, and panel boards [51].

2.6.2. Application of rice husk ash

RHA has been successfully employed in a variety of sectors, including as a raw material in the manufacturing of steel, concrete, and refractories [50, 51]. The efficiency of RHA in industrial applications is determined by the chemical composition of ash, which is primarily a proportion of silica content. In comparison to materials such as slag, silica fume, and fly ash, the RHA has been proven to be more efficient in terms of silica content [52].

A) Application of RHA in the steel industry

In the manufacture of high-quality flat steel, RHA is utilized as an intermediate agent. It is utilized as an insulating material with good insulating properties. It has some of the most essential properties, such as low heat conductivity, a high melting point, and a highly porous structure.

It is utilized and has a low bulk density because of its great capacity to prevent heat escape into the environment. It is used in the tundish container as a powder (tundish powder), to reduce heat transmission in the tundish container [53].

B) In the field of Ceramic and refractory industries

In the production of refractory materials, we can create insulating boards out of RHA, which is lightweight and cost-effective. It is utilized as a silica source in the manufacture of cordierite. When kaolinite is replaced with rice husk ash containing a high amount of silica in the mixture, more cordierites are produced with a lower crystallization temperature and lower activation energy of crystal [54].

C) Use of RHA as Silica Source

Ash is created when rice husk is burned. Because it includes a larger amount of silica, it may be possible to harvest silica for future use. It's used in the rubber sector as a strengthening agent, as a cleaning agent in toothpaste and cosmetics, and as an anti-caking agent in food [55]. Because of its hardness, silica is currently utilized in the construction industry for the manufacture of cement and concrete. It improves the strength and durability of concrete and cement used in the construction of bridges and the construction of nuclear power plant walls [56]. RHA is also ideal for the manufacture of silica aerogel, which has been used in a variety of applications. As, a catalyst supporter, and dielectric materials super thermal insulators [57].

D) In cement and construction industries

Composite called blended cement is increasingly utilized to provide strength and toughness to construction components. It is made by mixing rice husk ash into cement and is used in nearly all construction projects codes are available all around the world. Most material scientists have utilized rice husk ash as a mineral addition to improving concrete performance, and they discovered that RHA acts as a highly reactive pozzolan [58].

E) Some other applications of RHA

In the agricultural area, rice husk ash can is utilized as a stabilizing agent to improve soil residual characteristics. It is used in conjunction with cement and is referred to as a stabilizer [59]. RHA is also capable of purifying water [60]. Several attempts have been made to employ Rice Husk Ash in the vulcanization of rubber in recent years [61]. RHA may be used to synthesize High-Performance Phosphors [62].

2.7. Production Methods

Primary procedures, such as processing the metal matrix in a liquid or solid-state, or others (including semi-solid, in situ, and others), can be used to characterize metal matrix composite manufacturing techniques. Metal matrix composites are classified as solid-state processing (such as powder metallurgy), liquid state processing (such as stir casting, stir squeezed casting), and other approaches based on their manufacturing processes [8]. Stir casting is the most prolific, cost-effective, and easy of the different types of MMC manufacturing processes/methods [63]. Table 2.2 gives the comparison between various production processes in terms of different aspects.

Table 2.2: Comparative evaluation of the different techniques used for DRMMC fabrication (Hashim et al., 1999)

Method	Range of shape and size	Damage of reinforcement	Cost
Stir casting	Wide range of shapes; large size up to 500 kg	No damages	Least expensive
Squeeze casting	Limited to perform shape; up to 2 cm height	Sever damages	Moderately expensive
Powder metallurgy	Wide range but restricted	Reinforcement fracture	Expensive
Spray deposition	Limited shape but the large size	-	Expensive

2.8. Process Parameters

Stir or squeezed-stir casting is often utilized to create high-quality single or hybrid reinforced metal matrix composites. Casting with a squeezed stir Melting temperature, die temperature, string speed, string duration, reinforcement %, reinforcement preheating temperature, squeezing pressure, and other process factors all play a significant influence in producing high-quality MMCs. Figure 2.9 shows the acceptable process parameter ranges for stir and stir-squeezed casting. The proposed range of process parameters is based on the findings of many researchers, as stated previously [8].

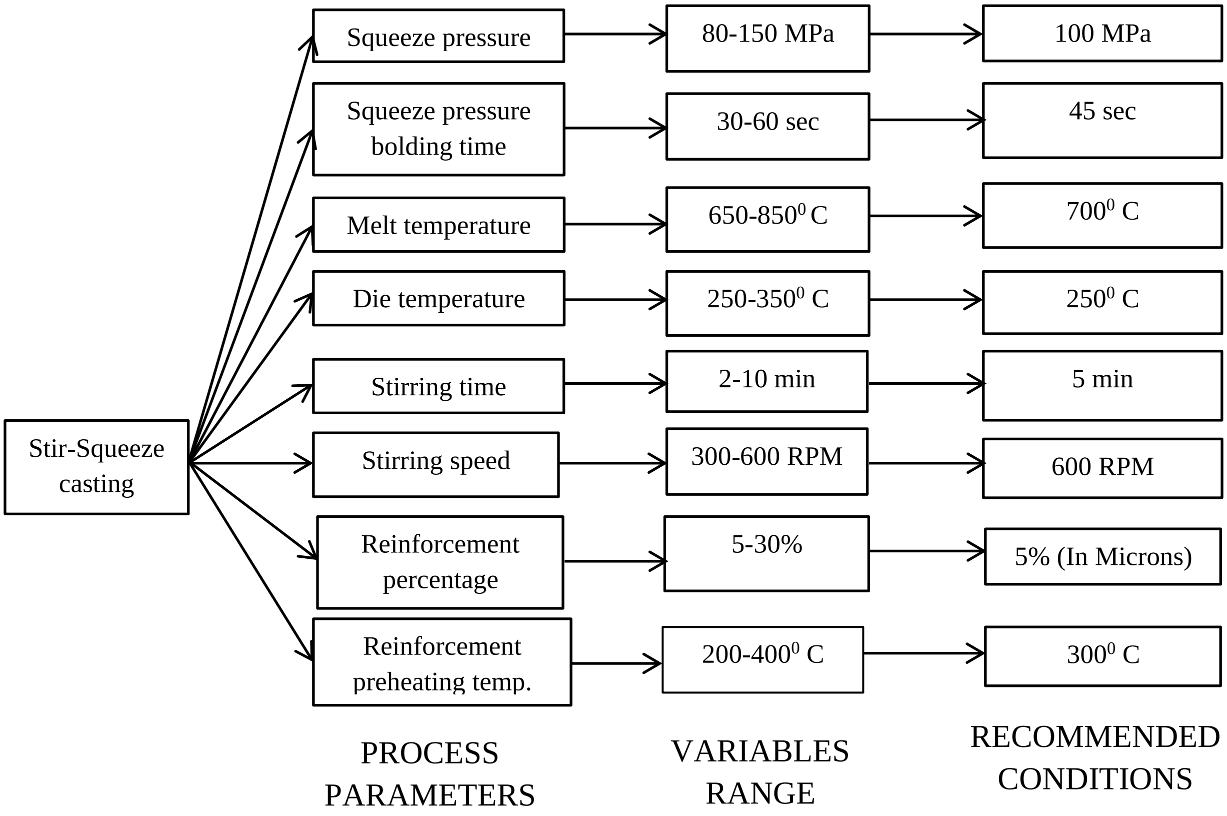


Figure 2.8: Recommended process parameters for stir-squeeze casting process (Ramanathan et al., 2019)

2.9. Stirrer

A mechanical stirrer is necessary for the Stir casting set up to create a vortex for the homogeneous dispersion of reinforcing particles into the molten matrix material and to enhance wettability. As a result, choosing the right blade angle, diameter, and the number is critical for achieving a good degree of mixing.

To investigate the effect of impeller blade angle, researchers used the water model and CFD model. The selected blade angles were 15, 30, 45, 60, and 90. The influence of impeller blade angle on the dispersion of solid particles in a liquid was examined using a water model. The results demonstrate that a stirrer with a blade angle of 30 functioned effectively and produced uniform dispersion with no solid particle buildup [65]. Furthermore, stirring duration has a significant impact on the dispersion of solid particles and the stirrer's power consumption. Figure 2.9 shows the typical image of four-bladed stirrers.

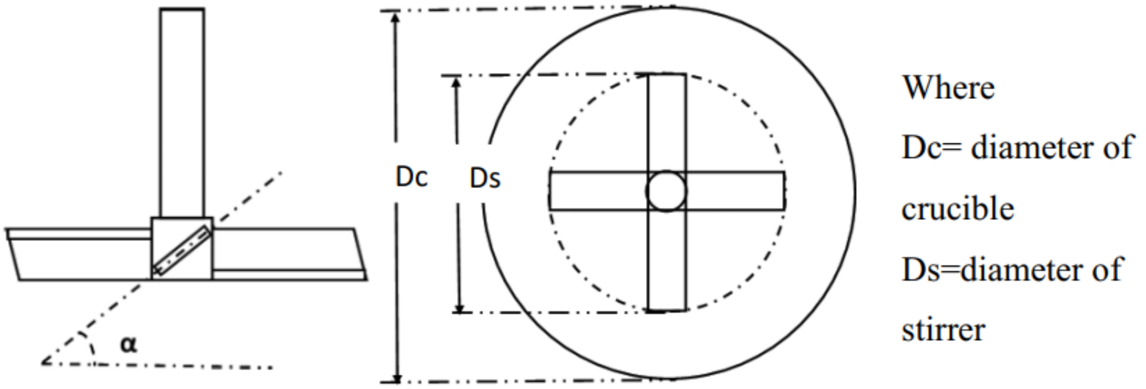


Figure 2.9: Stirrer blade angle (Mohit and Raj, 2018)

The researcher was used different models for the optimization of stirring parameters. The models used by the authors are the water model, FEM model, an experimental model. The authors were attempted to find the optimal values of stirring parameters for single-stage and multistage impeller stirrers.

To avoid clustering of reinforcement particles at the bottom, the blade should be less than or equal to 30% of the height of the fluid from the crucible's base. In addition, the blade's diameter should be half of the crucible's diameter. Figure 2.11 shows the position of the stirrer in the crucible during the action.

$$h \leq H_o$$

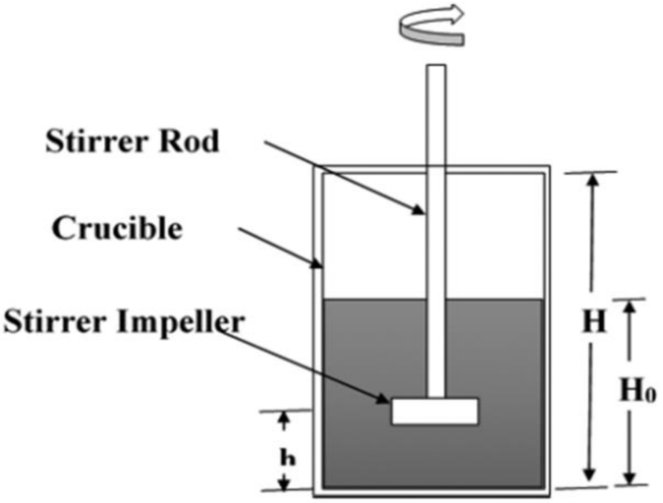


Figure 2.10: Position of the stirrer in crucibles

Table 2.3: Optimal values of stirrer parameters

Author	Blade angle (α)	Diameter of impeller (d)	Position of impeller (h)
	^{O}C	mm	Mm
Mohit and Raj	30	0.5D	0.25H0
Prabu et al	30	0.5D	-
Ravi et al.	30	-	0.3H0
Hashim et al.	-	-	0.3H0

2.10. Wettability between Matrix and Reinforcement Material

One element that has a major impact on the characteristics of metal matrix composites is wettability. The capacity of a liquid (molten matrix) to spread over a solid surface is known as wettability (reinforcement). It also refers to the degree to which liquid and solid are nearby. To enhance the wettability of the reinforcing particles with a liquid matrix material, a variety of approaches have been used [64].

1. The coating of the reinforcement particles is a wettable metal like Nickel and copper.
2. Pre-heating the reinforcement particle before being added to the molten matrix also promotes wettability.
3. Mechanical string leads to high wettability and
4. Ultrasonic irradiation of the melt.

2.11. Factors Affecting the Properties of AMMC

Although the previous section briefly discussed some of the properties of AMMC, the composite's exact set of properties depends on several factors. From the existing literature, three factors that could affect the properties of AMMC are identified. These are:

- Reactivity of the matrix and the reinforcing material
- The volume fraction of the reinforcing material
- Distribution of the reinforcing material

2.12. Literature Summary

Some studies on the manufacturing and characterization of aluminum matrix composites have been carried out, according to the literature review. The influence of processing conditions and various fabrication methods (such as liquid state and solid-state processing techniques) have been widely employed. The impact of weight composition reinforcement on the physical, mechanical, and tribological behavior of AMMCs has been investigated. In the manufacture of aluminum matrix composites, ceramic particles were frequently used as reinforcements. According to the literature, adding various particle reinforcements to an aluminum alloy (Al-6063) matrix improves the mechanical and tribological characteristics substantially.

2.13. Literature Gap

The features of many types of composites were produced and examined by earlier scholars. Future manufacturing technology is focused on producing low-cost, lightweight, high-performance items using boundless (unlimited) resources. Single-reinforced aluminum alloy (Al6063) matrix composites and hybrid-reinforced aluminum alloy (Al6063) matrix composites were made and investigated to enhance the performance of Aluminum alloy (Al6063) by varying the reinforcements used. However, the researchers did not mix only two of them (Al6063/RHA) to improve the mechanical and tribological properties of the Aluminum (Al6063) alloy [9] Was the only researcher to use the stir casting process to create a composite material from Al6063 matrix and Al6063 + RHA reinforcements.

As a result, Al6063 was chosen as the matrix material and RHA as the reinforcing material in this study. Combining RHA reinforcement in the form of none reinforced and reinforced at a specific weight composition of each, the hybrid composite was developed and investigated.

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

This section describes the matrix and reinforcements utilized in the production of hybrid aluminum alloy (Al-6063) matrix composites, as well as the manufacturing requirements. This chapter also covers the equipment utilized, the fabrication process employed, the fabrication procedures, sample preparation, and the experimental approach for characterizing the characteristics of produced composites. The processes taken during mechanical testing, tribological testing, and microstructure observation of the produced metal matrix composite (MMCs) are also shown.

3.1. Materials (Matrix and Reinforcements)

The materials used in this work for the development of hybrid Aluminum alloy (Al-6063) ware Aluminum alloy (Al-6063) as a base material and rice husk ash as reinforcement material.

Table 3.1: The materials required in gr to develop hybrid Al6063 composite

No.	Item	Quantity (gr)
1	Aluminum (Al-6063)	6900
2	Rice Husk Ash	600

3.1.1. Matrix

3.1.1.1. Aluminum Alloy (Al-6063) Matrix

The 6xxx series alloys containing magnesium and silicon provide moderate strengths and good corrosion resistance compared to other heat-treatable aluminum alloys. Because they are easily extruded, they are available in a wide range of structural shapes, as well as sheet and plate products. The versatility of these alloys is represented in Al-6063, which is one of the most commonly used aluminum alloys. The detailed chemical composition of this alloy is given in Table 3.2. Al-6063 aluminum plates and rods are of the most multipurpose heat-treatable alloys. Al-6063 alloy is also popular for its medium to high strength requirements, good toughness, and excellent corrosion resistance [66].

Figure 3.1: Aluminum alloy (AL-6063) scrap from life steel aluminum work

Table 3.2: Composition of aluminum alloy (Al6063)

Chemical Element	Al	Mg	Zn	Cu	Si	Mn	Ti	Fe	Cr	V	Pb	Ni
Composition (%)	95.9	0.87	0.0080	0.014	0.21	0.013	0.075	0.57	0.061	0.026	0.060	0.058

Table 3.3: Properties of aluminum alloy (Al6063)

Property	Value
Density	2.6 g/cm^3
Melting point	615 °C
Modulus of elasticity	68.9GPa
Tensile strength (σt)	145-186MPa
Elongation (ε) at break	18-33
Poisson's ratio (ν)	0.33
Thermal conductivity	201-218W/m*K
Linear Thermal expansion coefficient	2.34*10^{-5}K^{-1}
Specific Heat capacity	900J/Kg*K
Volume resistivity	30-35Ω*m

3.1.2. Reinforcements

The reinforcement phase is more powerful than the matrix phase, which is why it's named that. Reinforcements in composites offer stiffness, strength, thermal stability, and other structural characteristics. Low density, strong mechanical and chemical compatibility, good thermal stability, high Young's modulus, high compression, and tensile strength, good process ability, and economic efficiency are all properties of the reinforcing phase (Reinforcement) [18].

In a composite material, the reinforcement's primary function is to improve the neat resin system's mechanical characteristics. Long fibers aren't the only type of reinforcement that may be used. Particles, flakes, whiskers, short fibers, continuous fibers, and sheets are all examples of them.

In the present work, RHA is selected as reinforcement materials to develop hybrid Aluminum Al-6063 alloy matrix composite and the properties of each of those reinforcements are discussed as follows.

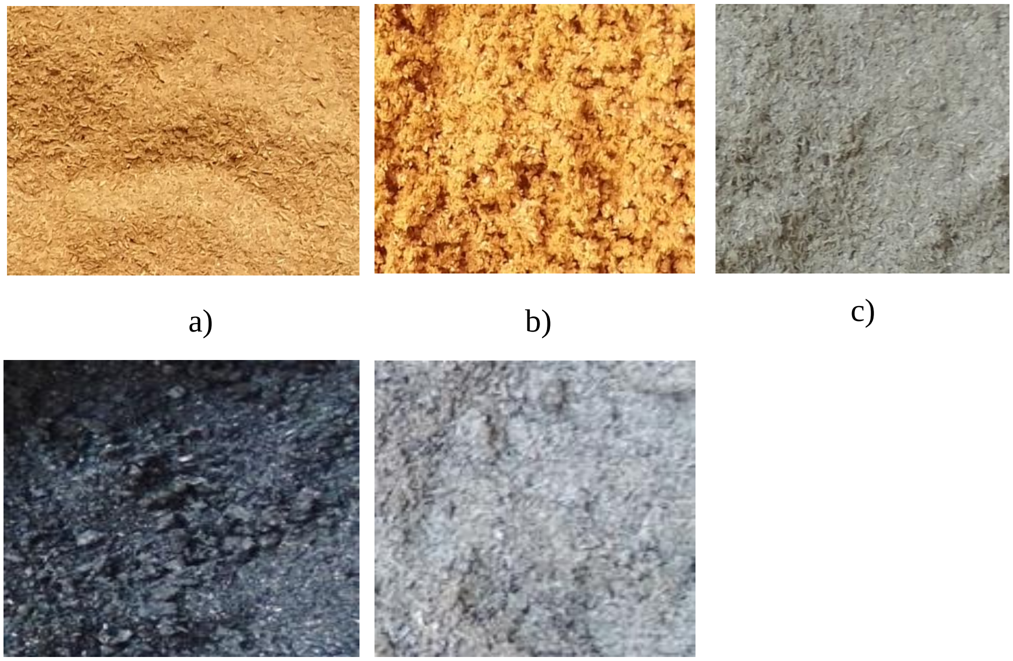
3.1.2.1. Rice Husk

Rice husk (RH) is a common agricultural waste product in rice-producing countries. Much of the husk left behind following rice processing is either burned or discarded. Even while some of this husk is transformed into end products such as feedstock and adsorbent, the majority is burned publicly, posing environmental and health risks, particularly in underdeveloped nations. As a result, finding ways to completely use the rice husk is critical. Silica can be pyrolyzed at high temperatures to produce rice husk ash (RHA) or extracted as sodium silicate from rice husk using a solvent extraction process. Rice husk ash outperforms rice husk in the majority of applications. Rice husk ash is a wide phrase that includes all types of ash created by burning rice husk. Recovering garbage to create eco-material with a high-end value would be good for the environment [44].

3.1.2.2. Preparation of rice husk ash

Rice husk is taken from Jimma zone Shebe around Seka wereda, and then it has washed with the help of water to eliminate the dust and dried at room temperature for 1 day. After it is washed rice husk is then heated to 200°C temperature for the 1-hour duration to remove the moisture and organic matter present in the RH. Due to heat treatment, the color of the husk is transformed from yellowish to black because of the burning of organic matter. It is further heated to 600°C for 12 hours to remove the carbonaceous material. After this operation, once again the color is changed from black to greyish white as shown in Figure 3.3. The burnt ash contains silica in rich quantity and is used as a reinforcement material for the preparation of composites. The percentage of ash in rice husk is about 10-25% higher than other biomass fuels, it has 85-87% silica content which shows a high level of porosity, less weight, and high external surface area.

The factors which show the effect on ash properties are burning conditions (temperature and duration), heating rate, the technique of an incineration variety of crops, and fertilizer used in the production of rice in the agricultural field. A typical analysis of rice husk ash is shown in Table 3.4.



a) b) c)

d) e)

Figure 3.2: Process on the preparation of RHA

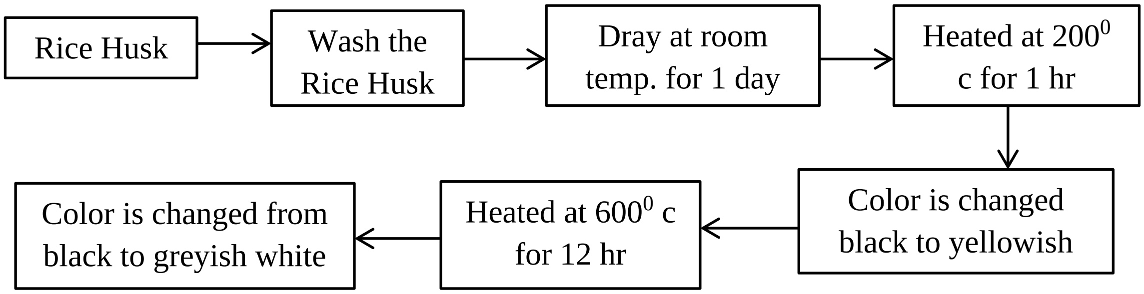


Figure 3.3: Process on preparation of RHA

Table 3.4: Chemical composition of RHA burnt at 600^0C

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
%	97.095	1.135	0.316	0.073	0.825	0.146	0.092	0.181	0.965

3.2. Equipment's Used to Fabricate and Prepare Composite Sample

Table 3.5 shows the equipment used to fabricate hybrid aluminum matrix composite and equipment used to prepare experimental samples.

Table 3.5: Fabrication and sample preparing equipment

Equipment's	Task	Model
Furnace	To burn the rice husk and melt aluminum alloy	Adjustable electrical furnace and fuel oil furnace
Stirrer	To distribute reinforcement material uniformly throughout the matrix material	Fabricated locally from stainless steel
Hand drill	To give rotational motion to stirrer after the stirrer is attached to the hand drill	
Lathe machine	To prepare the specimen for mechanical tests	TRAYON, C404

3.2.1. Furnace

It is a device that heats and melts metals, metal alloys, metal ores, and other materials so they may be processed further. As a heat source, the furnace can employ either electrical or fuel energy. As a result, a furnace is used to burn rice husk at a temperature of 600^0 C and to melt Aluminum Al-6063 alloy within the crucible at a temperature of 700^0 C. To construct furnaces, the following items are used: Body Frame (Plate and Angles), Refractory Bricks, Ceramic Blankets, Crucible, Heating Coil, Thermocouple, Temperature controller, Voltmeter, Ammeter, Transformer (Step down), etc.

3.2.2. Hand Drill and Stirrer

The hand drill is used to determine the diameter of the stirrer rod. A vortex is created in this sort of mechanical stirring system when the stirrer is a fixed to the hand drill and the hand drill rotates the stirrer.

Among all the options for producing AMMCs, the stir casting technique is the most cost-effective, easy, adaptable, and suited to large-scale manufacturing. Stir casting, on the other hand, is more selective due to 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 uniform distribution of the reinforcement material. In the stir casting process, mechanical stirring is used to distribute reinforcements throughout the matrix material. A Stirrer with a stirrer rod and stirrer blades is required to produce a vortex in the crucible. Normally, the stirrer is powered by an electric motor, however in this study; the stirrer was made with hand drilling tools.

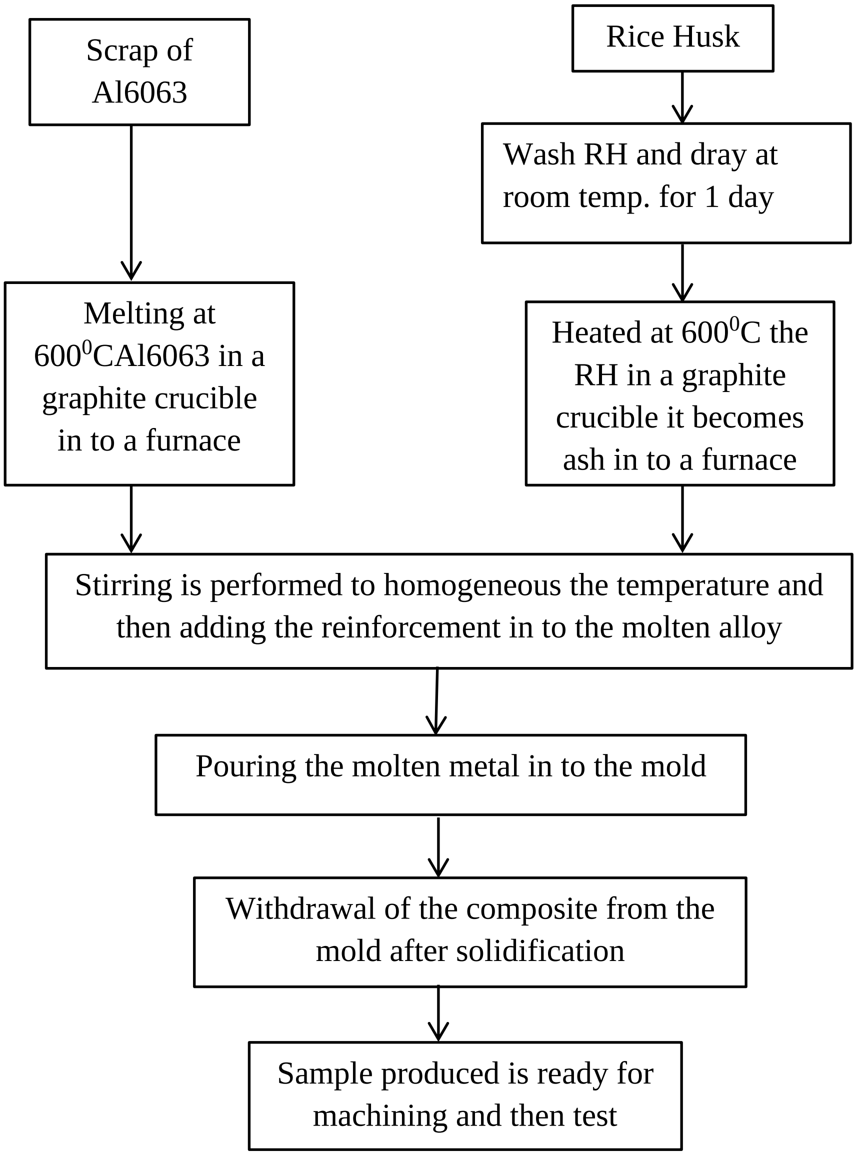


Figure 3.4: Flow chart showing steps involved in stir casting

3.2.3. Lathe Machine

It is a machine that performs a variety of operations on a work piece by rotating it around an axis of rotation, such as turning, threading, facing, knurling, drilling, and so on. Following the fabrication of the composite, it is prepared to the appropriate shape and size by ASTM standards to undertake experimentation. As a result, the sample is prepared using a lathe.

3.3. Testing Equipment’s

Table 3.6 shows the main equipment which was used for testing the properties of the developed hybrid aluminum matrix composite.

Table 3.6: Testing equipment’s

Equipment’s	Test name	Model
Digital balance	To measure the mass of materials	Tecnotest –TL 201/A
Universal test machine (UTM)	Tensile strength test and compression strength	WP 310 HYDRAULIC UTM-Gunt Hamburg
Rockwell hardness test	Hardness test	HVS-50
Scanning electron microscope (SEM)	Wear mechanism examination	JEOL
Micro Pin-on-disk Tribometer	Wear and friction test	TR-20-MICRO

A) Digital balance

The mass of an object is measured using a digital balance. In this investigation, a digital balance was used to measure the mass of the reinforcement and matrix according to specifications, as well as the mass of the hybrid composite for real density measurement and the mass of the hybrid composite before and after wear for tribological property analysis.

B) Universal testing machine (UTM)

The tensile strength, compressive strength, and other properties of materials are tested using a universal testing machine (UTM), also known as a universal tester or materials testing machine. Tensometer was the previous name for the tensile testing machine. The term "universal" refers to the machine's ability to perform a wide range of standard tests, including compression, tensile, peel, and bending tests.

C) Hardness testing machine

Hardness has several definitions according to different sectors.

- As per, the metal industry, hardness is resistant to permanent deformation.
- As per, metallurgist, it is resistant to penetration.
- As per the lubrication engineer, it is resistant to wear.
- As per the design engineer, it is a measure of flow stress.
- As per, mineralogist, it is resistant to scratching, and
- As per, machinists, it is resistant to machining.

Generally, Hardness can be defined as the resistance of a material to permanent deformation such as indentation, deformation, wear, abrasion, scratching, etc.

Hardness tests are a measure of the confrontation of material to limit plastic surface deformation to a small area. The static pitting test was the behavior in the present study to investigate the hardness of the specimen at which a ball indenter is pressed into the specimen to be tested. The ratio of the numbers of all test forces to the area or depth of the dimples provides the determination of the hardness.

D) Scanning electron microscope (SEM)

The scanning electron microscope (SEM) is the most widely used type of electron microscope. It examines microscopic structures by scanning the surface of materials [67]. In this investigation, SEM was used to study the morphology of the worn surface of hybrid materials.

E) Pin on Disk Test

Various varieties of tribometers are used to test materials for wear (such as wear rates and wear resistance), but the pin-on-disk test is one of the most popular types of wear and friction characterization instruments. The wear and friction tests are performed on pin-on-disk apparatus under ASTM G-99 standard.

3.4. Methods

To accomplish this, work the following methodologies were utilized.

3.4.1. Matrix and Reinforcements Selection

Before beginning the manufacturing of composite materials, it is necessary to determine the weight % of reinforcements in each specimen. The weight percent composition of reinforcements in this study is based on literature, and the following three factors are taken into account while determining the weight percent composition of reinforcements in each specimen.

- To avoid clustering of reinforcements and reduce the amount of porosity in the composite fabricated by the stir casting method, the total maximum weight composition of reinforcements in each specimen should be less than 30% based on the investigation of [8].
- According to [7], to investigate the effect of reinforcement on the properties of Al6063 alloy by making the Wt% of Al-6063 constant. So, the weight percentage addition of rice husk ash is 4%, 8%, 12%, and 16%. The usage of aluminum alloy is considered to be Wt% of rice husk ash out 100% to investigate the influence of reinforcements on the properties of aluminum alloy exactly.
- One specimen is prepared without reinforcements for comparison purposes.

Based on the above consideration, non-reinforced (Al-6063 alloy) and reinforced composite materials are fabricated by stir casting methods, and the detailed weight compositions are presented in Table 3.7.

Table 3.7: Weight composition of reinforcement

Specimen designation	Al-6063	Rice husk ash
None reinforced		
S1	100%	0%
Reinforced		
S2	96%	4%
S3	92%	8%
S4	88%	12%
S5	84%	16%

3.4.2. Estimating Mass of Matrix and Reinforcements Required for Each Specimen

The specimens for the tensile test, compression test, hardness test, microstructure test, and wear test were produced at the same time for the given composition of each specimen for the sake of simplification.

Figure 3.5: 2D cylindrical specimen

A Cylindrical specimen was recommended for metal matrix composite with a size of length (L) and diameter (D) as shown in Figure 3.6. The size and shape of the pattern depends on the types of tests conducted, such as;

- The size of tensile test specimen total length
- The size of the compression test specimen
- The size of the wear test specimen
- The size of hardness and microstructural test specimen
- The amount of material removed by machining (machining allowance)
- Shrinkage allowance

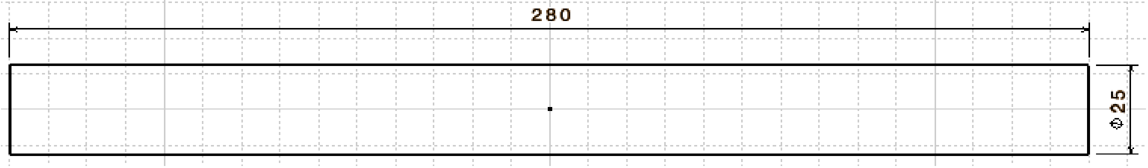


Figure 3.6: 2D CATIA drawing of cylindrical specimen

Length, L=250 mm Diameter, D= 25 mm

The volume of cylindrical specimen/mold can be calculated as follows,

$$V = \Pi x D^2 x L/4 \qquad \text{Eq. (3.1)}$$

Where, V= volume of specimen in cm^3

L= length in cm, L=280mm=28cm

D= diameter in cm, D=25mm=2.5cm

$V= \Pi \times (2.5cm)^2 \times (28cm)/4$ $\underline{V= 137cm^3}$

So, the volume of material required to produce two specimens.

$V=2x137cm^3$

$V=274cm^3$

Since the mold is sand mold, considering round pipe steel and others is obligatory. Thus, the estimated volumes for those are 110 cm^3.

So, the total volume required to fabricate the specimen is 384cm^3.

$V_{total} =384cm^3$

The required amount of matrix (Al-6063) and the reinforcement (rice husk ash) in each specimen are estimated as follows in kilogram based on the weight composition set in Table 3.7.

The density of matrix (Al-6063) and the reinforcement (rice husk ash) are:

The density of Aluminum alloy (Al-6063), ρ Al-6063 =2.6 gr/cm^3

The density of Rice husk ash (RHA), ρ RHA =25.5 gr/cm^3

The weight of the matrix (Al-6063) and the reinforcement (rice husk ash) in each specimen for the given compositions are estimated as follows.

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

Where; x= matrix/reinforcement

y = weight % of matrix/reinforcement

- Total Weight of Aluminum alloy (A-l6063), mAl6063= 6900 gr
- Total Weight of Rice husk ash (RHA), mRHA = 600 gr

3.4.3. Stirrer and Stirrer Setup Fabrication

A mechanical stirrer is required in MMC produced using the Stir casting process to generate a vortex for the homogeneous dispersion of reinforcing particles into the molten matrix material.

To achieve a satisfactory degree of mixing, an appropriate selection of a suitable blade angle, diameter, and number is critical. In this work, for the fabrication of a simple stirrer setup; 40x40 and 30x30 HRS, 15mm diameter staleness steal circular rod, 3mm thick staleness steel, and hand drill machine with 600RPM is used. The dimensions of the furnace and the crucible were accurately measured before the stirrer setup was built, and the stirrer setup was fabricated appropriately. The size and uses of each element of the stirrer arrangement are shown in Table 3.8.

Table 3.8: Stirrer and stirrer setup parts and usage

No.	Part	Dimension	Material	Usage
1	Leg	1980mm height, 60x60 HRS	Steel	Support all parts of stirrer setup and allow adjustable hand drill holder to move up and down
2	pin support hand drill holder	950mm height by 1000 length, 30x30 HRS	Steel	It can be moved up and down. So, used to adjust the stirrer in the required position and used to hold the hand drill machine.
3	Hand drill support	100mm height and 30mm diameter hole	Steel	This support is welded on the adjustable hand drill holder. Used to support and make an erect upright hand drill on position.
4	Stirrer rod and stirrer impeller	15mm diameter and 500mm height rod and 3mm thick and 50mm length and 40mm width welded at 30^o	Steel	Machine one end of the rod to 10mm to fit with hand drill grip size. The stirrer blade is welded at an angle of 30^o. Thus, this stirrer is used to make a vortex inside the crucible to distribute the reinforcement uniformly.
5	Hand drill machine	10 mm grip size		Give rotational motion to the stirrer

3.4.4. Fabrication of Al-6063 alloy Specimen

Fabricate the Al-6063 specimen by casting method, where a pattern is made from round pipe steel and a mold is prepared for pouring in the melted alloy by furnace by maintaining a suitable condition to avoid porosity and shrinkage.

3.4.5. Pattern and Mold Preparation

Sand casting is the most widely used casting process in the manufacturing sector due to its various advantages over other manufacturing processes. Sand casting is resistant to elevated temperature, almost all metal can be cast using a sand-cast, sand casting is used for casting components ranging from very small to extremely large size, etc. Because of such and other advantages, sand casting was used in this work to fabricate hybrid composites. Among different stapes in sand casting, mold preparation is the one which takes time and has been done with extreme care and skill.

The size of mold required to fabricate the composite depends on the size of specimens used for various tests. All specimens for various tests were fabricated at once using one mold. Thus, the size of molds to be prepared is 25mm in diameter and 280mm in length, as shown in figure 3.7. The size of the specimen is determined by the ASTM standard and some other considerations. The estimation of the mass of the matrix and reinforcements required for each specimen were discussed in the following sections and subsections. The procedures followed during preparing a sand mold, for the fabrication of hybrid aluminum matrix composites is discussed as follows with a photographic illustration.

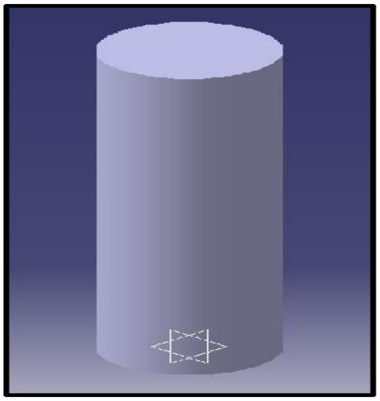


Figure 3.7: 3D CATIA of specimen

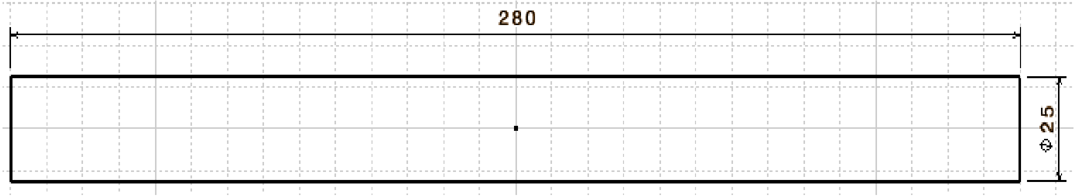


Figure 3.8: 2D of the specimen with dimension

3.4.6. Sand Mold preparation processes

A rod-shaped Pattern is made from round steel pipe on the size of specimens (25 mm diameter and 280mm in length) and the pattern is one pipe pattern. The round steel pipe pattern was prepared in a steel workshop. Figure 3.10 shows the pattern that was used in the fabrication of hybrid composite.

Figure 3.9: Round pipe pattern

Sand casting procedure: -

- Sand is Mulled
- The pattern is placed flat side down on a smooth surface
- The empty drag is placed around it
- The pattern is dusted with dry parting sand
- Mulled sand is riddled into the drag and tamped about the pattern
- After complete packing around a pattern, the bottom of drag is a screed
- Packed drag is carefully lifted from the patter and inverted
- The cope is similarly made with cores forming the spur and riser for filling
- Cope is placed a top drag and secured if necessary
- Mold is ready to pour

Figure 3.10: Sand casting mold

Figure 3.11: After cast image

3.4.7. Composite Fabrication

The Aluminum alloy matrix is placed in a crucible of the furnace and allowed to melt. After the aluminum matrix is melted successfully, the preheated reinforcements are added into the molten aluminum and mechanically stir at a rotational speed of 600rpm for 3-5minute. The mixture of molten aluminum and Reinforcement is then allowed to solidify inside the mold. Hybrid aluminum metal matrix composite was fabricated in such away.

Steps involved in the fabrication of composite materials are:

- Measure the required amount of aluminum matrix and reinforcements by mass for each specimen according to the specifications given in Table 3.8.
- Put Aluminum alloy in a graphite crucible and allow the fuel fire inside the furnace to melt the alloy. Once, the furnace is started, keep it for some minutes to confirm the molten state of aluminum alloy.
- Preheat the reinforcements to remove moisture content and to increase its wettability.

- Then, the corresponding preheated reinforcements were added into the molten aluminum at two stapes and stir mechanically at a rotational speed of 600rpm for 3minute to distribute the reinforcements uniformly.
- After stirring is performed, the slag was removed from the mixture of molten aluminum. The molten state of a mixture was then allowed to flow in the prepared sand mold and solidification takes place inside the mold.
- Finally, withdraw the composite from the mold after solidification, as shown in Figure 3.12 above and produced specimen based on ASTM standards for various tests.

Figure 3.13. Shows the steps involved during the manufacturing of hybrid aluminum matrix composite in form of a flow chart.

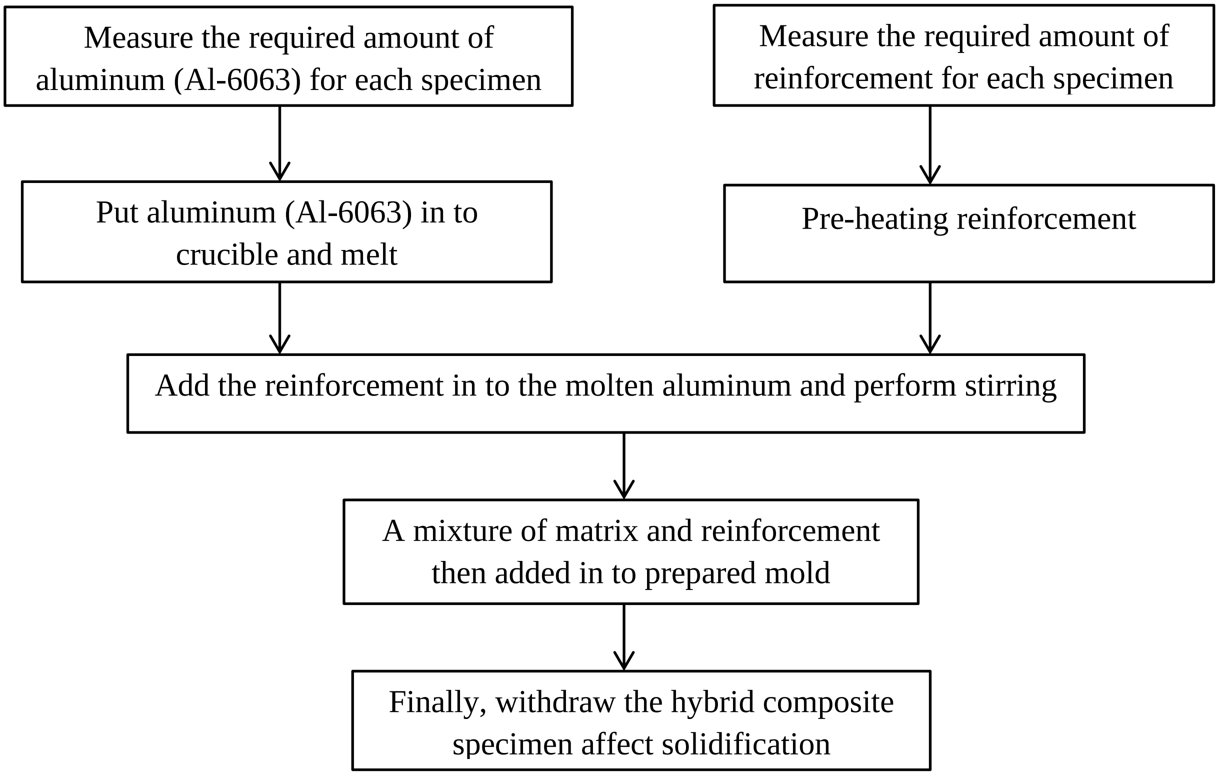


Figure 3.12: Flow chart of steps involved in fabrication of hybrid composite

3.4.8. Specimen preparation for an experiment

After successfully fabricating the Al-6063 specimen by casting method, it is then prepared for an experiment. The specimen is prepared to the required shape and size of a specimen by lathe and cutting.

Figure 3.13: Image of specimen

3.4.9. Equipment's Used to Prepare experiment specimen

The table below shows the equipment used to prepare experimental samples.

Table 3.9: Experiment sample preparation equipment's

Equipment's	Task	Model
Cutter	To cut specimen in the required length	Power hack sow
Lathe machine	To prepare a specimen for the required length ASTM standard	TROYAN C404

3.5. Experimentation Analysis

Experimental investigations were conducted on physical properties (such as density and porosity) and mechanical properties (like tensile strength, compression strength, and hardness). Moreover, microstructural and tribological properties (such as wear loss and coefficient of friction), were also performed. During experimentation, the most valuable results for each test were collected and those results were analyzed for simulation and discussed. Finally, critical conclusions were drawn according to the discussed and analyzed result and simulation. In the present work, the following experiments were performed, and their experimental procedures were discussed in detail as follows.

3.5.1. Density and Porosity Measurement

The physical properties of the substance are density and porosity. The density of a substance may be described as its mass divided by its volume in theory.

The theoretical density (ρth) of hybrid aluminum matrix composite was calculated using the rule of mixtures as shown in Eq. (3.3) [68]. Consider the produced Hybrid aluminum matrix composite is the mixture of aluminum alloy (Al-6063) and rice husk ash (RHA).

$$\frac{1}{\rho thx} = \frac{wt\%\ Al6063}{\rho Al6063} + \frac{wt\%RHA}{\rho RHA} \quad \text{Eq. (3.3)}$$

Where: ρthx= theoretical density of composite specimen x= 1, 2, 3, 4 and 5; wt% Al-6063= mass percent of aluminum alloy in the composite specimen; wt% RHA= mass percent of rice husk ash in the composite specimen; ρAl-6063= density of aluminum alloy; ρRHA = density of rice husk ash.

Experimentally, the Density hybrid aluminum matrix composite can be formulated as follows: the actual density of composite can be calculated using Archimedes principle. The cylindrical specimen was weighted in the air (m_{air}) and weighted again in distilled water (m_{water}). The actual/experimental density (ρ_a) was calculated according to Eq. (3.4) [74].

$$\rho \mathrm{a} = \frac{mair}{mair - mwater}\,\rho \mathrm{water} \quad \text{Eq. (3.4)}$$

Where: ρ_a = actual/ experimental density; m_{air} = mass of composite in air and m_{water} = mass of composite in distilled water and ρ_{water} = density of distilled water at 25^oC = 997.044 kg/m^3.

The porosity of each hybrid composite material can be determined based on Eq. (3.5) [75].

$$\mathrm{P} = 1 - (\rho \mathrm{a}/\rho \mathrm{th}) \quad \text{Eq. (3.5)}$$

Where P = the porosity of composite material, ρa = the actual density of composite material, and ρth = the theoretic density of composite material.

3.5.2. Tensile Test

The tensile strength of a material is the ability of a material to resist loads that are applied in the longitudinal direction of a specimen in the outward direction. Tensile specimens are prepared from a casted circular bar of Al-6063 alloy. The report of [24] indicates that ASTM standards E-8 and E-8M are standard test methods for the tensile testing of metallic materials. A standard tensile specimen is shown in Figure 3.14 with a circular cross-section was used. Tensile specimens of circular cross-section with a standard diameter of 11mm. according to ASTM E-8, the gauge length should be at least four times its diameter for ASTM E-8. Thus, 50 mm of gauge length was used. The end section diameter and length of 13 mm and 16 mm respectively were used as shown in figure 3.15. To prepare the tensile test specimen, TRAYON, C404 model Lathe machine was used.

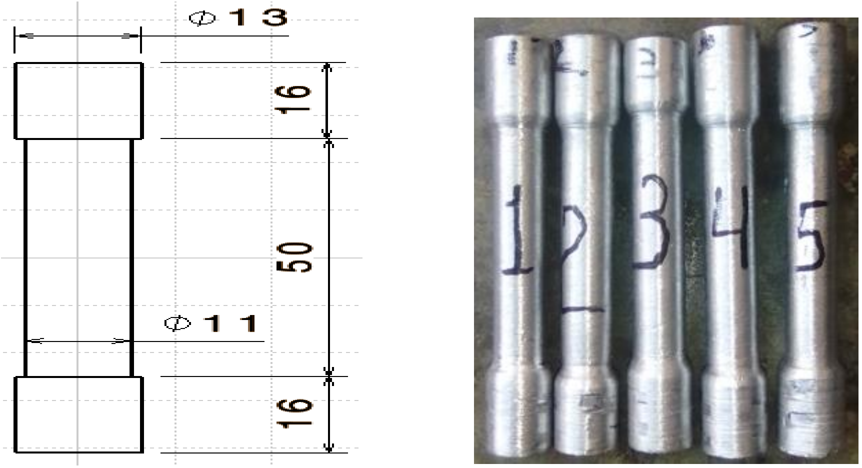


Figure 3.14: ASTM E-8 standard tensile specimens with circular cross-section

3.5.3. Compression Test

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

The compressive strength is usually obtained experimentally through a compressive test, with applying of a uniaxial compressive load. The cylindrical specimens for the compression test were prepared based on the ASTM E-9 standard with a length-to-diameter ratio of 3:1 (L= 25mm with 13mm diameter), and then the test was performed using the universal testing machine (UTM) of 50KN load capacity. The load was applied till fracture of the specimens occurs.

Figure 3.15: ASTM E-9 standard compression specimen

3.5.4. Hardness Test

In the present work, the Rockwell hardness tester machine was used to measure the hardness value of the Aluminum alloy (Al-6063) matrix composite with rice husk ash sample processed by the Rockwell hardness tester. Rockwell hardness tester consists of a diamond cone or hardened steel ball indenter. These hardness tests were conducted on cast aluminum alloy (Al-6063). Before the hardness test is measured, the surface of the material is grinding and polished. During the tasting, 60 kgf was used with duration of 6sec. Figure 3.17 shows the specimens used for the hardness test with a measurement of 18mm diameter and 6mm height.

Figure 3.16: Standard hardness specimens

3.5.5. Wear and Friction Test

Wear is described as the progressive loss of mass from a solid body's surface owing to mechanical forces [69]. The dry sliding wear tests were performed at room temperature using a computerized TR-20-MICRO model micro pin-on-disc Tribometer that followed the ASTM G-99 standard. Micro pin-on-disc is a technique for attaching small pins to a pin (specimen); disk, load, and pin holder are the major components of a tribometer, as depicted in figure 3.18. EN-31 hardened steel disk was the disk material utilized in this research. Three different loads were employed in the test (10N, 30N, and 50N in the step of 20N). The following parameters were used: constant wear track diameter (50mm), test time (5 minutes), disk rotation (200rpm), and sliding distance (251.2m).

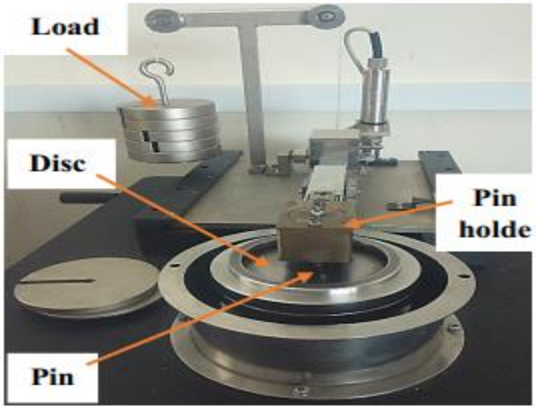


Figure 3.17: Micro pin on disk tribometer during testing

The produced composite specimen was initially constructed as per ASTM G-99 standard to a dimension of 6mm diameter and 12mm height for tribological property research, as shown in Figure 3.19. The specimen was then polished with fine sandpaper, securely secured in a specimen container, and pushed against a revolving disk using computer-controlled settings. The coefficient of friction and wear loss was continually recorded during the test. The graph of coefficient of friction vs. time was obtained from the computer that was connected to the wear test instrument. Electronic weighing equipment with a precision of ±0.0001g was utilized to calculate the wear loss.

Figure 3.18: ASTM G-99 standard wear specimens

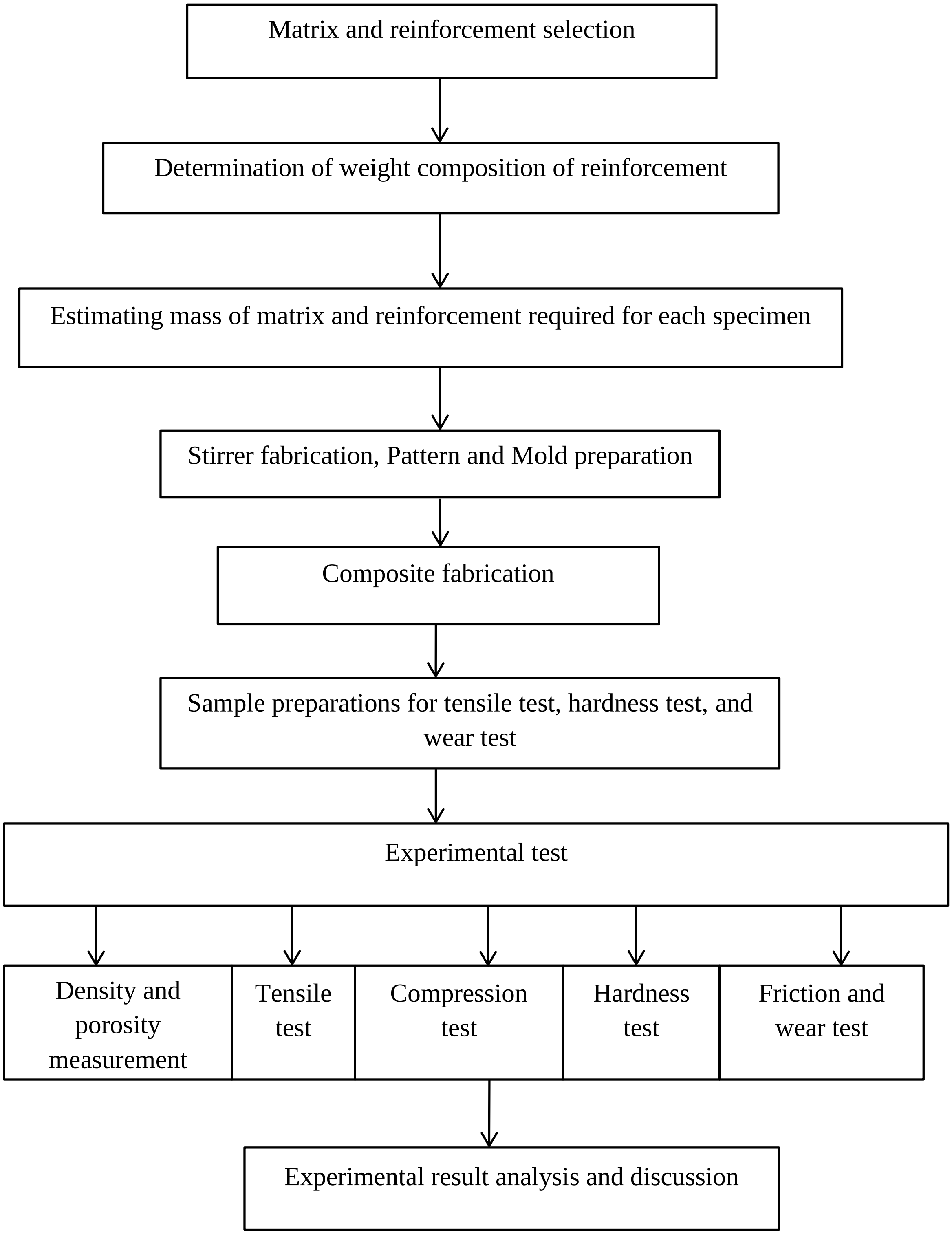


Figure 3.19: General procedures used in this research work to fabricate and characterize hybrid aluminum matrix composite

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Experimental Result of Density and Porosity Test

The physical properties of the substance are density and porosity. The density of a substance may be described as its mass divided by its volume in theory. The generated hybrid composite's theoretical density is computed using the mixing rule, as given in Eq. (3.3), and the actual density is measured using the Archimedes principle, as indicated in Eq (3.4). Eq. (3.5) may be used to calculate the porosity of each hybrid composite material.

Figure 4.1 depicts the density fluctuation of the hybrid composite specimen as shown in Table 4.1. The theoretical density of a hybrid composite is higher than the observed density due to the presence of voids and the segregation of heavier particles towards the bottom. The density of the hybrid composite is somewhat greater than the density of the non-reinforced specimen, according to the research. The presence of aluminum and reinforcements are the increases in the percent of reinforcements that have increased density. The density of hybrid composites decreases as the weight % of RHA grows, whereas it increases as the weight percentage of RHA increase.

Table 4.1: Density and porosity of hybrid Al6063/RHA matrix composite

Designation	Al6063/ rice husk ash composite	Theoretical density (gr/cm^3)	Actual density (gr/cm^3)	Porosity (%)
S1	Al6063	1.73	1.697	1.9
S2	Al6063/4% rice husk ash	1.798	1.754	2.4
S3	Al6063/8% rice husk ash	1.867	1.815	2.8
S4	Al6063/12% rice husk ash	1.943	1.880	3
S5	Al6063/16% rice husk ash	2.024	1.953	3.5

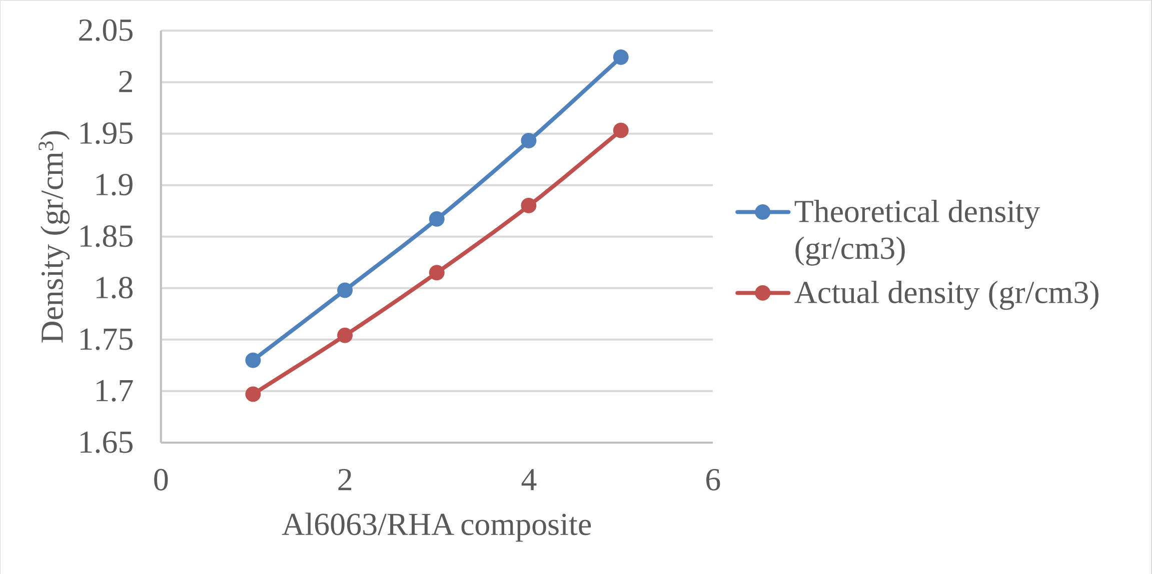


Figure 4.1: Theoretical and actual density of hybrid aluminum alloy composite

As a report of [69] porosity levels within the range of 2-4% are acceptable levels in cast composites. From Figure 4.2 as listed in Table 4.1, the porosity level of the developed hybrid composite is in the range of 1.9-3.5%, which is acceptable according to the report. This indicates that the stir casting technique is highly efficient to fabricate hybrid aluminum alloy composites.

The use of a degassing agent is responsible for the low porosity level and minimal casting defects in the composites produced. As the percentage of RHA is increased the porosity level decreases and high porosity is observed at Al6063/0% RHA. From the observation, it can be understood that an increase in porosity level is due to the relatively high density of Al and RHA and the moisture content of mold. As the density increase, segregation of reinforcements towards the bottom of the crucible occurs. Beyond that, according to the report of [70] the porosity level of the composite rises as a result of gas bubbles during stirring; gas inoculation during reinforcement addition; hydrogen soluble capability of aluminum; and the pouring high from the crucible to the mold.

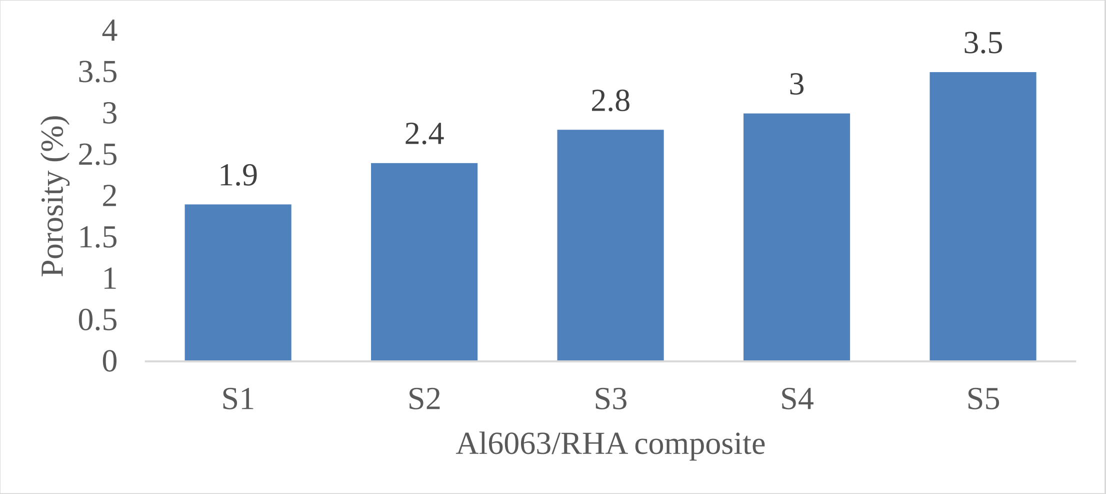


Figure 4.2: Porosity (%) level of the developed composite

4.2. Experimental Result of Tensile Test

The tensile strength of the material is the stress that a material can withstand while being stretched, before breaking. A tensile test is a 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 the specimen over some distance. The cross-sectional area of work peace will change when the load is applied. But in engineering stress-strain curves it is not possible to measure accurate area at the time when the load is applied. Figure 4.3 shows a circular cross-section, dog bone type, tensile test specimens with gage length (G), specimen diameter (D), and fillet radius (r) of 50mm, 11mm, and 3mm, respectively. The brittle fracture occurs in the tensile specimen. This test is performed at a constant crosshead speed of 3mm/min with a UTM capacity of 50kN. The test results indicate force versus elongation and stress vs percentage elongation.

Figure 4.3: Tensile test UTM machine

The ultimate tensile strength and % elongation findings of hybrid Al6063/RHA composite testes under 50KN load capacity UTM are listed in Table 4.2. The test results show how non-reinforced specimens (cast Al6063 alloy) compare to reinforced composite specimens.

Table 4.2: Tensile strength of the developed hybrid metal matrix composite

Designation	Al6063/ rice husk ash composite	Ultimate tensile strength UTS (MPa)	Elongation E (%)
S1	Al6063	48.19	23.86
S2	Al6063/4% rice husk ash	65.66	22.02
S3	Al6063/8% rice husk ash	66.19	21.57
S4	Al6063/12% rice husk ash	141.95	21.41
S5	Al6063/16% rice husk ash	168.35	20.05

The ductile properties of each of the produced composites are shown in Figure 4.5. Different percent RHA can improve the mechanical properties of aluminum alloys. Hardness rises but ductility diminishes when different percent reinforcements are added to the base matrix [7]. With the addition of reinforcements, the ductility of aluminum alloy (Al6063) diminishes, as seen in figure 4.5. The lowest percentage elongation was obtained at Al6063/16% RHA which decreases the ductility of the base matrix by 15.97%.

The ultimate tensile strength of hybrid Al6063/RHA composites exposed to a tensile test in a comparable environment is shown in Figure 4.4. The inclusion of RHA improved the ultimate tensile strength of hybrid Al6063 composites. The UTS of non-reinforced cast Al6063 was the lowest (48.19MPa). With a value of 168.35MPa, the Al6063/16% RHA hybrid composite had the highest UTS value. Because of the presence of a reactive ingredient called silicon and magnesium in the alloy, the UTM has improved owing to strong interface bonding between the matrix and reinforcements phases, decreased void, and high wettability of reinforcements. Interface bonding transfers the load from the matrix to the reinforcements, increasing UTS. The rise in UTS was attributed to the absence of pores in hybrid composites. The addition of 16% RHA increased ultimate tensile strength by 49.34%. The tensile strength of hybrid composites (S2, S3, S4, and S5) is increased by 36.25%, 37.35%, 44.56%, and 49.34%, respectively, when compared to non-reinforced composites.

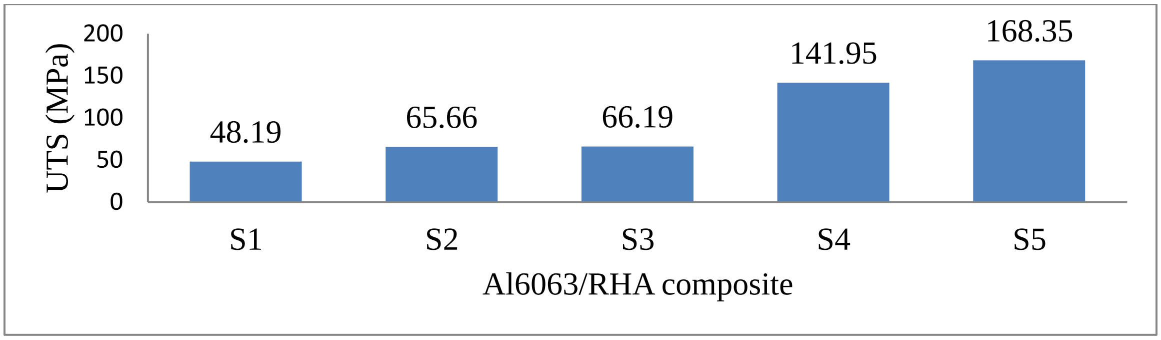


Figure 4.4: Ultimate tensile strength of hybrid Al6063/RHA composite

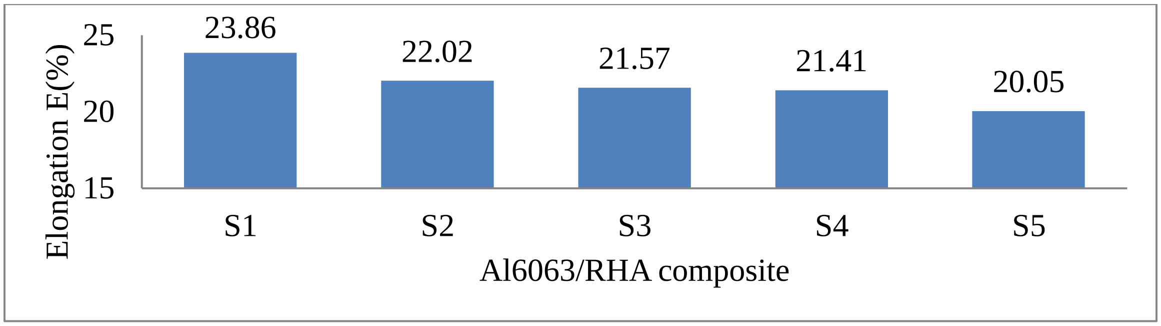


Figure 4.5: Percentage elongation of hybrid Al6063/RHA composite

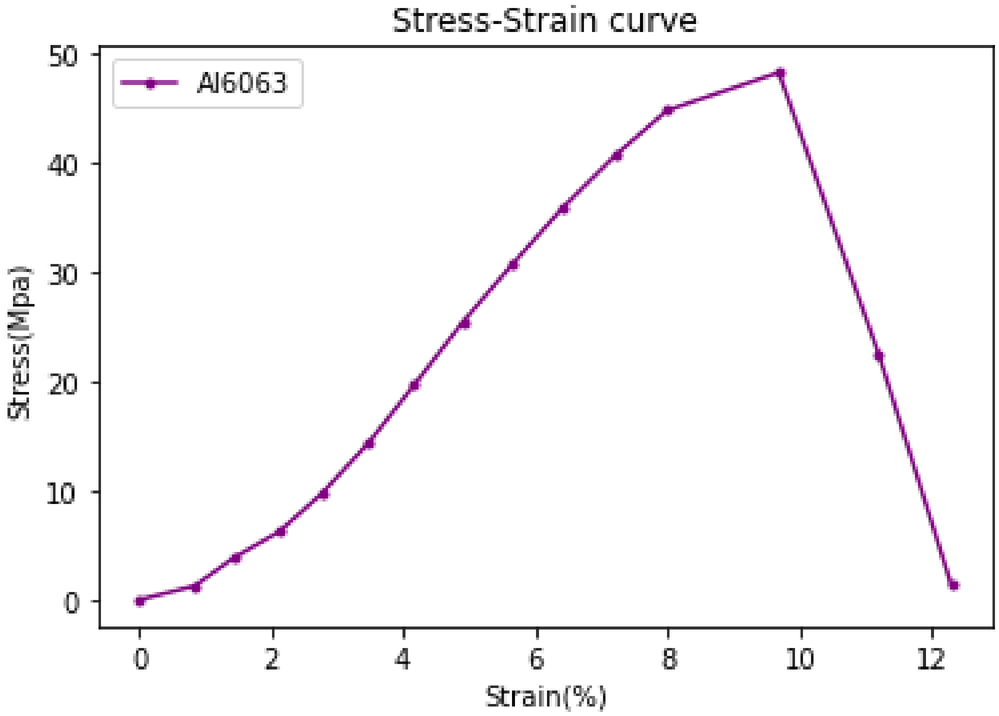


Figure 4.6: Stress-strain curve of non-reinforced Al6063

Figure 4.6, Shows that tension test result of Al6063 stress-strain curve increases until the ultimate stress limit (48.19MPa) of the specimen, which means failure will happen beyond this limit. Stress-strain curve of test the curve clearly shows as stress increases the corresponding strain

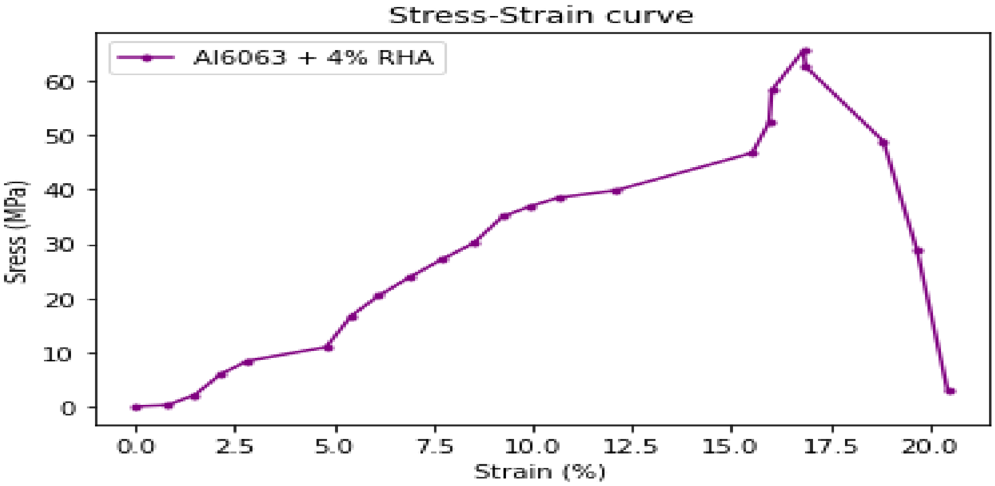


Figure 4.7: Stress-strain curve of Al6063 reinforced by 4% RHA

Figure 4.7, Shows that tension test result of Al6063/4% RHA composite stress versus strain curve of the test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (65.66MPa) of the specimen then failure will happen beyond this limit.

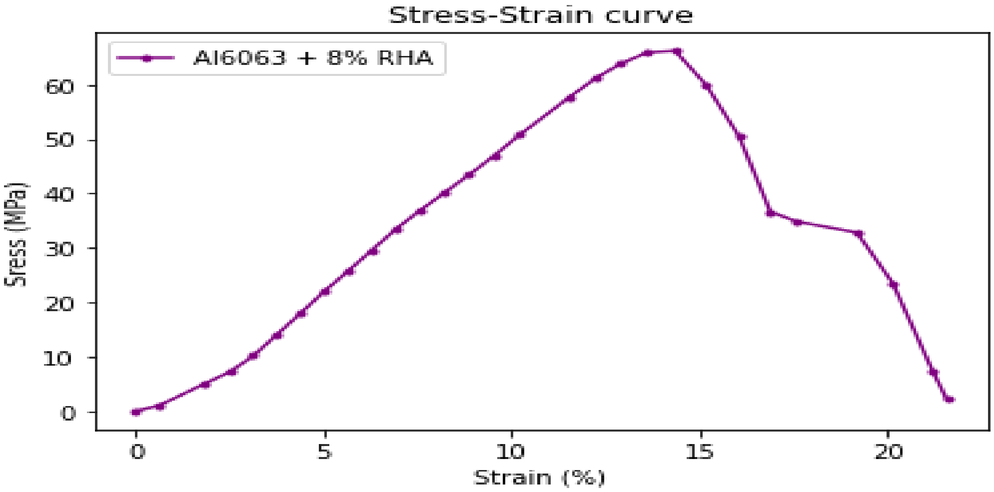


Figure 4.8: Stress-strain curve of Al6063 reinforced by 8% RHA

Figure 4.8, Shows that tension test result of Al6063/8% RHA composite stress versus strain curve of test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress limit (66.19 MPa) of the specimen.

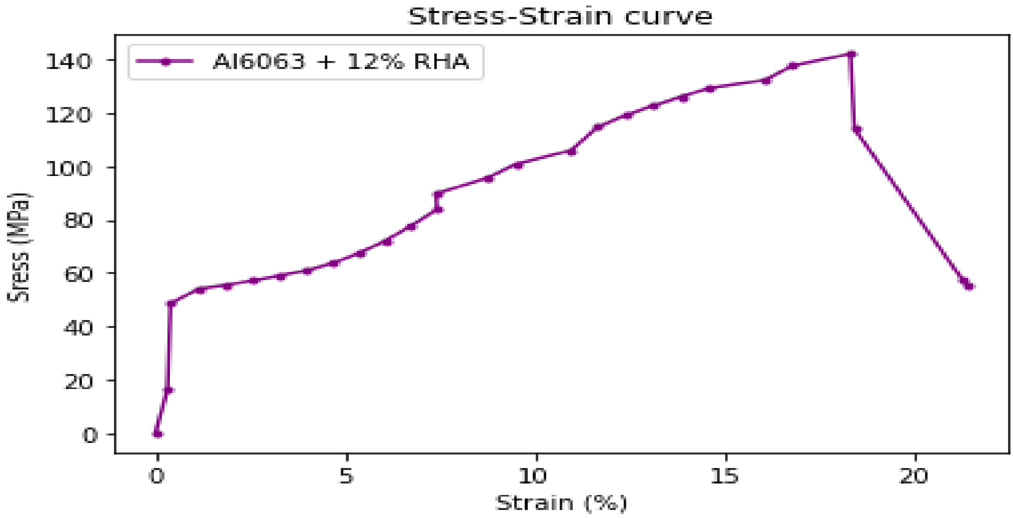


Figure 4.9: Stress-strain curve of Al6063 reinforced by 12% RHA

Figure 4.9, Shows that tension test result of Al6063/12% RHA composite stress versus strain curve of test, the curve shows as stress and strain is directly proportional until the ultimate stress limit is obtained (141.95 MPa) of the specimen then the specimen will failed to withstand the stress acting on the specimen.

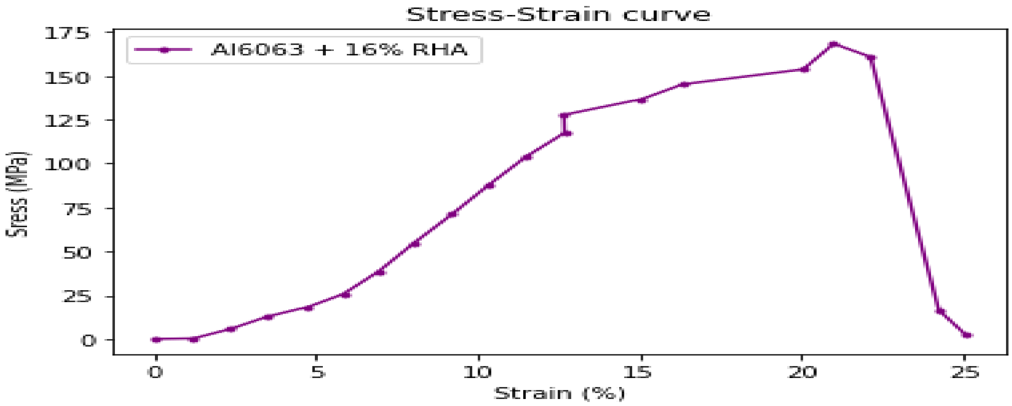


Figure 4.10: Stress-strain curve of Al6063 reinforced by 16% RHA

Figure 4.10, Shows that tension test result of Al6063/16% RHA composite stress versus strain curve of the test, the curve clearly shows as stress increases the corresponding strain increases until the ultimate stress (168.35 MPa) of the specimen then failure will happen beyond this limit.

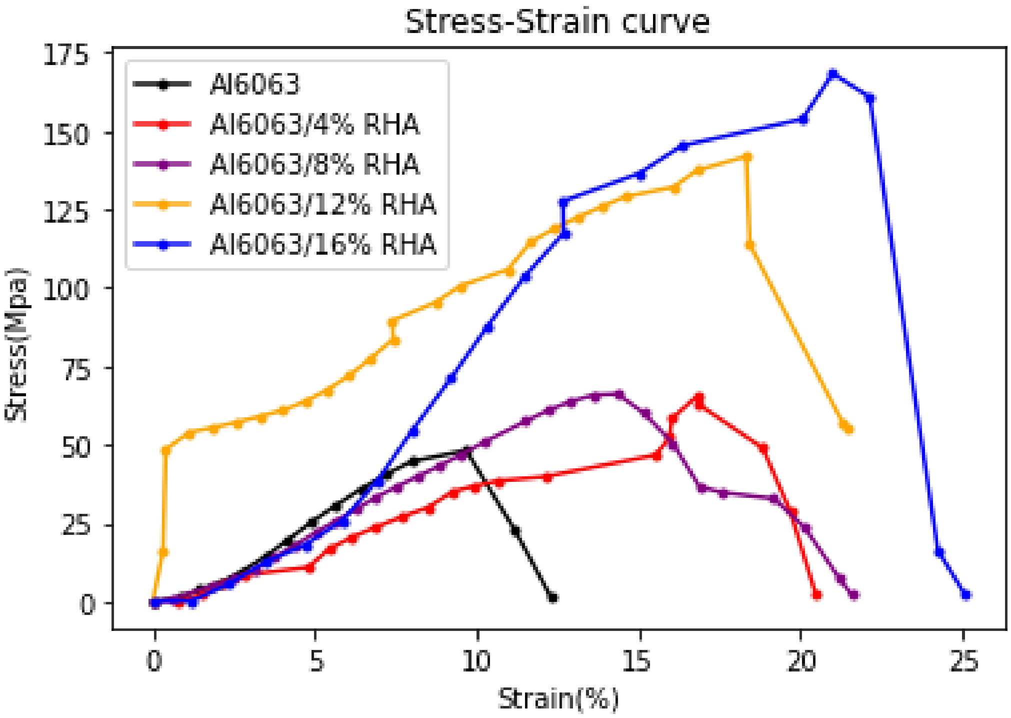


Figure 4.11: Stress-strain curve of tensile test for all samples

4.3. Experimental Result of Compression Test

Simple tension, or uniaxial stress that increases inter-atomic separation, is the subject of the preceding discussion. The compression test was performed by ASTM guidelines. Compression strength, also known as compressive strength, is a material's ability to endure stresses that cause it to shrink in size, as opposed to tensile strength, which withstands loads that cause it to lengthen. The mechanical behavior of the composites and matrix alloy under pressing pressure was evaluated using compression tests. As indicated in figure 4.11-4.15, compressive stress and elongation were computed and shown as a stress-elongation curve. When a compression load is applied to spacemen, deformation may occur: for brittle materials, crushing or fracture may occur, whereas, for ductile materials, elastic or plastic deformation may occur.

The compressive strength of the Al-RHA composite was tested at room temperature utilizing computerized universal testing equipment in this study. Compression strength was measured using standard specimens measuring 13 mm in diameter and 25 mm in length. Table 4.3 shows the experimental results of compressive strength of AMMC composite reinforced with different percentages RHA (0%, 4%, 8%, 12%, and 16%).

Table 4.3: Compression strength results for Al6063/RHA composite

Specimen	RHA mixture (%)	Compression Strength (Mpa)
S1	0%	392.75
S2	4%	401.86
S3	8%	404.20
S4	12%	408.57
S5	16%	417.31

The compressive strength of the metal matrix composite created was higher than that of the non-reinforced alloy, according to the results of this study's experiments. It should be noticed that adding RHA to the composites increased their compressive strength. Compression force causes the specimen to fracture owing to the bulging motion. And a material's malleability is defined by its ability to bulge under compression force. The experimental results show that when the weight % of RHA in the Al-RHA composite grows, the composite's compressive strength improves but its malleability decreases. This is because the composite is hard and brittle due to the presence of hard particles RHA [1]. Sample 1 has a compressive strength of 392.75 MPa in the non-reinforced state, whereas sample 5 (Al+ 16% RHA) has a compressive strength of 417.31 MPa. The appropriate dispersion of RHA within the matrix or strong interfacial interaction between the Al and RHA surfaces was responsible for this [71].

Due to the homogeneous distribution of reinforcing particles throughout all samples in these studies, increasing the volume fraction of RHA particles had a substantial impact on the composites' compressive characteristics, with intensity increasing as the percentage of RHA rose. The use of stir casting which evenly mixes the filler material, maybe one of the causes for the improvement in compressive strength. As a consequence, the bonding capacity and, as a result, the compressive strength of the material improves. Pure aluminum's ultimate compressive strength was 392.75 MPa, but when 4% RHA was added, the compressive strength rose by 2.3% to 401.86 MPa. The compressive strength rising by 2.9% with the addition of 8% RHA, rising to 404.20 MPa. When 12% RHA was added, the compressive strength improved by 4% and increased to 408.57 MPa. And also, when adding 16% RHA, the compressive strength of pure aluminum was improved by 6.2% and increased to 417.31 MPa. However, the rate of increase in compressive strength decreased slightly with increasing volume fraction of RHA particles. This is due to the influence associated with the agglomeration of void-forming particles. The compressive strength of Al-RHA increased rapidly as the percentage of RHA increased to (8%), but after 8% RHA, the rate of increase in compressive strength of the Al-RHA composite increased. Therefore, increasing the volume fraction of the RHA particles reduces the rate of increase in the final compressive strength.

During compression, the specimen will shorten. The material will tend to spread in the lateral direction and thus increase the cross-sectional area. Compressive stress is a phenomenon that occurs in the body when two opposing or equal forces try to compress the body. In these cases, the length of the body is reduced due to the stress trying to compress the body. The height of the specimen decreases and the diameter increases with increasing load.

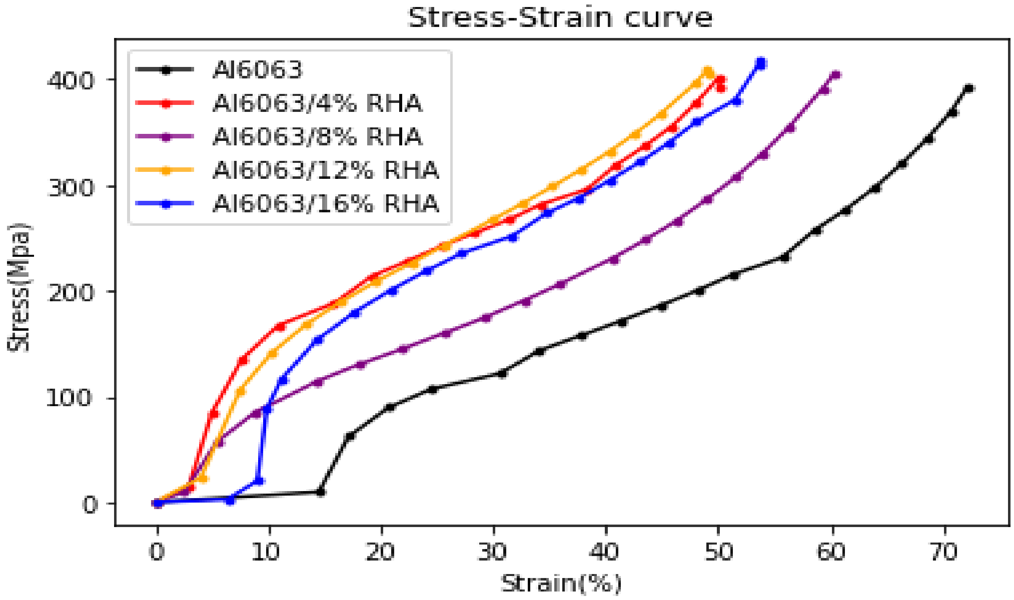


Figure 4.12: Stress strain graph of compression test for all (S1-S5) samples

4.4. Experimental Result of Hardness

Rockwell hardness tester equipment was used to determine if the hybrid composite is more resistant to scratching or penetration. During the taste, a 60kg.f load was employed for 6 seconds. Rockwell hardness test results of hybrid aluminum alloy (Al6063) matrix composites are shown in Table 4.4. For each, five trials were utilized, and the average value was calculated. The hardness of the hybrid composite is higher than that of the cast alloy (Al6063) without reinforcement.

The results demonstrated that the hardness of aluminum alloy (Al6063) rises as the proportion of rice husk ash increases. The high hardness of the aluminum alloy, the dispersion of reinforcement particles, and the superior wettability of rice husk ash with the matrix all contribute to this enhancement. Due to hybrid reinforced, the hardness result reported in Table 4.4 is improved and equivalent to the hardness results presented by [72, 73].

Table 4.4: Hardness strength of the developed hybrid metal matrix composite

Designation	Al6063/ rice husk ash composite	Rockwell Hardness (HRF)					Average Rockwell hardness (HRF)
		Test					
		1	2	3	4	5	
S1	Al6063	78.6	76.3	73.3	71.6	80.9	76.14
S2	Al6063/4% rice husk ash	50.5	57.7	55.7	58.6	58.7	56.24
S3	Al6063/8% rice husk ash	65.4	68.4	69.2	68.4	70.2	68.32
S4	Al6063/12% rice husk ash	86.5	87.1	87.2	87.5	88.2	87.3
S5	Al6063/16% rice husk ash	88	88	88.4	88.4	89.4	88.44

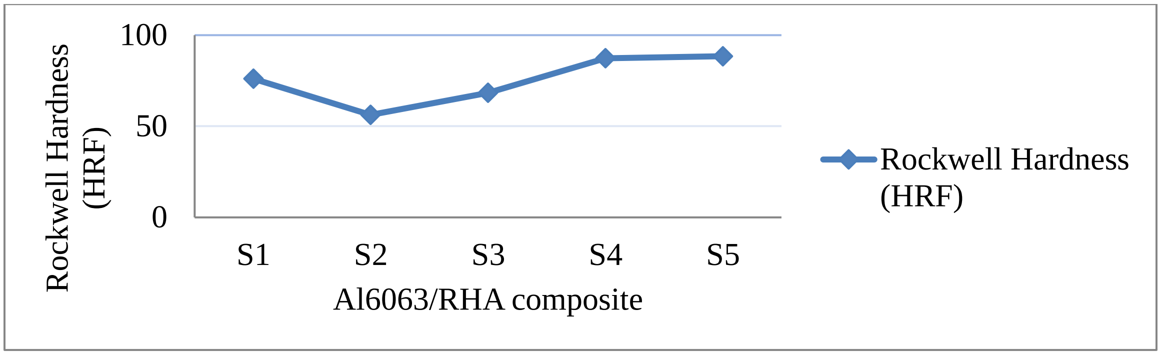


Figure 4.13: The effect of weight percentage of reinforcements on the hardness of Al6063

4.5. Experimental Result of Wear

A micro pin-on-disc wear tester was used to assess the wear loss and coefficient of friction of the hybrid aluminum composites (TR-20-MICRO). The tests were carried out according to the ASTM G-99 standard in dry sliding circumstances at room temperature. The wear tests were performed on specimens with a diameter of 6mm and a length of 12mm at three distinct weights of 10N, 30N, and 50N, at a constant speed of 200RPM and a sliding distance of 50 mm. The weight of the specimens was measured using a digital weighing machine (technotest TL 201/A) with an accuracy of ±0.0001g before and after the wear tests.

Wear loss (g) and coefficient of friction (COF) was calculated based on the results of the test. The list of COFs about normal load and weight composition is shown in Table 4.4 COF Variation vs. Load is depicted in Figure 4.5. The coefficient of friction increases as the load increases from 10N to 50N in 20N increments, as seen in the graph. This rise is because when the normal load increases, the contact area between the specimen's surface and the disk expands. The friction force increases as the contact area between the surfaces of sliding objects grow. The coefficient of friction rises as a result.

Figure 4.6 shows the variation of coefficient of friction (COF) with weight composition. It can be shown from the experimental record that unreinforced (Al6063 cast) has a higher coefficient of friction (COF) than hybrid reinforced composite. The presence of solid lubricant molybdenum disulfide (MoS2), which forms thin lubricating films or coatings over the surface while sliding, is related to the decrease in coefficient of friction (COF). The thin layer that forms between the sliding surfaces precludes subsurface contacts. As a result, the friction coefficient was reduced.

The lowest COF friction (0.27 at 30N load) was observed for high % reinforced specimen Al6063/16% RHA. As the report of [7], the presence of RHA has also an effect on the friction coefficient due to it forming an aluminum layer at the contact zone.

Table 4.5: Coefficient of friction Vs load result

Load	Al6063/ rice husk ash composite				
	S1	S2	S3	S4	S5
	COF				
10N	0.71	0.57	0.42	0.68	0.32
30N	0.34	0.74	0.45	0.57	0.27
50N	0.48	0.44	0.47	0.62	0.43

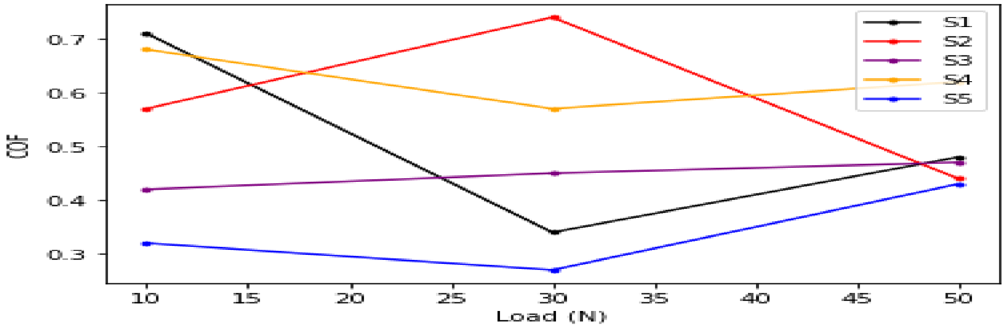


Figure 4.14: Variation of COF Vs load

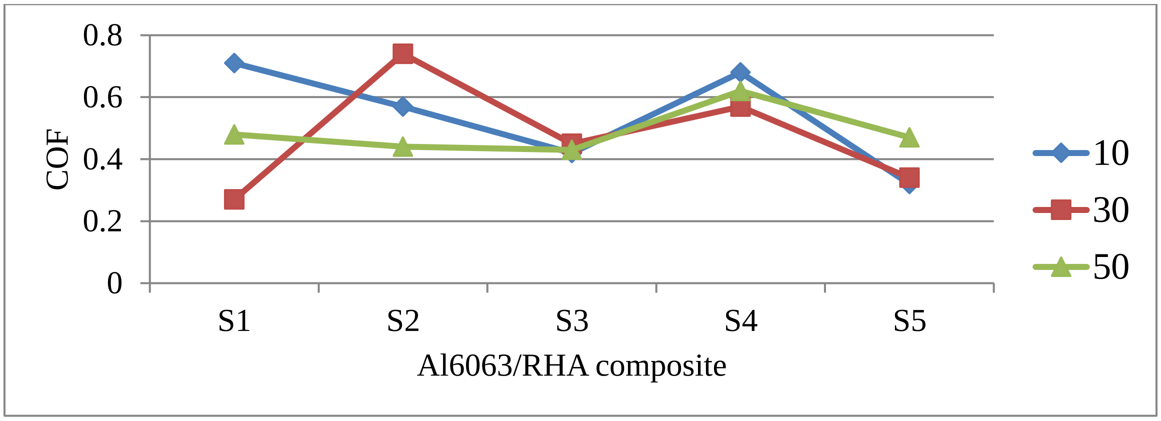
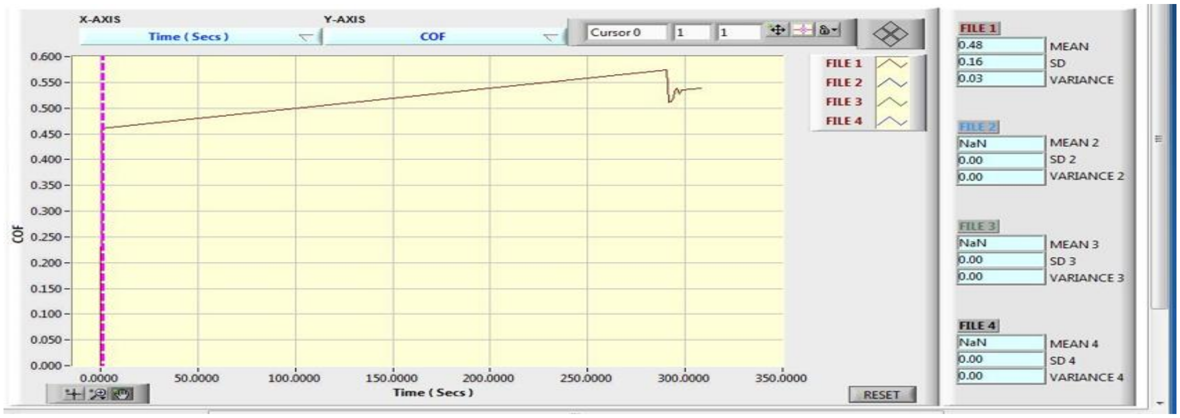


Figure 4.15: Variation of COF Vs weight composition



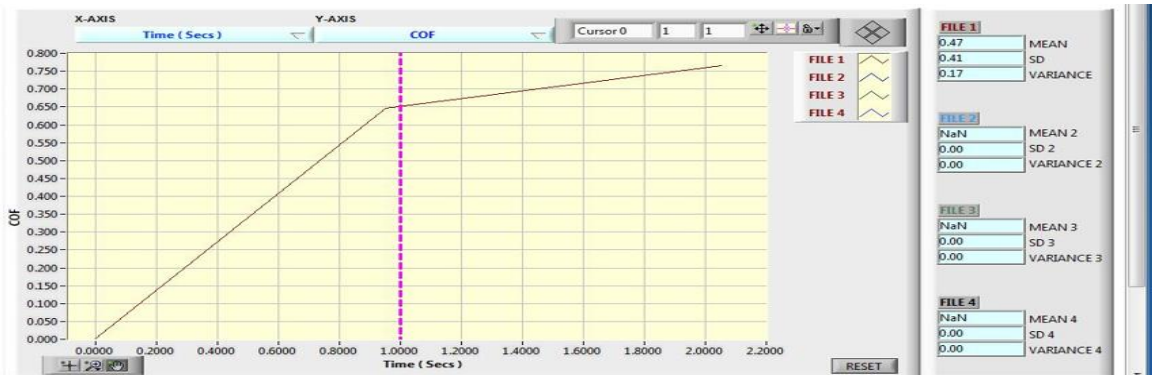
FILE 1
MEAN 0.48
SD 0.16
VARIANCE 0.03

FILE 2
MEAN 2 NaN
SD 2 0.00
VARIANCE 2 0.00

FILE 3
MEAN 3 NaN
SD 3 0.00
VARIANCE 3 0.00

FILE 4
MEAN 4 NaN
SD 4 0.00
VARIANCE 4 0.00

Specimen 1 – Al6063 at 50N load



FILE 1
MEAN 0.47
SD 0.41
VARIANCE 0.17

FILE 2
MEAN 2 NaN
SD 2 0.00
VARIANCE 2 0.00

FILE 3
MEAN 3 NaN
SD 3 0.00
VARIANCE 3 0.00

FILE 4
MEAN 4 NaN
SD 4 0.00
VARIANCE 4 0.00

Specimen 5 – Al6063/16% RHA at 50N load

Figure 4.16: Coefficient of friction Vs time on Micro pin on disc tribometer at 50N load

Figure 4.14 depicts the fluctuation of wear loss against normal load as a function of a composite specimen, and Table 4.6 contains experimental findings of weight loss (g) for normal load and weight composition (S1, S2, S3, S4, and S5). Wear loss increases linearly as the load increases from 10N to 50N. This is because when the load grows, the contact area increases, resulting in increased fatigue force, deformation force, and the temperature rises. Crack development and propagation, deformation, pooling of reinforcing particles, and the creation of wear debris all increase as a result of this increase. The increase in wear debris also reduces the material's wear resistance. The buildup of wear debris causes lubricating layers to break down and composite surfaces to plow. As a result, weight loss increases as the load increases. The greatest weight loss for the reinforced specimen was 0.0362g at 50N stress, whereas the minimum weight loss for the 12 percent RHA reinforced specimen (Al6063/12 percent RHA) was 0.0033g, as shown in

Figure 4.10. When aluminum alloy was strengthened, its wear resistance increased by 34.37 percent at 50N stress. S4 > S1 > S5> S2 > S3 was the order of composite specimen wear performance from best to worst.

Table 4.6: Wear loss Vs load result

Load	Al6063/ rice husk ash composite				
	S1	S2	S3	S4	S5
	Wear loss				
10N	0.0007	0.1716	0.0532	0.1221	0.0003
30N	0.0023	0.0062	0.0017	0.0021	0.0430
50N	0.0096	0.0130	0.0362	0.0033	0.0115

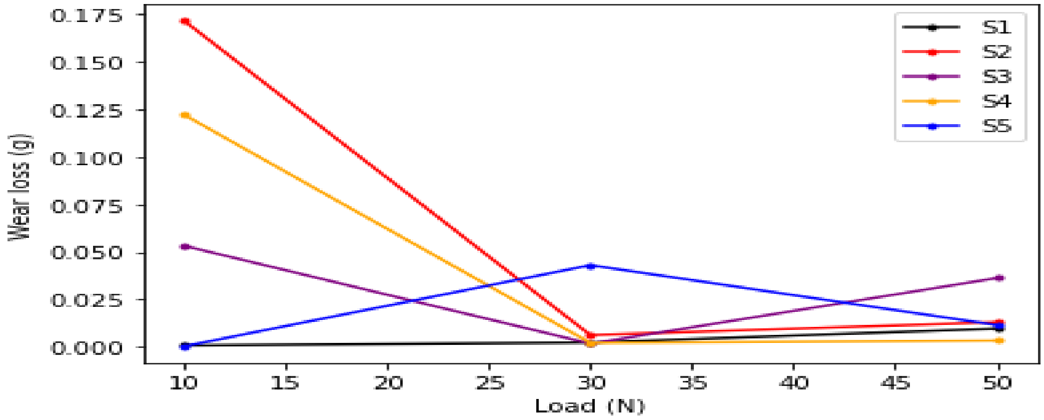


Figure 4.17: Variation of wear loss Vs load

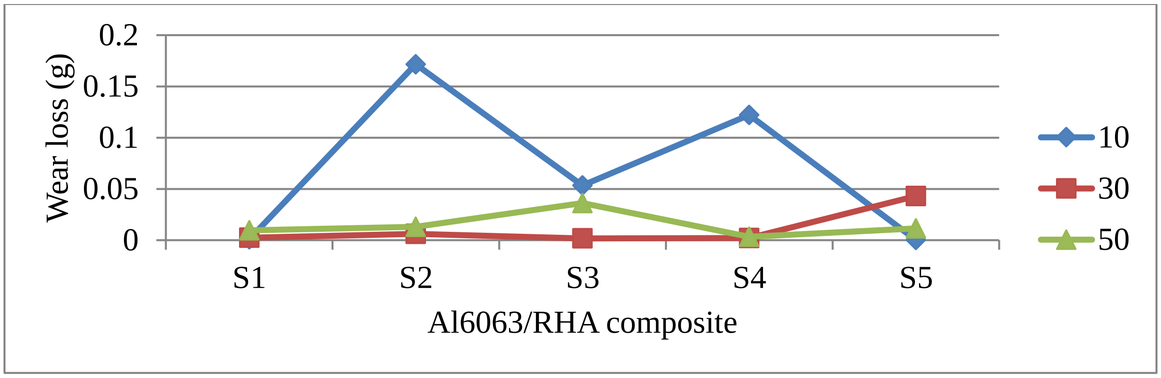


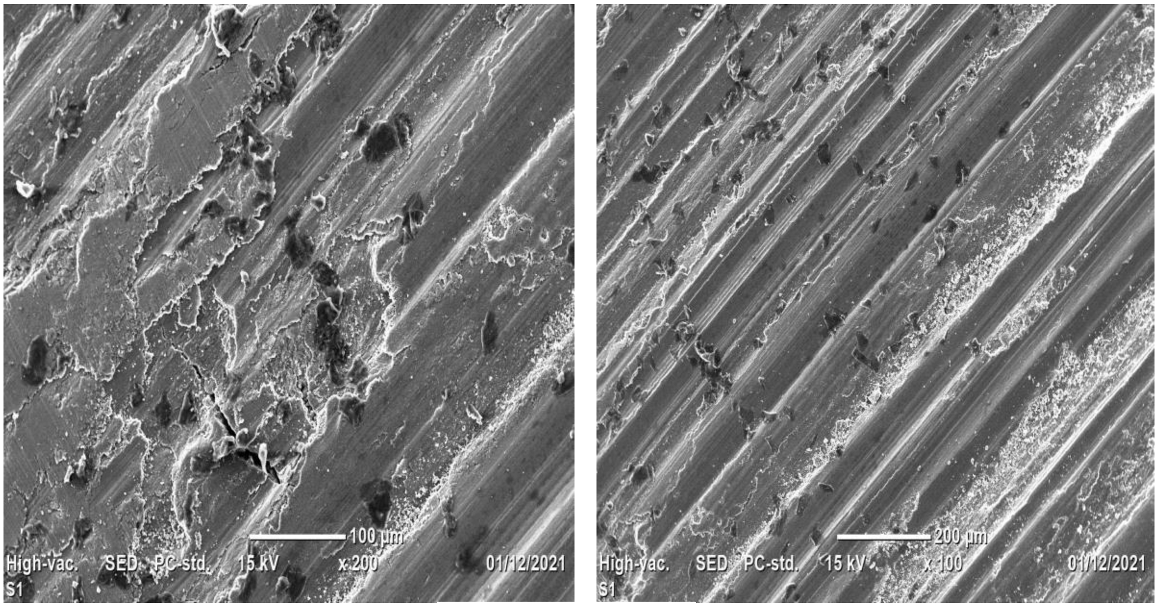
Figure 4.18: Variation of wear loss Vs weight composition

4.6. Wear Mechanism

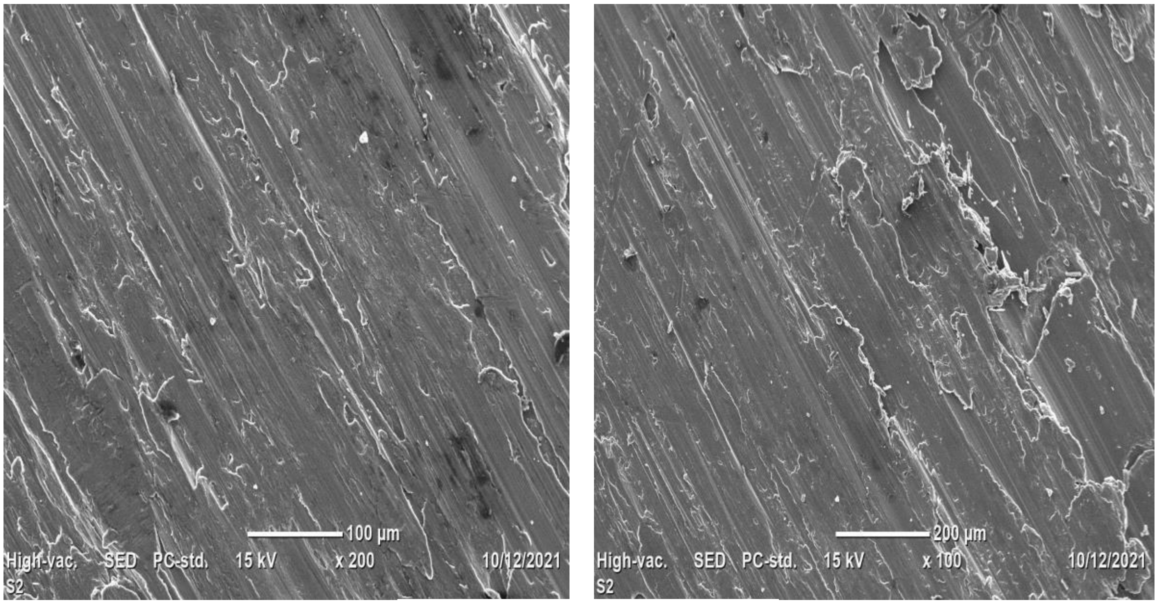
The scanning electron microscopy of the Al-RHA composites was carried out. The magnifications considered for the study are 100x, 2o0x, 500x, 1000x, and 2000x. Though for the present case are 100x and 200x images of the composites are shown below. The microstructural study of pure Al, Al-4% RHA, Al-8% RHA, Al-12% RHA and Al-16% RHA are shown below in Fig. 4.19(S1–S5) respectively. From the SEM images it can be observed that for all the composites longitudinal grooves along with partial irregular pits are present. It is thus indicating that adhesive wear phenomenon is occurring at the worn surface. Further, seen that the effects of micro-cuts and micro-ploughing takes place, which is an indication of abrasive wear phenomenon. Thus, we can conclude from the SEM analysis that both adhesive and abrasive wear mechanism occurs for the composite during tribological testing with abrasive wear more in nature.

Wear processes such as wear debris; plowing, cracking, deformation wear, pool out, and material removal was detected during SEM study of worn surfaces. The main wear processes of hybrid metal matrix composites were wearing debris and material removal.

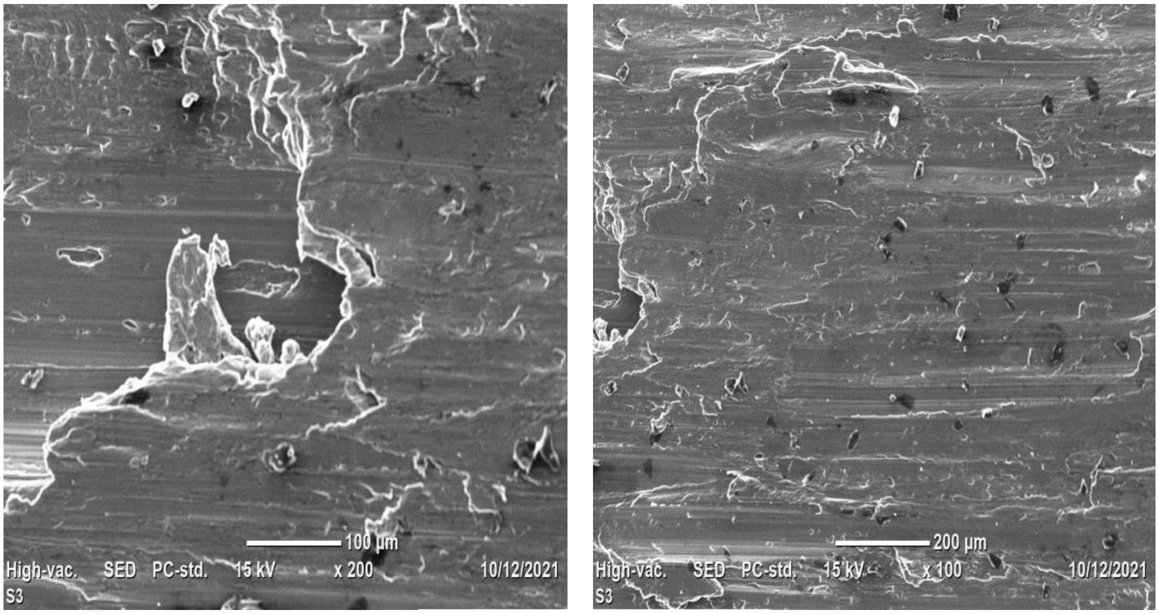
Fewer wear flaws (such as plowing, material removal, and wear debris) were detected in the direction of sliding after the insertion of reinforcements. Due to the existence of hard wear-resistant particles and solid lubricant reinforcements, this is the case.



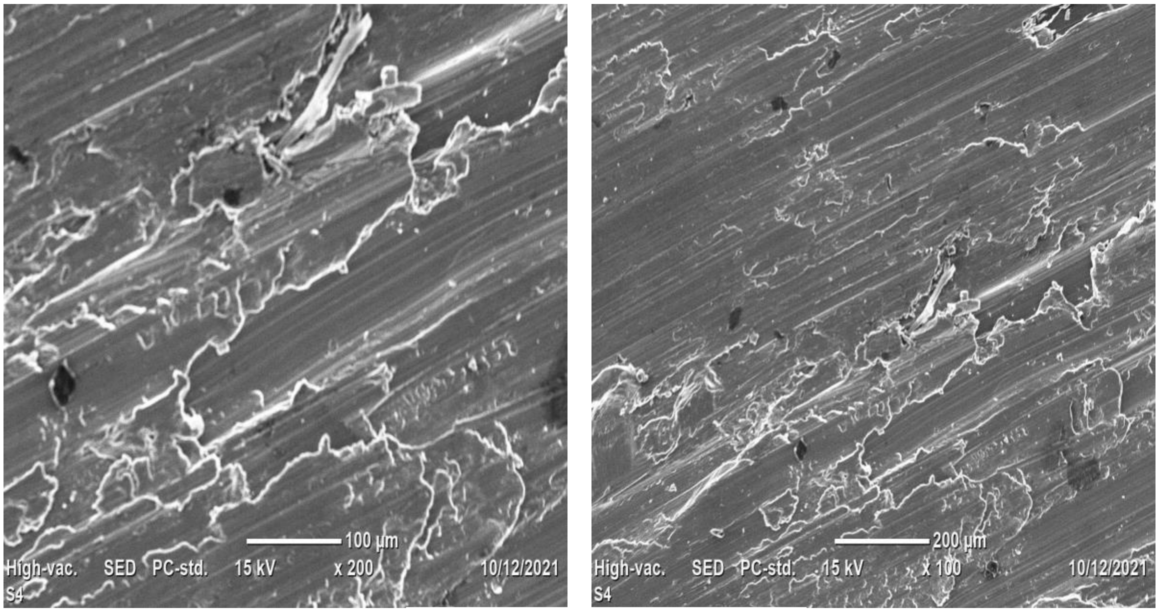
S1 – Al6063



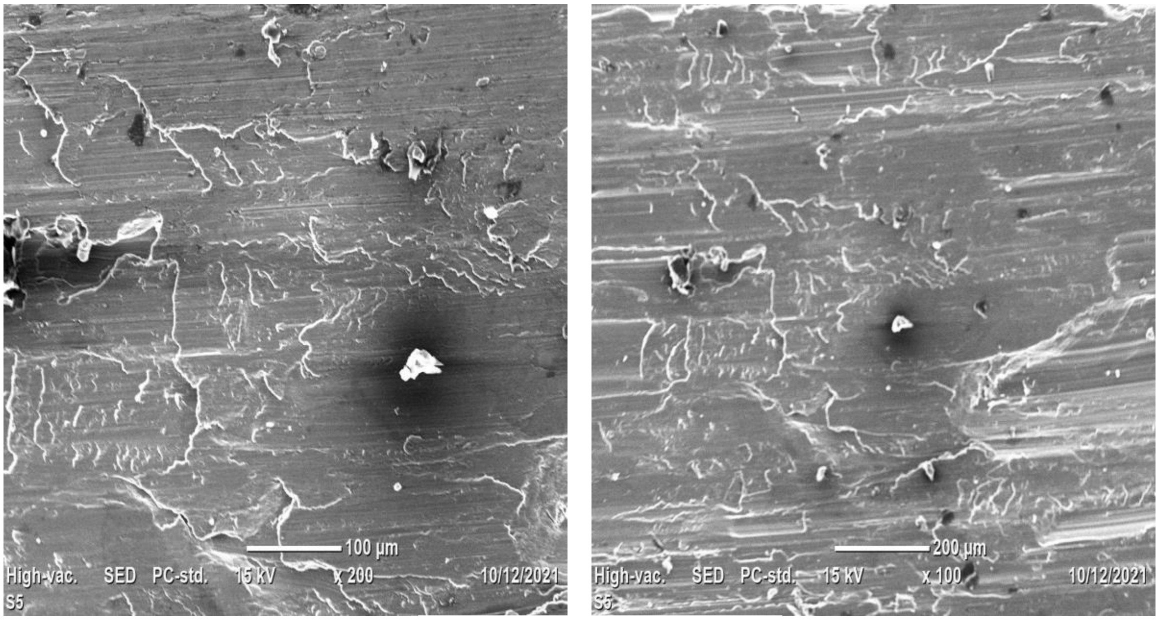
S2 – Al6063/4% RHA



S3 – Al6063/8% RHA



S4 – Al6064/12% RHA



S5 – Al6063/16% RHA

Figure 4.19: SEM images (S1-S5) of hybrid composite

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

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, the detailed literature review was done for fabrication and selecting the composition of composite material. In the present work, fabrication of hybrid aluminum alloy (Al6063) metal matrix composite with a different weight percentage of rice husk ash and stir casting and evaluation of microstructure, density, porosity, tensile strength, compression strength, hardness, wear loss, coefficient of friction and wear morphology was done. The conclusions are as follows:

- Stir casting is a highly efficient, simple, and cost-effective process of producing aluminum matrix composites that is also well-suited to mass production.
- The density of reinforced Al6063 composite increased to some amount as compared to cast non-reinforced aluminum alloy (Al6063) owing to the density of non-reinforced. At Al6063/16% RHA, the maximum density was found. The porosity level reduced as the proportion of RHA rose, while non-reinforced composites had significant porosity.
- The test results reveal that tensile strength, compression strength, and hardness all rise as the weight % of reinforcement increases.
- The coefficient of friction increases as the load increases from 10N to 50N in 20N increments. The contact area between the specimen's surface and the disk grows as a result.
- Wear loss increases linearly as the load increases from 10N to 50N. At 50N stress, the greatest weight loss for the unreinforced specimen was 0.0362g, whereas the minimum weight loss for the reinforced specimen (Al6063/16 percent RHA) was 0.0033g. S5 > S4 > S3 > S2>S1 was the order of composite specimen wear performance from best to worst.
- The composites' primary wear processes are wearing debris and material removal.

5.2. Recommendation

Stir casting is recommended as the most practical procedure owing to its low cost, simplicity, and ability to assure uniform reinforcing particle distribution. Because the Al6063/RHA composite outperforms the base material in terms of hardness, tensile strength, wear loss, and coefficient of friction, it can be recommended as a good replacement for materials with a higher density that are used in automotive bodies, engine blocks, connecting roads, rotor drums/disks, and so on. Producing a big number of hybrid aluminum alloy (Al6063) reinforced with RHA in an appropriate stir casting setup and using it for vehicle parts enhances the machine's strength, durability, and total weight. This results in minimal fuel usage and a long machine life.

5.3. Future Work

The following works are suggested for future works from different perspectives in the field of Al6063/RHA HMMCs:

- Design of stir casting set up using speed controller motor and temperature control unit with atmosphere control system enables optimization of process parameters and will lead to produce a better-quality composite.
- Design and use of permanent casting mold lead to the fabrication of better-quality composite.
- Investigation of the machining characteristics and optimizing the machining parameter for this hybrid composite is an important aspect of machining.
- Further processing this hybrid composite (such as extrusion, forging heat-treating, etc.) and studying mechanical, physical, and tribological properties is another aspect of research on hybrid composite.
- Further studies on this hybrid composite material of mechanical properties (grain strength, toughness and fracture test) of the specimen.
- Investigating the effect of varying the weight composition RHA on the tribological properties of high strength hybrid composite at 12% of RHA will be better in the field of tribology.
- Fabrication of AMMCs by other advanced processes like powder metallurgy, diffusion, deposition, etc. may be done to achieve different sets of mechanical properties.

REFERENCES

[1]. Rajasekar Thiyagarajan, Vignesh Ganesan, Milon Selvam Dennison, & Nelson A.J.R (2018). Preparation and characterization of aluminum metal matrix composite by using stir casting technique. International Research Journal of Engineering and Technology (IRJET) Volume: 05 pp62-66.

[2]. Wright, W. J., & Askeland, D. R. (2014). The Science and Engineering of Materials 2nd Edition.

[3]. Mallick, P., Fiber reinforced composites materials, manufacturing and design, Boca

Raton, FL CRC Press, 2008.

[4]. García-García, D., Carbonell, A., Samper, M. D., García-Sanoguera, D., & Balart, R. (2015a). Green composites based on polypropylene matrix and hydrophobized spend coffee ground (SCG) powder. Composites Part B: Engineering, 78, 256–265.

[5]. Kaushik, G., Singhal, P., & Chel, A. (2019). Agro waste Materials as Composites for Biomedical Engineering. In Handbook of Environmental Materials Management (pp. 1925–1940). Springer International Publishing.

[6]. Yadav, K. K., and Dr. Dalbir Singh Lohchab (2016) Influence of Aviation Fuel on Mechanical properties of Glass Fiber-Reinforced Plastic Composite. International Advanced Research Journal in Science, Engineering and Technology, Vol. 3, pp 1-10.

[7]. Halil, K., ˙Ismail Ovalı, Sibel Dündar, & Ramazan¸ (2019) Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy. J mater res technol.; 2019; 8(6):5348–5361.

[8]. Ramanathan, A., Pradeep Kumar Krishnan, & Rajaraman Muraliraja (2019). A review on the production of metal matrix composites through stir casting-Furnace design, properties, challenges, and research opportunities. Journal of Manufacturing Processes 42, pp213–245.

[9]. Khairaldien, W. M., Khalil, A. A., Bayoumi, M. R., Production of aluminum-silicon carbide composites using powder metallurgy at sintering temperature above aluminum melting point. Journal of material science and engineering, 2005, A399, p. 822-831.

[10]. Luangvaranunt, T., Dhadsanadhep, C., Umeda, J., Nisaratanaporn, E., Kondoh, K., Aluminum-4 mass%Copper/Alumina composites produced from aluminum copper and rice husk ash silica powders by powder forging, Materials transactions, 2010, 51(4), p. 756-761.

[11] Senthil, M. S., and Maheswaran Karuppaiah (2019). Hardness Property Measurement, Grain Size Reduction and Heat Treatment of AA6061+CuO Composite with and without TiB2 Addition. Revue des Composites. et des Materiaux Avances Vol. 29, No. 1, pp33-37.

[12] Haghshenas, M., (2016) Metal–Matrix Composites.University of Waterloo, Waterloo, Canada.

[13] Cheung H., Ho M., Lau K., Cardona F., Hui D., "Natural Fibre-Reinforced Composites for Bioengineering and Environmental Engineering Applications," Composites: Part B, 2009.

[14]. Kaczmar et al. (2000), “The Production and Application of Metal Matrix Composite Materials”, Journal of Materials Processing Technology, 1(3): pp. 58-67.

[15]. Dhanabala Krishnan et al. (2015), “Evaluation of Tensile Properties of Particulate Reinforced Al-Metal Matrix Composites”, International Journal of Engineering Science and Technology, 5(1): pp. 173-175.

[16]. Pankaj Sharma, and Amit Kumar (2016), “Developments of Mechanical and Metallurgical Behaviour of Al-SiC Reinforced Metal Matrix Composite”, International Journal of Advanced Engineering Research and applications, 2(4): pp. 215-222.

[17] A. Sahoo, “synthesis and characterization of bio-composite.”2016.

[18] Haghshenas, M., (2016) Metal–Matrix Composites. University of Waterloo,Waterloo,Canada.

[19] Sathishkumar, T.P., J Naveen and S Satheeshkumar (2014), Hybrid fiber reinforced polymer composites - a review. Journal of Reinforced Plastics and Composites, Vol. 33(5) pp454–471.

[20] Chandramohan, D., &. K. Marimuthu (2011) a review on natural fibers. International Research Journal of Engineering and Technology Vol. 8.

[21] M.Z Bukhari et al. (2011), "Application of Metal Matrix Composite of Al-SiC as Electronics Packaging Materials", Indian Journal of Material Science, 10(11): pp. 484-489.

[22] Kaczmar et al. (2000), "The Production and Application of Metal Matrix Composite Materials", Journal of Materials Processing Technology, 1(3): pp. 58-67.

[23] Rajesh Agnihotri and Santosh Dagar (2017), "Mechanical Properties of Al-SiC Metal Matrix Composites Fabricated by Stir Casting Route", Research in Medical & Engineering Sciences, 1(1): pp. 1-6.

[24] Callister, W. D., (2007) Materials Science and Engineering, an Introduction. United States of America: The University of Utah.

[25] Kaw, A.K., (2006) (2nd edition) Mechanics of composite materials. Taylor & Francis Group, United States of America.

[26] S. Sheshan, A. Guruprasad, M. Parbha, A. Sudhakar, J. Indian Inst. Sci., 76 (1996), 1-14.

[27] M. Rosso, 12th International Scientific Conference on Achievements in Mechanical & Materials Engineering, Gliwice, Poland, 2003.

[28] Ajay Singh Verma, Sumankant, Narender Mohan Suri, Yashpal, Material Today: Proceedings, 2, (2015), 2840-2851.

[29] J. Hashim, L. Looney, M.S.J. Hashmi, Journal of Materials Processing Technology, 92-93, (1999), 1-7.

[30] M. Vijaya, K. Srinivas, N.B. Tiruveedula, Study of tribological behavior of AA6351/SIC/Gr hybrid metal matrix composite using Taguchi technique, Int. J. Veh. Struct. Syst. (IJVSS) 11 (3) (2019).

[31] W.H. Hunt Jr, Aluminum metal matrix composites today, Mater. Sci. Forum 331 (2000) 71–84.

[32] Y. Zhou, M. Hosur, S. Jeelani, P.K. Mallick, Fabrication and characterization of carbon fiber reinforced clay/epoxy composite, J. Mater. Sci. 47 (12) (2012) 5002–5012.

[33] M. Shukla, S.K. Dhakad, P. Agarwal, M.K. Pradhan, Characteristic behavior of aluminum metal matrix composites: a review, Mater. Today Proc. 5 (2) (2018) 5830–5836.

[34] N.E. Udoye, O.S.I. Fayomi, A.O. Inegbenebor, Assessment of wear resistance of aluminum alloy in manufacturing industry-a review, Procedia Manuf. 35 (2019) 1383–1386.

[35] D. Singla, K. Amulya, Q. Murtaza, CNT reinforced aluminum matrix composite review, Mater. Today Proc. 2 (4–5) (2015) 2886–2895.

[36] Pulkit, G., Anbesh Jamwal, Devendra Kumar, Kishor Kumar Sadasivuni, Chaudhery Mustansar Hussain, & Pallav Gupta, (2019). Review Article on Advance research progresses in aluminum matrix composites: manufacturing & applications. j mater res technol.;8(5): 4924–4939.

[37] Kaw, A.K., (2006) (2nd edition) Mechanics of composite materials. Taylor & Francis group, United States of America.

[38] P.Tudu, “processing and characterization of natural fiber-reinforced polymer composites,” 2009.

[39] K. Gupta, “A study on the mechanical behavior of bamboo fiber-based polymer composites, department of mechanical engineering national institute of technology Rourkela, may 2014.

[40] M. Grah, “sheep wool – a natural material used in civil engineering sheep wool – a natural material used in civil engineering,” no. February 2017.

[41] M. Y. Hashim, A. Mujahid, A. Zaidi, and S. Ariffin, “plant fiber-reinforced polymer matrix composite: a discussion on composite fabrication and characterization technique,” 2015.

[42] D.S. Prasad, A.R. Krishna, Production and mechanical properties of A356. 2/RHA composites. J. Adv. Sci. Technol. 33(51–58) (2011) 2019.

[43] Dwivedi, Shashi Prakash, Satpal Sharma, and Raghvendra Kumar Mishra, International Journal of Advanced Materials Manufacturing Characterization Vol4 Issue 2 (2014).

[44] K.K. Alaneme, I.B. Akintunde, P.A. Olubambi, T.M. Adewale, Fabrication characteristics and mechanical behavior of rice husk ash, alumina reinforced Al–Mg–Si alloy matrix hybrid composites, J. Mater. Res. Technol. 2 (2013) 60– 67.

[45] Farooque, K. N., et al, Bangladesh Journal of Scientific and Industrial Research 44.2 (2009): 157-162.

[46] Dwivedi, Shashi Prakash, Satpal Sharma, and Raghvendra Kumar Mishra, International Journal of Advanced Materials Manufacturing Characterization Vol4 Issue 2 (2014)

[47] Matori, Khamirul Amin, et al, Journal of Basic and Applied Sciences 1.3 (2009): 512.

[48] Ugheoke, Benjamin Iyenagbe, et al Leonardo, Electronic Journal of Practices and Technologies 9 (2006): 167-178.

[49] Deiana, Cristina, et al, Industrial & Engineering Chemistry Research47.14 (2008): 4754-4757.

[50] Mehta, Povinder K U.S. Patent No. 4,105,459. 8 Aug. 1978.

[51] Farooque, K. N., et al, Bangladesh Journal of Scientific and Industrial Research 44.2 (2009): 157-162.

[52] Sun, Luyi, and Kecheng Gong, Industrial & engineering chemistry research 40.25 (2001): 5861-5877.

[53] Huang, Yue, Roger N. Bird, and Oliver Heidrich, A review, Resources, Conservation and Recycling 52.1 (2007): 58-73.

[54] El-Fadaly, E., I. M. Bakr, and MR Abo Breka, Journal of American Science 6.10 (2010): 241-247.

[55] Chandrasekhar, S. A. T. H. Y., et al, Journal of materials science 38.15 (2003): 3159-3168.

[56] Rao, G. Rama, A. R. K. Sastry, and P. K. Rohatgi, Bulletin of Materials Science 12.5 (1989): 469-479.

[57] Gonçalves, M. R. F., and C. P. Bergmann, Construction and Building Materials 21.12 (2007): 2059-2065.

[58] Tomoshige, Ryuichi, et al, Materials Science Forum. Vol. 437. 2003.

[59] Basha, E. A., et al, Construction and Building Materials 19.6 (2005): 448-453.

[60] Naito, Atsushi, Food, and Fertilizer Technology Center, 1999.

[61] Chowdhury, Md Rashadul Islam, and Catherine N. Mulligan, Journal of hazardous materials 190.1 (2011): 486-492

[62] Siriwardena, S., H. Ismail, and U. S. Ishiaku, Polymer International 50.6 (2001): 707-713.

[63] Madeva. N., V. Auradi, K. I. Parashivamurthy, S. A. Korid, & Shivananda B. K. (2018) Synthesis and characterization of Al6061-SiC-graphite composites fabricated by liquid metallurgy. Materials Today: Proceedings 5, pp2836–2843.

[64] Hashim, J., L. Looney, M.S.J. Hashmi, (1999) Metal matrix composites: production by the stir casting method. Journal of Materials Processing Technology 92-93, pp1-7.

[65] Ravi, K.R., Sreekumar V.M., Pillai R.M., Chandan Mahato, K.R. Amaranathan, R. Arul Kumar, and B.C. Pai, (2007) Optimization of mixing parameters through a water model for metal matrix composites synthesis. Materials and Design 28 (2007) 871–881.

[66] Davis, J.R., (ed) (2001) Alloying, Understanding The Basics. United States of America, ASM International.

[67] Mang, T., Kirsten Bobzin, and Thorsten Bartels; (2011), Industrial Tribology, 2011 WILEY-VCH Verlag & Co. KGaA, Boschstr. 12, 69469 Weinheim, Germany.

[68] Rajesh, P., Yogesh Dewang, R.S. Rana, Dinesh Koli and Shailendra Dwivedi, (2018). Fabrication of magnesium matrix composites using powder metallurgy process and testing of properties. Materials Today: Proceedings 5, pp6009–6017.

[69] Gowri, M. C., Manjunath Shettar, Sharma SS,Achutha Kini, & Jayashree, (2018) Enhancement in Hardness and Influence of Artificial Aging on Stir Cast Al6061-B4C and Al6061-SiC Composites. Materials Today: Proceedings 5, pp2435–2443.

[70] Bharath., V., Madev Nagaral, V Auradi & S. A. Kori (2014). Preparation of 6061Al-Al2O3 MMC's by Stir Casting and Evaluation of Mechanical and Wear Properties. 3rd International Conference on Materials processing and Characterization (ICMPC 2014). Procedia Materials Science, 6, pp1658 –1667

[71] Lal Krishna and Sandeep P. (2015), "Development of Silicon Carbide Reinforced Aluminum Metal Matrix Composite for Hydraulic Actuator in Space Applications", International Journal of Research in Engineering & Technology, 3(8): pp. 41-50.

[72] Ashok Kumar, V., Anil M P, Rajesh G. L., Vijaykumar Hiremath, & V. Auradi (2018). Tensile and Compression Behaviour of Boron Carbide Reinforced 6061Al MMC's processed through Conventional Melt Stirring. Materials Today: Proceedings 5, pp16141–16145.

[73] Rao, E. S., and N.Ramanaiah (2017), Influence of Heat Treatment on Mechanical and Corrosion Properties of Aluminium Metal Matrix composites (AA6061 reinforced with MoS2). Materials Today: Proceedings 4, pp11270–11278.

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

[75] Aatthisugan, I., Razal Rose, A., & Selwyn Jebadurai, D. (2017). Mechanical and wear behaviour of AZ91D magnesium matrix hybrid composite reinforced with boron carbide and graphite. Journal of Magnesium and Alloys, 5, pp 20–25.

APPENDIX

A. Appendix: Tables

Table A.1: Mass of specimens in air and in distilled water for experimental density and porosity measurement

Designation	Al6063/RHA composite	Mass of the specimen in air (g)	Mass of the specimen in water (g)
S1	Al6063	8.532	3.503
S2	Al6063/4% RHA	8.743	3.759
S3	Al6063/8% RHA	8.885	3.990
S4	Al6063/12% RHA	8.902	4.178
S5	Al6063/16% RHA	9.380	4.578

Table A.2: Mass of specimens before and after wear test at 10N, 30N, and 50N load

Designation	Al6063/RHA composite	Before wear test (g)	After wear test (g)		
			10N	30N	50N
S1	Al6063	0.8661	0.8654	0.8631	0.8535
S2	Al6063/4% RHA	1.0016	0.8300	0.8238	0.8108
S3	Al6063/8% RHA	0.8966	0.8434	0.8417	0.8055
S4	Al6063/12% RHA	1.0184	0.8963	0.8942	0.8909
S5	Al6063/16% RHA	0.9954	0.9951	0.9521	0.9406

Material: Al6063

Initial measurement length: 50mm

Specimen diameter: 11mm

Date: 25/11/2021

Table A.3: Output stress-strain table for pure Al6063

No.	Stress, S[N/mm^2]	Strain, E[%]
0	0.00	0.00
1	1.26	0.84
2	3.89	1.45
3	9.68	2.76
4	19.68	4.17
5	35.88	6.42
6	44.72	7.99
7	48.19	9.68
8	22.52	11.19
9	1.37	12.29

Material: Al6063

Initial measurement length: 50mm

Specimen diameter: 11mm

Date: 25/11/2021

Table A.4: Output stress-strain table for Al6063/4% RHA

No.	Stress, S[N/mm^2]	Strain, E[%]
0	0.00	0.00
1	2.1	1.49
2	8.42	2.83
3	16.76	5.44
4	23.78	6.89
5	30.09	8.51
6	36.93	9.94
7	46.78	15.53
8	52.33	15.95
9	65.66	16.87
10	48.94	18.83
11	2.84	20.45

Material: Al6063

Initial measurement length: 50mm

Specimen diameter: 11mm

Date: 25/11/2021

Table A.5: Output stress-strain table for Al6063/8% RHA

No.	Stress, S[N/mm^2]	Strain, E[%]
0	0.00	0.00
1	1.05	0.64
2	7.26	2.53
3	14.1	3.77
4	21.99	5.02
5	29.46	6.27
6	36.83	7.56
7	43.35	8.86
8	50.72	10.21
9	61.14	12.23
10	66.19	14.35
11	50.51	16.05
12	34.83	17.59
13	7.47	21.19

Material: Al6063

Initial measurement length: 50mm

Specimen diameter: 11mm

Date: 25/11/2021

Table A.6: Output stress-strain table for Al6063/12% RHA

No.	Stress, S[N/mm^2]	Strain, E[%]
0	0.00	0.00
1	16.42	0.32
2	57.14	2.58
3	67.45	5.38
4	83.66	7.42
5	100.7	9.5
6	114.59	11.66
7	125.96	13.86
8	134.9	16.07
9	139.95	17.53
10	141.95	18.32
11	113.86	18.43
12	57.35	21.28
13	55.24	21.41

Material: Al6063

Initial measurement length: 50mm

Specimen diameter: 11mm

Date: 25/11/2021

Table A.7: Output stress-strain table for Al6063/16% RHA

No.	Stress, S[N/mm^2]	Strain, E[%]
0	0.00	0.00
1	0.35	1.23
2	5.66	2.36
3	18.04	4.7
4	25.82	5.85
5	38.55	6.93
6	54.82	8.03
7	87.71	10.33
8	117.42	12.66
9	136.52	15.01
10	153.85	20.05
11	168.35	20.05
12	160.92	22.13
13	16.27	24.24
14	2.48	25.06

B. Appendix: Figures

Figure B 1: Aluminum scrap and testing its composition

Figure B 2: Full image of processing RHA

Figure B 3: Full image of stirrer machine and stirring process

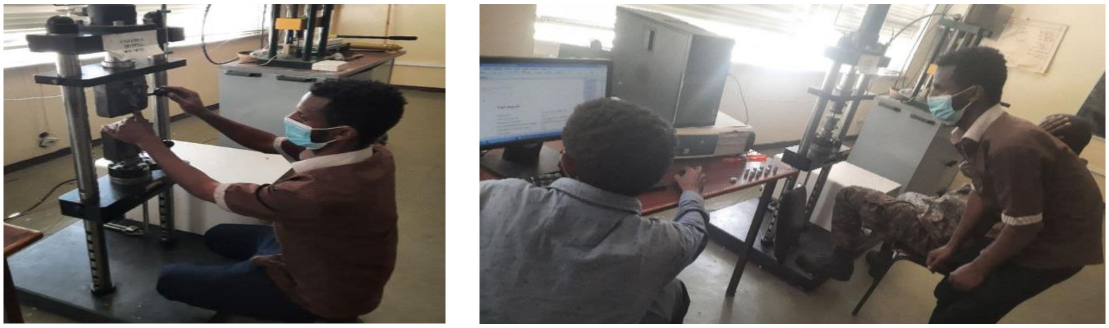


Figure B 4: Universal testing machine (UTM)

Figure B 5: Full image of Rockwell hardness test and micro pin on disc tribometer use for wear test


FILE 1 S001MKT

Sample ID :- 03 , Remarks :- , Wear track diameter :-50, Date :-

FILE 2

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 3

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 4

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

X-AXIS Time (Secs)

Y-AXIS COF

Cursor 0 1 1

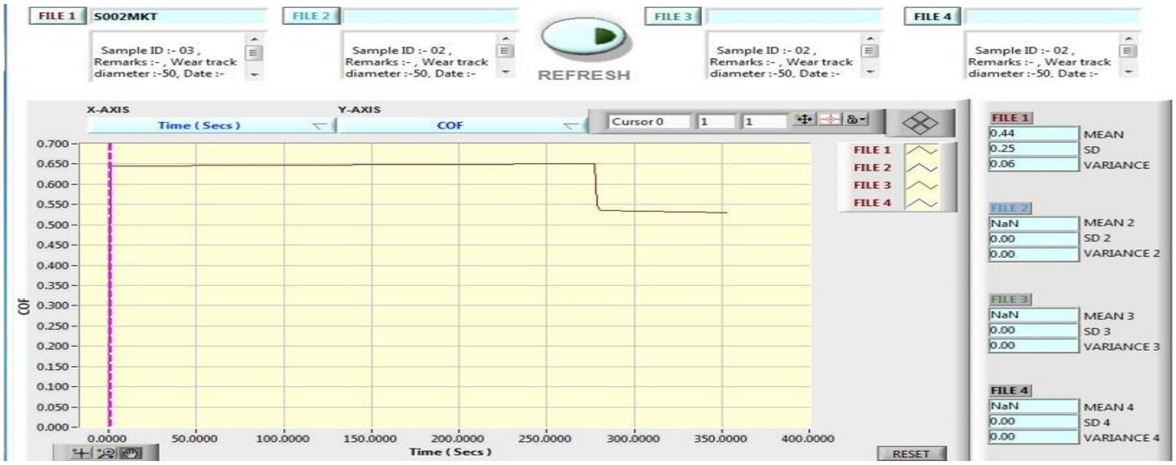
FILE 1
0.48 MEAN
0.16 SD
0.03 VARIANCE

FILE 2
NaN MEAN 2
0.00 SD 2
0.00 VARIANCE 2

FILE 3
NaN MEAN 3
0.00 SD 3
0.00 VARIANCE 3

FILE 4
NaN MEAN 4
0.00 SD 4
0.00 VARIANCE 4

Specimen 1- Al6063 at 50N load


FILE 1 S002MKT

Sample ID :- 03 , Remarks :- , Wear track diameter :-50, Date :-

FILE 2

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 3

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 4

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

X-AXIS Time (Secs)

Y-AXIS COF

Cursor 0 1 1

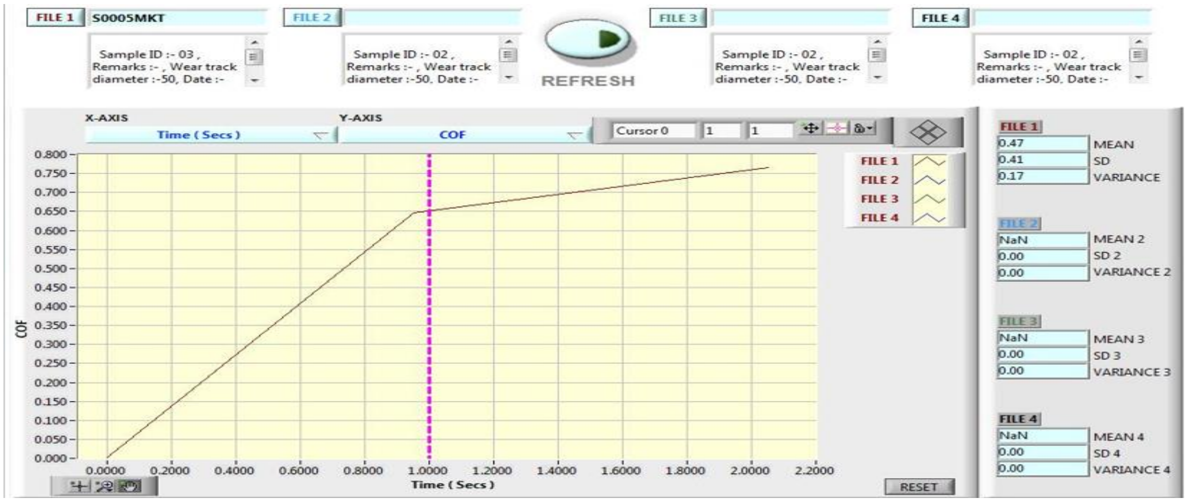
FILE 1
0.44 MEAN
0.25 SD
0.06 VARIANCE

FILE 2
NaN MEAN 2
0.00 SD 2
0.00 VARIANCE 2

FILE 3
NaN MEAN 3
0.00 SD 3
0.00 VARIANCE 3

FILE 4
NaN MEAN 4
0.00 SD 4
0.00 VARIANCE 4

Specimen 2- Al6063/4% RHA at 50N load


FILE 1 S0005MKT

Sample ID :- 03 , Remarks :- , Wear track diameter :-50, Date :-

FILE 2

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 3

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 4

Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

X-AXIS Time (Secs)

Y-AXIS COF

Cursor 0 1 1

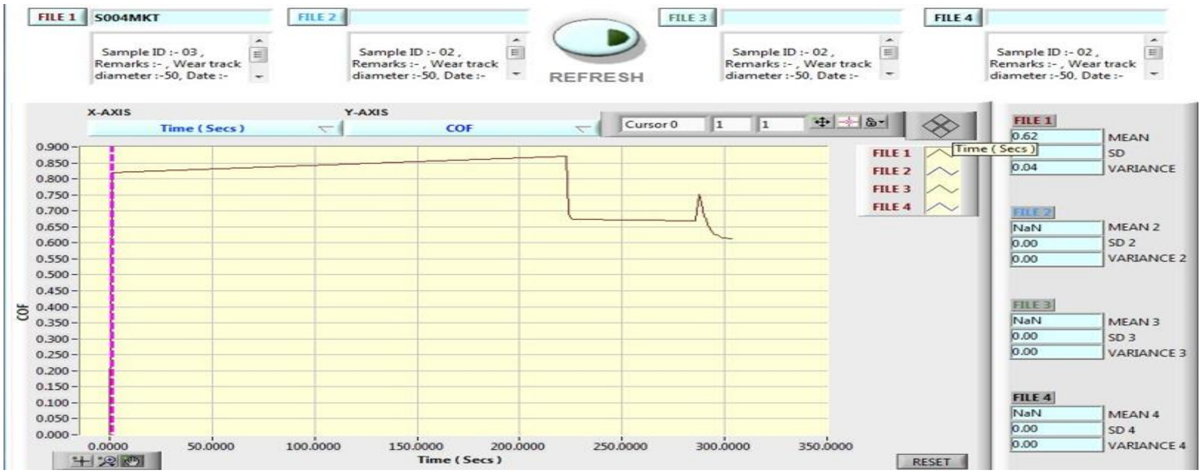
FILE 1
0.47 MEAN
0.41 SD
0.17 VARIANCE

FILE 2
NaN MEAN 2
0.00 SD 2
0.00 VARIANCE 2

FILE 3
NaN MEAN 3
0.00 SD 3
0.00 VARIANCE 3

FILE 4
NaN MEAN 4
0.00 SD 4
0.00 VARIANCE 4

Specimen 3- Al6063/8% RHA at 50N load


FILE 1 S004MKT

Sample ID :- 03 , Remarks :- , Wear track diameter :-50, Date :-

FILE 2: Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 3: Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 4: Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

X-AXIS: Time (Secs)

Y-AXIS: COF

FILE 1: MEAN 0.62; SD; VARIANCE 0.04

FILE 2: MEAN 2 NaN; SD 2 0.00; VARIANCE 2 0.00

FILE 3: MEAN 3 NaN; SD 3 0.00; VARIANCE 3 0.00

FILE 4: MEAN 4 NaN; SD 4 0.00; VARIANCE 4 0.00

Specimen 4- Al6063/12% RHA at 50N load


FILE 1 S003MKT

Sample ID :- 03 , Remarks :- , Wear track diameter :-50, Date :-

FILE 2: Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 3: Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

FILE 4: Sample ID :- 02 , Remarks :- , Wear track diameter :-50, Date :-

X-AXIS: Time (Secs)

Y-AXIS: COF

FILE 1: MEAN 0.43; SD 0.12; VARIANCE 0.02

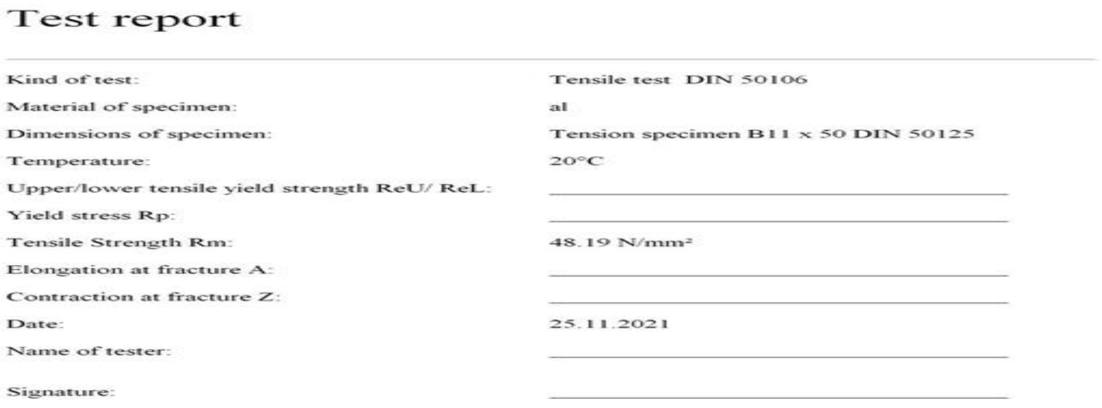
FILE 2: MEAN 2 NaN; SD 2 0.00; VARIANCE 2 0.00

FILE 3: MEAN 3 NaN; SD 3 0.00; VARIANCE 3 0.00

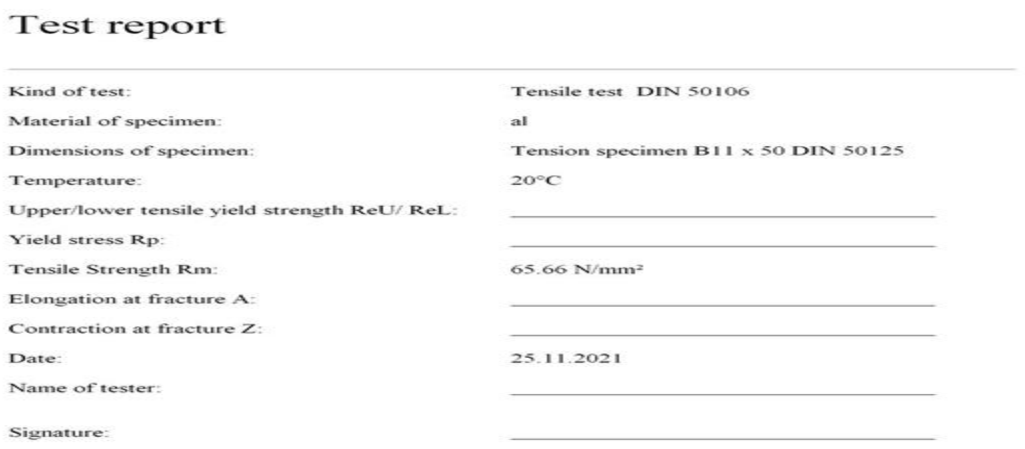
FILE 4: MEAN 4 NaN; SD 4 0.00; VARIANCE 4 0.00

Specimen 5- Al6063/16% RHA at 50N load

Figure B 6: Graph (S1-S5) of coefficient of friction Vs time on micro pin on disc tribometer at 50N load

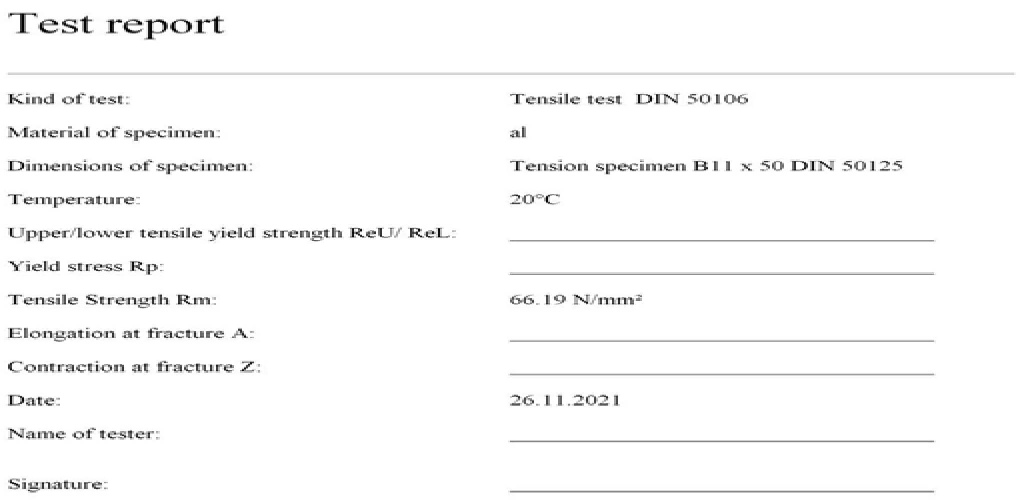

Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	al
Dimensions of specimen:	Tension specimen B11 x 50 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	48.19 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	25.11.2021
Name of tester:	
Signature:	



Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	al
Dimensions of specimen:	Tension specimen B11 x 50 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	65.66 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	25.11.2021
Name of tester:	
Signature:	

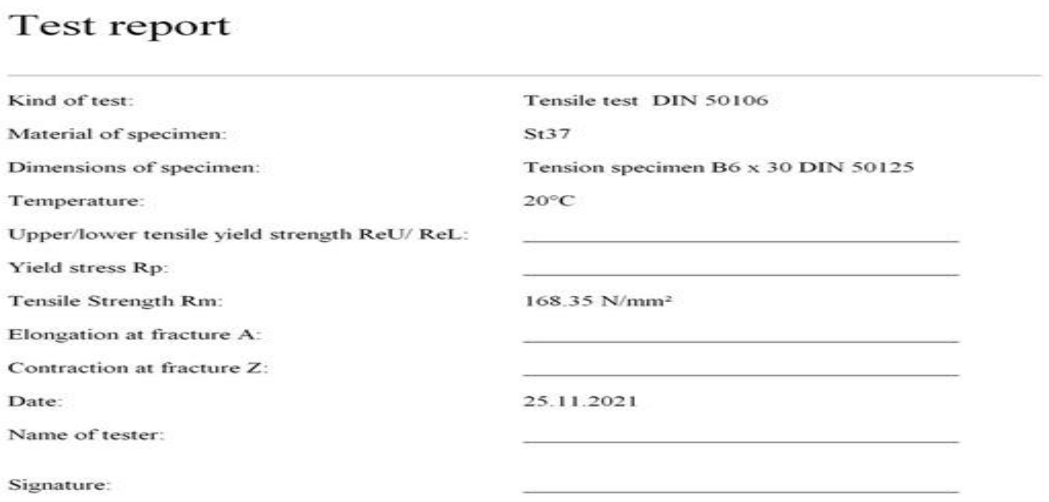


Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	al
Dimensions of specimen:	Tension specimen B11 x 50 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	66.19 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	26.11.2021
Name of tester:	
Signature:	

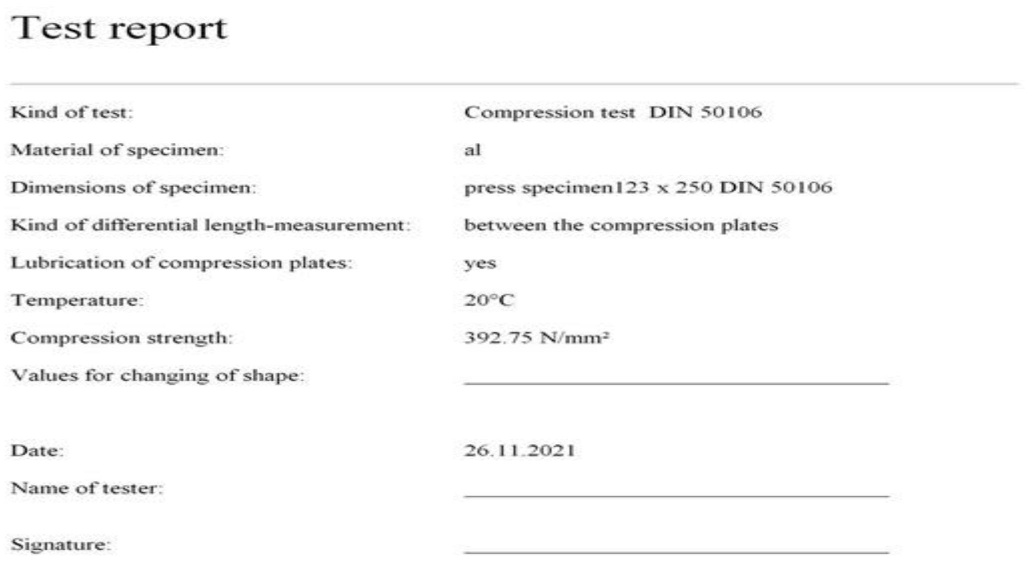
Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	al
Dimensions of specimen:	Tension specimen B11 x 50 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	141.95 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	25.11.2021
Name of tester:	
Signature:	



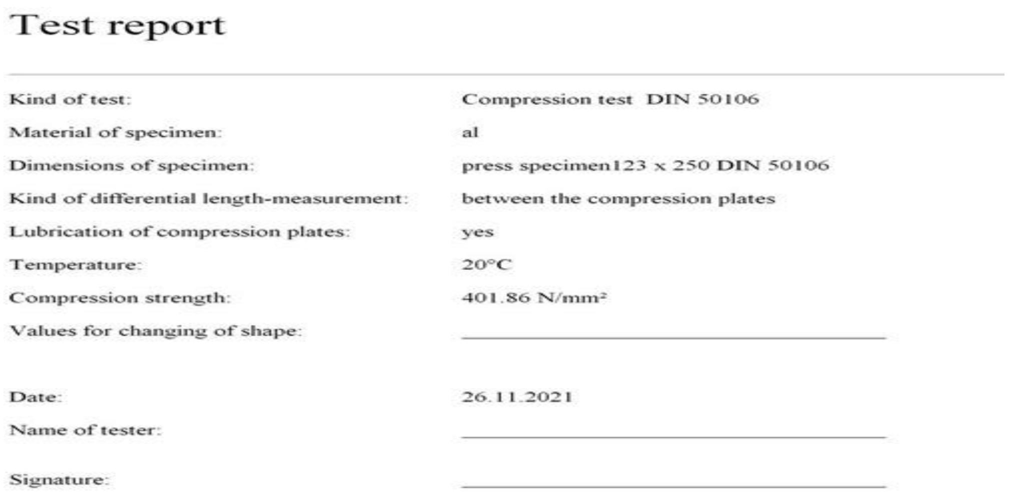
Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	St37
Dimensions of specimen:	Tension specimen B6 x 30 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	
Yield stress Rp:	
Tensile Strength Rm:	168.35 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	25.11.2021
Name of tester:	
Signature:	



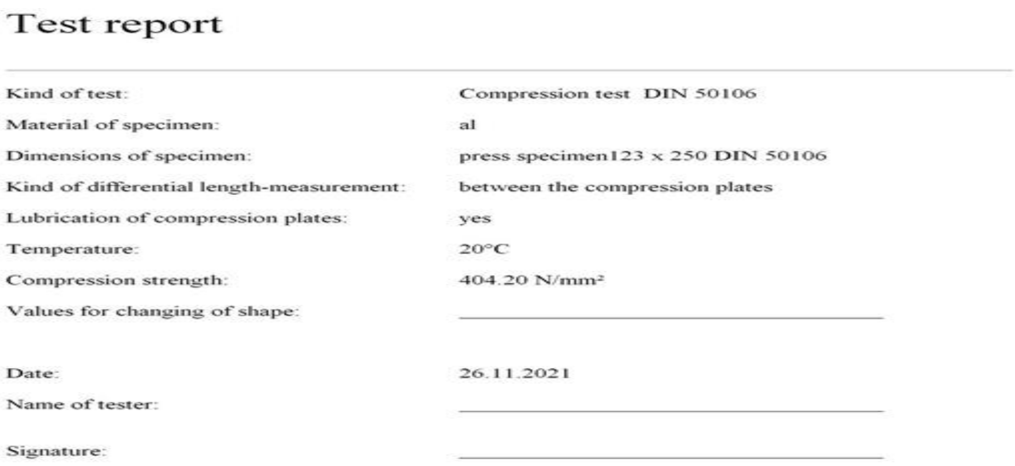
Test report

Kind of test:	Compression test DIN 50106
Material of specimen:	al
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement:	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	392.75 N/mm²
Values for changing of shape:	
Date:	26.11.2021
Name of tester:	
Signature:	



Test report

Kind of test:	Compression test DIN 50106
Material of specimen:	al
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement:	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	401.86 N/mm²
Values for changing of shape:	
Date:	26.11.2021
Name of tester:	
Signature:	

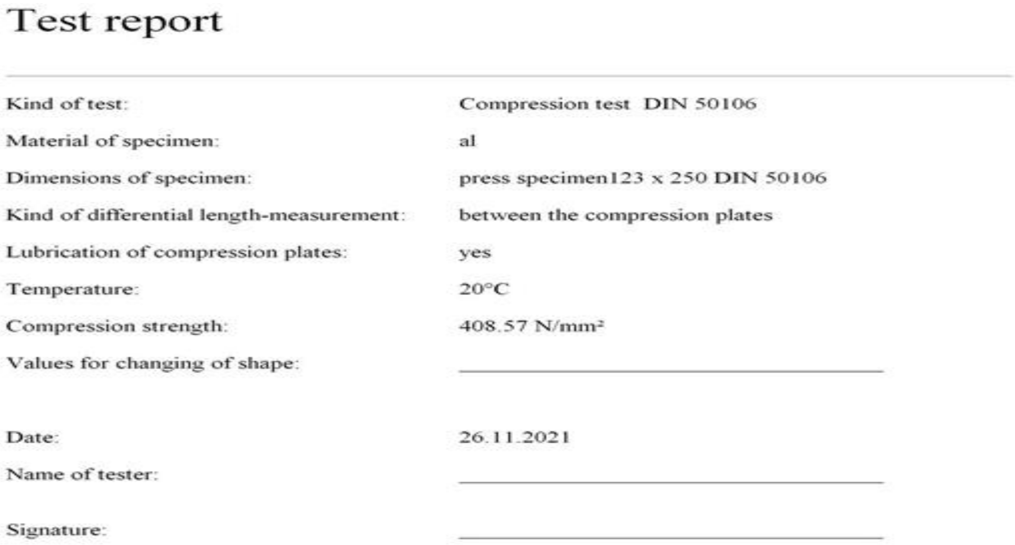


Test report

Kind of test: Compression test DIN 50106
Material of specimen: al
Dimensions of specimen: press specimen123 x 250 DIN 50106
Kind of differential length-measurement: between the compression plates
Lubrication of compression plates: yes
Temperature: 20°C
Compression strength: 404.20 N/mm²
Values for changing of shape: ____________________

Date: 26.11.2021
Name of tester: ____________________

Signature: ____________________

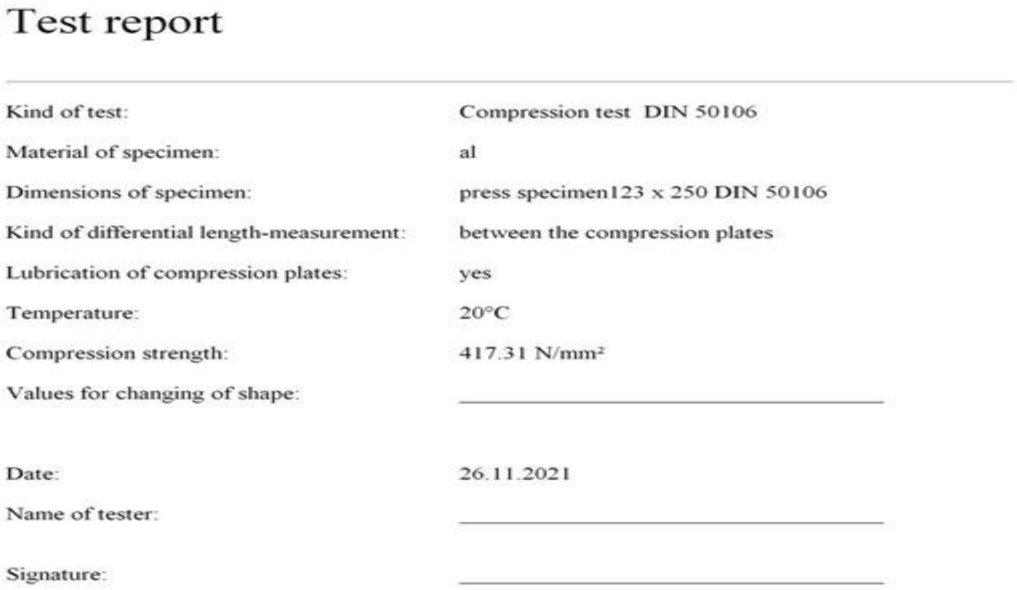


Test report

Kind of test: Compression test DIN 50106
Material of specimen: al
Dimensions of specimen: press specimen123 x 250 DIN 50106
Kind of differential length-measurement: between the compression plates
Lubrication of compression plates: yes
Temperature: 20°C
Compression strength: 408.57 N/mm²
Values for changing of shape: ____________________

Date: 26.11.2021
Name of tester: ____________________

Signature: ____________________

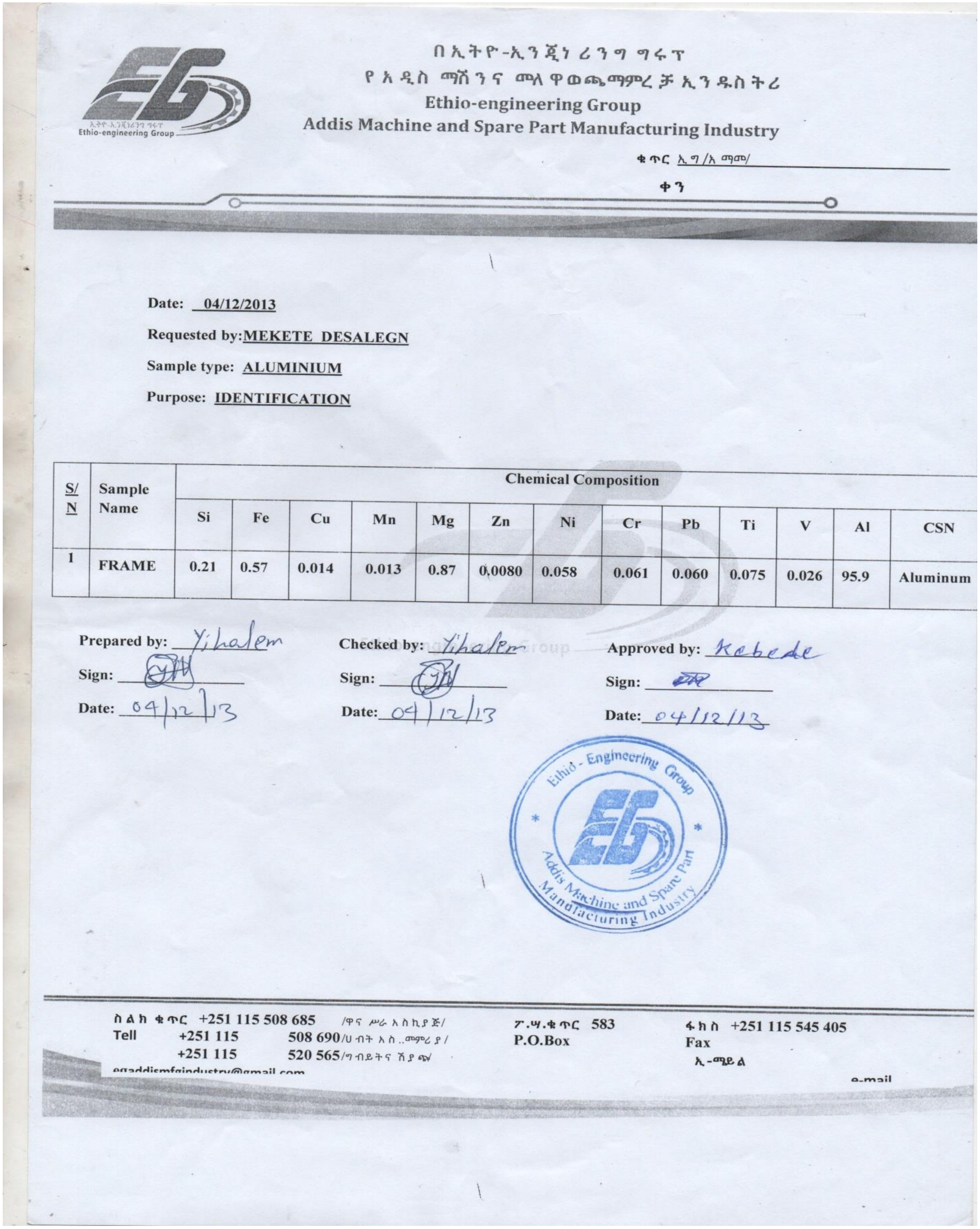


Test report

Kind of test: Compression test DIN 50106
Material of specimen: al
Dimensions of specimen: press specimen123 x 250 DIN 50106
Kind of differential length-measurement: between the compression plates
Lubrication of compression plates: yes
Temperature: 20°C
Compression strength: 417.31 N/mm²
Values for changing of shape: ____________________

Date: 26.11.2021
Name of tester: ____________________

Signature: ____________________



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Ethio-engineering Group
Addis Machine and Spare Part Manufacturing Industry

ቁጥር ኢግ/አ ማመ/

ቀን

Date: 04/12/2013

Requested by: MEKETE DESALEGN

Sample type: ALUMINIUM

Purpose: IDENTIFICATION

S/N	Sample Name	Chemical Composition												
		Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Ti	V	Al	CSN
1	FRAME	0.21	0.57	0.014	0.013	0.87	0.0080	0.058	0.061	0.060	0.075	0.026	95.9	Aluminum

Prepared by: Yihalem
Sign:
Date: 04/12/13

Checked by: Yihalem
Sign:
Date: 04/12/13

Approved by: Kebede
Sign:
Date: 04/12/13

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+251 115 520 565/ግብይትና ሽያጭ/
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