Faculty of Engineering & Science, Curtin Malaysia
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The utilization of Palm Oil Fuel Ash in Aluminium Metal Matrix Composites Materials

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DECLARATION

The best of my knowledge and belief, this thesis contains no material previously published by any other person except where due to acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree in any university.

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LIST OF PUBLICATIONS

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1. Loh, Y.R. and Zain, N.H.M. and Rahman, Ekhlasur and Willey, L. and Sujan, D. 2012. Silica Extraction from Palm Oil Fuel Ash. *Curtin University Conference (CUTSE) Engineering Goes Green*, Nov 6-7 2012, pp. 307-313. Sarawak, Malaysia: Curtin University School of Engineering. http://hdl.handle.net/20.500.11937/27713

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ABSTRACT

The increase in prices of petroleum, combined with the depletion of their resources, have resulted in a new trend to utilise new natural resources, as well as the bio-based composites. The impact of the productions from agriculture indicates that the waste generation would increase in millions of tons per year. Recently palm oil fuel ash (POFA) has become a significant research interest, especially in Malaysia due to its abundance as agricultural solid waste in this country. POFA is produced after the combustion of oil palm fibre as boiler fuel to produce steam for palm oil mill. Research shows that POFA contains about 79% silica and a significant portion of alumina. Beside silica and alumina, other chemical components that detected through X-Ray Diffraction (XRD) analysis in POFA are potassium oxide, calcium oxide and magnesium oxide. Therefore, due to the existence of rich siliceous material (comparable to fly ash and other waste materials), POFA has the potential for possible inclusion in MMC composites for improved properties.

The aim of this research work is to develop Aluminium Metal Matrix Composite (AL-MMC) by utilizing the agro-industrial waste that is Palm Oil Fuel Ash (POFA) as a reinforcement to the Aluminium alloy. Stir casting method is chosen for the fabrication of the new MMC. The mechanical and tribological properties are studied with different volume percentages and sizes of POFA as a reinforcement material.

The results shows that the variation of new ALMMCs density was increased by the percentage volume(vol.%) and reduced by the sizes of the POFA. The highest tensile and impact strength of the composite were obtained for 5 vol. % of POFA with the size of 76 to 150 µm. Moreover, it is observed that 5vol. % of POFA with sizes of 75 µm and 151 to 300µm produced better hardness and less weight loss. Therefore, this research indicates that the concentration (volume percent), as well as the size of the fibre in a metal matrix, is a key factor in determining the mechanical and tribological performances of MMC composite materials. The new of ALMMC's become one of the most important structural materials depending on the requirement for a specific strength with good wear properties. The research also contributed an added value option for the palm oil waste management as long term and sustainable pollution – solution for the factory.

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NOMENCLATURE

Notation	Description
µ	micro
µm	micrometre
Al_2O_3	Alumina / Aluminium Oxide
ALMMCs	Aluminium Metal matrix composites
ASTM	American Society for Testing and materials
B_4C	Boron Carbide
BHN	Brinell Hardness
CCA	Corn Cob Ash
cm	centimetre
CMC	Ceramic matrix Composites
COF	Coefficient of Friction
E	Young Modulus
EFB	Empty Fruits Branch
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
g/cm3	Gram per centimetre cube
Gpa	Giga pascal
J(kgm^2s^{-2})	Joule
kg	kilogram
m	meter
mm	millimetre
MMC	Metal matrix Composites
Mpa	Mega pascal
MPOB	Malaysia palm Oil Board
N	Newton
^oC	Degree Celsius

^{o}F	Degree Fahrenheit
PMC	Polymer Matrix Composites
POCp	Palm oil Clinker
POFA	Palm oil fuel ash
POME	Palm oil mill effluent
RHA	Rice husk Ash
S	second
SEM	Scan Electron Microscope
SiC	Silicon Carbide
SiO_2	Silicon Dioxide
Vol. %	Volume percentage
wt.%	Weight/ Mass percentage
XRD	X- Ray Diffraction
XRF	X-ray Fluorescence

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CHAPTER 1: INTRODUCTION

1.1 Background

A composite material is a material consisting of two or more physically or chemically distinct phases. The reinforcing component is distributed in the continuous or matrix component. When the matrix is a metal, the composite is termed as Metal Matrix Composite (MMC)(Minton 1997). MMCs are popular substitute materials for automotive, satellite systems, ballistic protection, general industries, sporting goods, aviation, and are also vastly applied in other engineering fields. This is because MMC possesses excellent mechanical properties and wears resistance. The reinforcement material can be fibres, particles or fillers; its function is to improve the overall mechanical and physical properties of the metal matrix. The fibre composites can either be, among others, continuous or discontinuous fibres and short fibres. The distribution, concentration, orientation, shape and size of the fibres will result in the fibres composites to be "tailored" in its mechanical and tribological properties according to the designer's needs. The properties of the MMCs are results from natural properties of constituent materials, all depending on matrix-reinforcement interfacial bonding and interaction between metal matrix and types of reinforcement materials (Ling 1999).

The composites high strength to density ratio compared to conventional monolithic material. Consequently, these composite materials are attractive, lightweight candidate options to achieve reduced fuel consumption and reduced greenhouse gas emissions in the transportation industries. Moreover, the MMCs can be used at a higher service temperature compared to their base metal counterpart. Furthermore, the reinforcement may improve specific stiffness, strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability. Automobile manufacturers have recently begun to use MMCs in their products. For example, there are engine components that have been introduced, consisting of an Aluminium-alloy matrix that is reinforced with Aluminium oxide and carbon fibres. This AL-MMC is light in weight and resistant to wear and thermal distortion. MMC is also employed in drive-shafts (that have higher rotational speeds and reduced vibrational noise levels), extruded stabiliser bars, and forged suspension and transmission components. Therefore, the initiation of the application of MMC is only the beginning of the evolution curve of modern materials (Kainer, 2006). The motive behind the use of MMC components in the automobile, agriculture and mining sectors are based on requirements for weight reduction and in pursuit of high efficiency and performance in the material (Mavhungu et al. 2017).

The increase in prices of petroleum, combined with the depletion of their resources, have resulted in a new trend to utilise new natural resources, as well as the bio-based composites. The growth of world population, increasing number of urbanisation and rising standard of living have to lead to high demand for agro-industry products such as oil palm, cocoa, pineapple, sugar cane and pepper products. The impact of the productions from agriculture indicated that the waste generation would increase in millions of tons per year. The waste is the substance or the objects, which are disposed or unwanted surplus substance or rejected products arising from the application of any process in general. Some are used as biofuel for electrical power generation (example: power generation at the oil palm industry). The waste from the boiler will affect the earth, the environment and the quality of life in air and water pollution. Currently, the most cost-effective of the agro-industrial waste management solution is by recycling it back to nature (e.g. as fertiliser and biomass) and generally used as biofuel for electrical power generation. As a result, the agro-industrial waste management becomes a significant issue especially the cost of disposal and pollution. However, this has a limitation, in terms of a substantial volume of agro waste to be managed for the Agro-waste industry.

Recently palm oil fuel ash (POFA) has become a significant research interest, especially in Malaysia due to its abundance as agricultural solid waste in this country. POFA is produced after the combustion of oil palm fibre as boiler fuel to produce steam for palm oil mill. Research shows that POFA contains about 79% silica and a significant portion of alumina and another hard particle (Safiuddin, Md.Isa, and Jumaat 2011). Beside silica and alumina, other chemical components that detected through X-Ray Diffraction (XRD) analysis in POFA is potassium oxide, calcium oxide, magnesium oxide, and andiron oxide. Therefore, due to the existence of rich siliceous material (comparable to fly ash and other waste materials), POFA has the potential for possible inclusion in MMC composites for improved properties. For raw POFA, it consists of irregular-shaped particles with a spongy and porous structure, with a sizeable fraction showing cellular texture. Therefore, nano-technological research can also be conducted on creating, manipulating and exporting the POFA as the nanostructured material to lead to beneficial uses of this bio-agricultural waste material (P Chindaprasirt, S Rukzon 2008)

This research report was dedicated to synthesising POFA based Al-MMC by utilising locally available Agro-Industrial waste materials (POFA). The research examined the mechanical, and tribological properties of the fabricated POFA based Aluminium metal matrix composite material. This study was able to improve the understanding of POFA based Al-MMC and consequently will help to solve the environmental problems.

1.2 Problem Statement

Research indicates that the concentration (volume percent), as well as the size of the fibre in a metal matrix, is a key factor in determining the mechanical and tribological performances of MMC composite materials. Extensive research has been conducted on the application of bio-waste namely fly ash in Al-MMC in recent time. However, the performance of the resulting MMC composites is not up to the mark in terms of mechanical performances. Moreover, the tribological performance of natural filler reinforced MMC are limited in the literature. Recently Palm oil fuel ash (POFA) has become a significant research interest, especially in South East Asian Countries due to its abundance as agricultural solid waste in this region. Research shows that POFA contains a considerable percentage of silica, alumina and other hard particles. Beside silica and alumina, other chemical components that detected through X-Ray Diffraction (XRD) analysis in POFA is potassium oxide, calcium oxide, magnesium oxide, and andiron oxide. Therefore, due to the existence of rich siliceous material (comparable to fly ash and other waste materials), POFA can be a potential filler in MMC composites for improved mechanical and tribological performances.

1.3 Research Questions

The specific research questions are as follows:

- Can the chosen matrix (AL6061) be incorporated with chosen reinforcement Palm oil fuel ash (POFA) by using a suitable fabricated method to produce new ALMMC?
- What are the influences of volume percentage and sizes of POFA on the mechanical and tribological performances of the MMC composite?

1.4 Aim and Objective of the Research

The research project was aimed to develop Aluminium Metal Matrix composite (AL-MMC) by utilizing the agro-industrial waste that is Palm Oil Fuel Ash (POFA) as a reinforcement to the Aluminium alloy.

Specific objectives are as follows:

- To explore the possibility to fabricate a new ALMMCs by using AL6061 as matrix due to its basic properties; the light (low-density) metals and also of commercial importance. The stir casting method is suitable fabrication method for any Aluminium alloy with fibres.
- To study mechanical properties (tensile strength, impact and hardness) of the new AL-MMCs with different volume percentages and sizes of POFA as a reinforcement material.
- To study the tribological performance of the new AL MMCs with different volume percentages and sizes of POFA as a reinforcement material.

1.5 Significance of the Research Findings

This research project will demonstrate the synthesis and characterisation of a newly developed green ALMMC through the utilisation of POFA as a reinforcement material. This research project is expected to act as a new beginning to extensive research on composite materials utilising agro-industrial waste. The dimension of this research may be expanded by developing new green composite materials utilising locally available agro-industrial wastes and natural recycled cellulose fibres. The anticipated results of the research will contribute to more added value option for palm oil waste. Hence it becomes a long term and sustainable pollution-solution. The new MMC material not only is expected to offer incoming profits for the Palm Oil Industry but also Malaysia. Such findings may reduce or eliminate disposal cost, as well as air and water pollutions.

1.6 Scope of the Research

The research commenced with the identification of the chemical composition of the POFA for the oil palm waste products of different locations as well as their different sizes. The result of the test provided the initial justification before proceeding to the fabrication process. The composite was fabricated using stir casting machine. The mechanical performances of the developed composites were restricted to tensile strength, impact and hardness. The tribological performance of the composite was expressed in terms of wear dry sliding to measure mass or weight loss and coefficient of friction.

1.7 Layout of the Thesis

The thesis consists of experimental research to synthesise POFA based Al-MMC by utilising locally available Agro-Industrial waste materials (POFA) in order to evaluate its mechanical and tribological properties. The Scanning Electron Microscopy (SEM) has been conducted for surface morphology study. This thesis is divided into five chapters as follows:

Chapter 1

Introduction to the problem statement, research gap, research problems, this leads to the aims and objectives of the research and the scope of the study.

Chapter 2

Literature review or background knowledge explains past research studies of metal matrix composites (MMC) reinforced by Agro-Industrial waste. These studies started on past findings, their chosen matrix and chemical content namely Silica dioxide (SiO_2), Alumina (Al_2O_3) and Silicon Carbide (SiC) and other chemicals as reinforced materials and their mechanical and tribological properties. Subsequently, the utilisation of Agro-Industrial waste as reinforcement in MMC and their mechanical and tribological properties have been discussed.

Chapter 3

The chapter starts with the experimental flow chart followed by the fabrication methods of the composites. The Mechanical and tribological tests and ASTM standards for tensile test, impact test, hardness test and dry sliding tests using Ball-on-disk wear dry sliding test are explained in this chapter. Finally, the microstructural characterisation of ALMMC using Scanning Electron Microscope (SEM) is described.

Chapter 4

The results of mechanical and tribological tests are presented and analysed in this chapter. The chapter started with the chemical composition analysis of AL6061 and POFA. The density of the composites based on various sizes and concentration of POFA are analysed next. Subsequently, the detailed analysis of the mechanical (tensile strength, impact, hardness) and tribological (wear dry sliding) properties of the new AL MMC consists of AL6061 as matrix and POFA as reinforcement materials are presented. The study of the correlation between mechanical and tribological properties of the developed AL MMC are emphasised in order to find the optimum mix of AL6061 as matrix and POFA size and volume percentage as a reinforcement material.

Chapter 5

Conclusions and recommendations concluded the findings of the research on the new AL-MMC consisting of AL 6061 as matrix and POFA as reinforcement materials, and finally, a list of recommendations for further investigation has been proposed.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature review is a compilation of study of the new product of Metal matrix composites (MMCs). Composite materials are engineered or naturally occurring, made from two or more constituent materials with significantly different physical and chemical properties, which remain separate and distinct within the finished structure (Masuelli 2013). The discipline of material sciences involves investigating the relationship that exists between the structures and properties of materials. In contrast, material engineering is, by these structure-property correlations, designing or engineering the structure of a material to produce a predetermined set of properties. Mechanical properties especially relate deformation to an applied load; examples include impact, hardness and tensile strength. The material processing, structure, properties and performance are interrelationships for producing a new product. Solid material had been grouped into three basic classifications: metal, ceramic and polymers, all are based on chemical composition and atomic structure (Callister and JR. 2001).

The composites are considered as promising materials that have many applications in high-technology, such as advanced vehicles (for example, automobiles, aircraft and trains) with highly efficient and better performance and no environmental impact. Composites are one of the most widely used materials due to their adaptability to a different situation in serving specific purposes and also desirable properties (Ling 1999). The composite material consists of two materials (continuous and discontinuous material) of different nature completing and allowing us to obtain a new material that contains the set of performance characteristics. The continuous phase is called matrix, and the discontinuous phase is called the reinforcement, or reinforcing materials (Ling 1999). The mechanical and physical performances of the composite materials are more significant than the components taken separately. The discontinuous phase is usually harder and with mechanical properties superior to those of the continuous phase. The microstructure of the final product of the composites will reveal how the reinforcement material will be diffused or packed or have an interface with the matrix. Therefore, the mechanical and tribological properties correlate with the types, sizes and orientation the reinforcement in the matrix (Nirmal, Hashim, and Ahmad 2015).

The new composite materials may be preferred for being stronger, lighter, or to reduce cost compared to monolithic. Figure 2.1 shows the general mixture of composites, and the classification of the composite, depending on the types of matrix and reinforced materials. The matrix can be metal, polymer or organic, ceramic or mineral and the reinforcement can be particles, fibres and structural. Composites are designed to display a combination of the best characteristics of each of the component materials. The mixture of the matrix and reinforcement lead to the classification of the composites (Callister and JR. 2001)

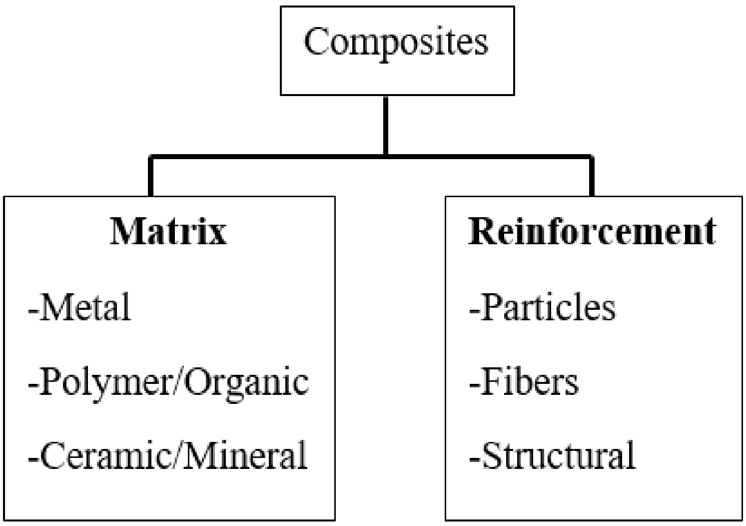


Figure 2.1: General mixture of composites (Callister and JR. 2001).

The findings indicate that MMC is a combination of chemical content and agro-industrial waste as reinforcement and metal as a matrix. The MMC consist of matrix Zr2.5Nb reinforcement by Silicon Carbide (SiC) for different volume fraction, size and shape effect on its indentation behaviour and deformation mechanism (Shedbale et al. 2017). The MMC was fabricated with Bamboo leaf ash (BLA) 2%, 4% and 6% as reinforcement and Aluminium alloy Al-4.5% Cu alloy as a matrix using stir casting method (B. P. Kumar and Birru 2017). Another MMC fabrication technique is sandwich technique on Magnesium sheet as matrix and reinforcement by Carbon

Nanotube (CNT) (Isaza Merino et al. 2017). Balaji fabricated MMC with an AL 7075 as a matrix, SiC as a reinforcement using stir casting method. Authors reported that this MMC has a potential application in aircraft and space industries due to higher strength to weight ratio, high wear resistance and creep resistance (Balaji, Sateesh, and Hussain 2015). The MMC where Al-Cu is used as a matrix, with Boron Carbide as reinforcement, using two steps stir casting to prevent clustering and agglomeration (Ravindranath et al. 2017). Rice Husk Ash (RHA) and fly ash were used as reinforcement materials, and fabricated with Al-Si alloy as a matrix, which was done by Senapati in order to analyze the wear properties of the product of MMCs (Senapati, Nanda, and Satapathy 2016). A review was done regarding utilising agro-waste as reinforcement materials for the production of new concrete as composites (Prusty, Patro, and S.s.Basarkar 2016). The MMCs using Al 6061 as the matrix was fabricated with Nano Titanium Carbide (TiC) as MMC (Pandey et al. 2017). The author used stir casting method for the fabrication process.

Meanwhile, Sharma fabricated MMC with Aluminium and fly ash using stir casting method (V. K. Sharma, Singh, and Chaudhary 2017). Saravanakumar fabricated the MMC by using Aluminium alloy AA2219 as a matrix and Graphite powder (Gr) as a reinforcement (Saravanakumar, Sivalingam, and Rajesh 2018). The agro-industrial waste (Fly ash) and Silicon Carbide was utilized as reinforcement materials and Aluminium alloy Al 6082 as a matrix material to produce another MMC (Reddy and Srinivas 2018).

Another research was utilised the Sillimanite (an abundant mineral from the coastal region of India) as a reinforcement material for Aluminium alloy Al-Si that is LM30 as a matrix for MMC. The reinforcement material was added to the matrix, from 3wt. % to 18wt. % with different sizes. These ranges of sizes include1-20µm, 32-50µm and 75-106µm (Sharma, Nanda, and Pandey 2018). Afoladi fabricated the MMC using method powder for MMC that consist of a pore-forming agent from RHA and sugarcane bagasse with 2wt% of Nickel reinforcement. (Dele-Afolabi et al. 2018).

It was clearly shown that the fabrication of the composites depends on the types of matrix, reinforcement materials and also the application of the product (Mistry and Gohil 2018).

2.2 Matrix Materials

As mentioned earlier, the role of the matrix in the composites is to transmit the fibres to the external mechanical loads and to protect the fibres against external attack (Ling 1999). The matrix can be metal, polymer or organic, ceramic or mineral as indicated in Figure 2.1. The success of a product depends on the selection of the engineering materials in order to match the properties requirements of the application. The early successes in altering materials were mainly the result of trial and error, the result of properties and performance of a product, as a direct result of its structure and processing. By changing the properties, it will induce a change in the material structures (Callister and JR. 2001).

2.3 Classification of Composites

The classification of the composite materials based on the type of matrices is shown in Figure 2.2.

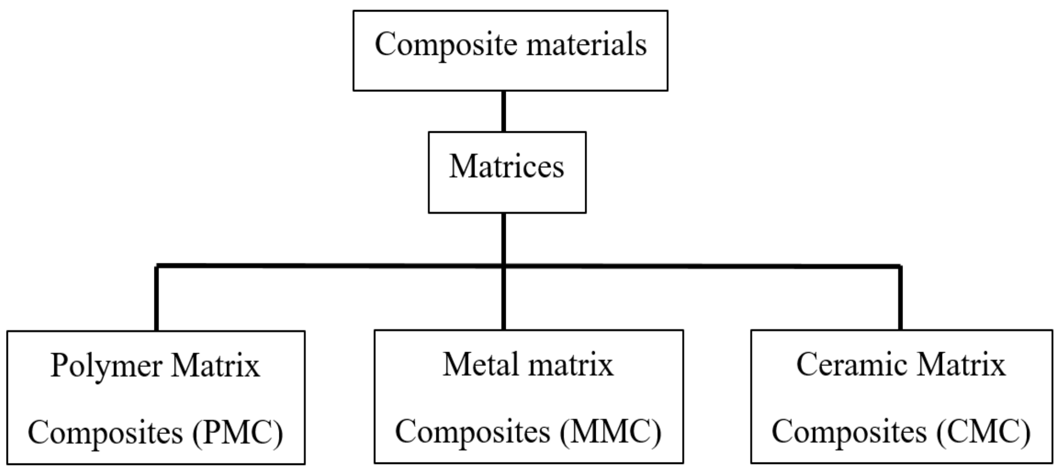


Figure 2.2: Classification of composites based on matrices (Ling 1999)

They are organic or polymer or carbon-carbon composites (PMC), metallic or minerals matrix (MMC) and Ceramic composites (CMC). The product of composites from different matrix and reinforcement will lead to a suitable fabrication process. The mechanical and tribological properties of the product also will be different. The reinforcement will increase mechanical performance, whereas the role of the matrix is to transmit to the fibres the external mechanical loads and to protect the fibres against external attack (Ling 1999).

2.3.1 Polymer Matrix Composites (PMC)

The most common advanced composites are polymer matrix composites (PMC). These composites consist of a polymer such as epoxy, polyester, urethane (also called resin) or organic or carbon. It is reinforced with thin-diameter fibres that were graphite, aramids and boron (also called filler).

Carbon matrix reinforced by carbon are called carbon-carbon composites, and organic material and carbon-carbon composites can be a matrix, as both of them are in PMC classification. Carbon-carbon composites are used in a very high-temperature environment up to 6000^{o}F (3315^{o}C) and are 20 times stronger and 30% lighter than graphite. Among their advantages include low cost, high strength, and simple manufacturing principles. The main drawbacks of PMC are of low operating temperature, high coefficients of the thermal and moisture expansion, and low elastic properties in a specific direction. Some materials, such as polymers absorb or de absorb moisture, which results in dimensional changes (Kaw 1997). The findings on PMC indicated that using epoxy as matrix and Silicon Carbide (SiC) as reinforced material, the wear rate is reduced by increasing the sliding velocity of the specimen (Agarwal, Patnaik, and Sharma 2013).

2.3.2 Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites (CMC) have matrices such as Alumina, Calcium Aluminosilicate, which are reinforced by fibres such as carbon or silicon carbide (SiC). The advantages of CMCs include high strength, hardness, high service temperature limit for ceramic, chemical inertness, and low density. CMCs are more attractive for applications, where both high mechanical properties and extreme service temperatures are desired. One of the most common methods to manufacture CMSs is called the hot pressing method. Through this method, the CMCs findings indicated that its application is in high-temperature areas, where the MMCs and PMCs cannot be used. Therefore, the typical application includes cutting tool inserts in an oxidising and high-temperature environment (Kaw 1997). Composites materials with organic matrix can be used only in a temperature range not exceeding 200^{o}C to 300^{o}C. However; composites materials with a metallic and mineral matrix are used beyond 600^{o}c and 1000^{o}C respectively (Ling 1999).

2.3.3 Metal-Matrix Composites (MMC)

As the name implies, for metal-matrix composites (MMCs), the matrix is a ductile metal. Metals are mainly reinforced to increase or decrease their properties to suit the needs of the design. MMCs have several advantages over PMCs, which includes higher elastic properties, higher service temperature, insensitivity to moisture, higher electric and thermal conductivities, and better wear, fatigue, and flaw resistance. The drawbacks of MMCs over PMCs include higher processing temperatures and higher densities MMCs, which are mainly used to provide advantages over monolithic metals such as Steel and Aluminium (Kaw 1997).

The automobile manufactures, agriculture and mining sector have recently begun to use MMCs in their product. Demands of the new MMCs are generally applicable for low density, mechanical and chemical compatibility, thermal stability, high Young’s modulus, high compression and tensile strength, good processability as well as cost-efficient. The research development of MMCs is to provide innovative engineering materials solution, such as a lightweight matrix but with higher strength. Ultimately, the MMC research development is to provide advantages over monolithic and conventional metals such as Steel, Aluminium and other metal (Kainer 2006).

Lately, research on the production of new MMCs became an innovative material by fabricating light metal as a matrix. The matrixes, such as Al 7075, pure Al 2219, Al-Cu, Al-Si alloy and many more Aluminium alloys wrought for a new composite (Balaji, Sateesh, and Hussain 2015; Ravindranath et al. 2017;Senapati, Nanda, and Satapathy 2016) The production concept of the MMCs is to improve the strength of the matrix as continuous material by reinforcement with discontinuous fibre. The new composite materials may be preferred for being stronger, lighter, or reduce cost compared to monolithic (Mistry and Gohil 2018).

When weight reduction of the component is a priority, the use of light metal has a prospect. The development objectives of light metal composite materials increase the tensile strength at room temperature. The selection of suitable matrix alloy is mainly determined by the intended application of the composites material. With the development of light metal composites materials that are mostly easy to process, conventional light metal alloys are applied as matrix material. In MMCs, Aluminium(AL), magnesium(Mg), Titanium(Ti) and Copper(Cu) are frequently used as matrix elements (Kainer 2006). The detailed studies about new MMCs involved the followings: the reinforcement materials, the chosen matrix, utilising the Agro-Industrial waste as a reinforcement material, the method of fabrication and the mechanical and tribological properties.

2.4 Reinforcement Materials

The difference between the composite materials is not just on its matrix, but also due to reinforcement materials. Three main divisions of the composites are based on reinforcement materials, including particle reinforced, fibre-reinforced and structural. Figure 2.3 (Callister, G and Rethwisch 2011) shows clearly the different products of composites by the types of reinforcement materials, sizes and how reinforcement was embedded in the matrix. The particles reinforced can be large particle or dispersion strengthened. The fibre reinforcement may be in the form of continuous, and the fibre can be aligned. Compared to discontinuous or short fibre reinforcement, it can be aligned and also random oriented. The structural reinforcement can be laminated, among others, with matrix or sandwich panels. Reinforcement of the metal matrix composites has manifold demand profile, which is determined by production and processing (Callister, G, and Rethwisch 2011).

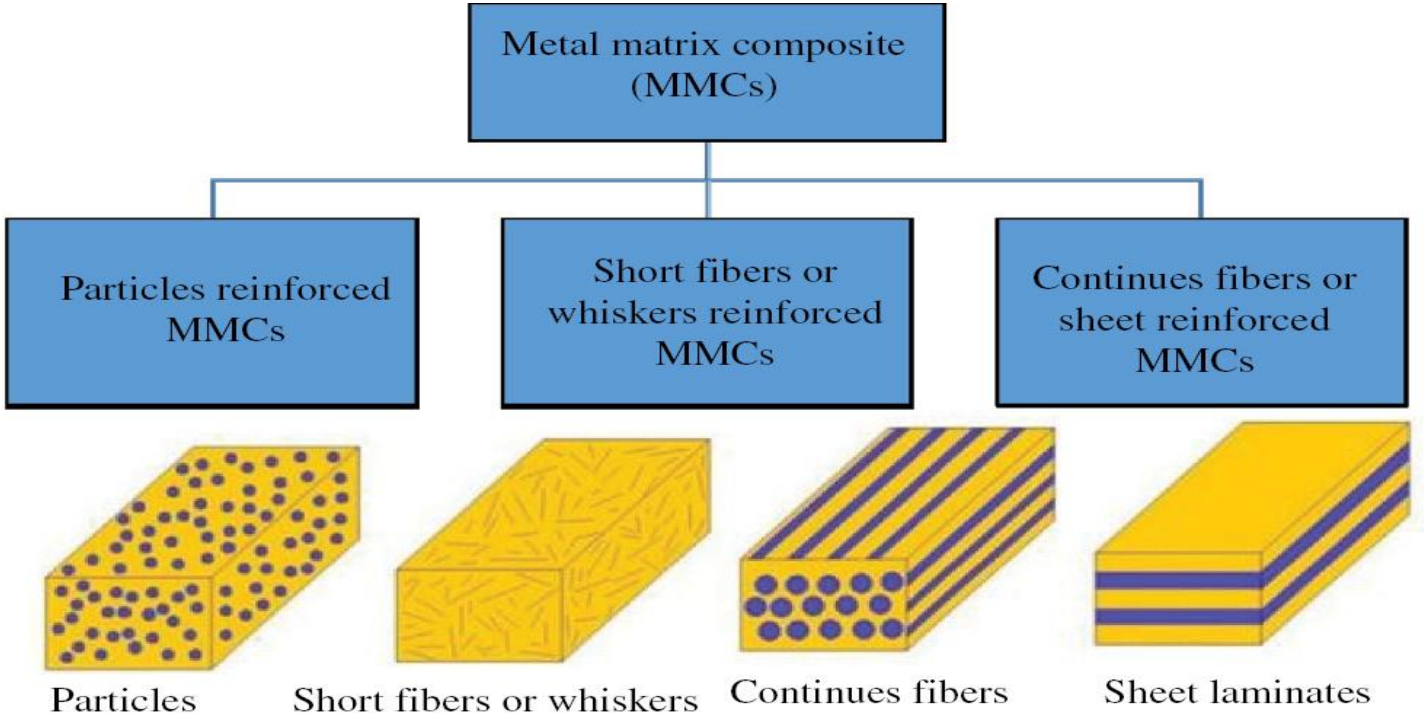


Figure 2.3: The metal matrix composites with reinforcements (Mistry and Gohil 2018)

Each of the different shape of the reinforcements immersed in the matrix with ways and produce different properties of the composites. The properties of reinforcement in the matrix are as follows:

i) **Particulate composites -** particles are immersed in matrices such as alloy and ceramic. The advantages are improved in strength, increased operating temperature and oxidation resistance.

ii) A **flakes composites** - used as flat reinforcement of matrices
They provide advantages such as high out-plan flexural modulus, higher strength, and low cost but is limited

iii) **Fibres composites -**matrix is reinforced with short (discontinuous or random) or long (continuous) fibres. The discontinuously reinforced composites with short fibres, whiskers or particulates or it can be random fibre composites. The continuous fibre composites will be more structured as shown in Figure 2.4. (Callister, G, and Rethwisch 2011).

The parameters of the reinforcement dispersed in the continuous matrix will influence the strength of the composites. The geometry of the reinforcement will also be characterised by its shape, its size, the concentration of the reinforcement, its disposition (its orientation). Clearly shows in Figure 2.5, the schematic diagram of the parameters of the reinforcement material in the matrix. The parameters are distribution, concentration, orientation shapes, and sizes. All parameters will link to the method of fabrication of the composites. Each option will impart different benefits to the final part, the strength of the composites (Flinn and Trojan 1990).

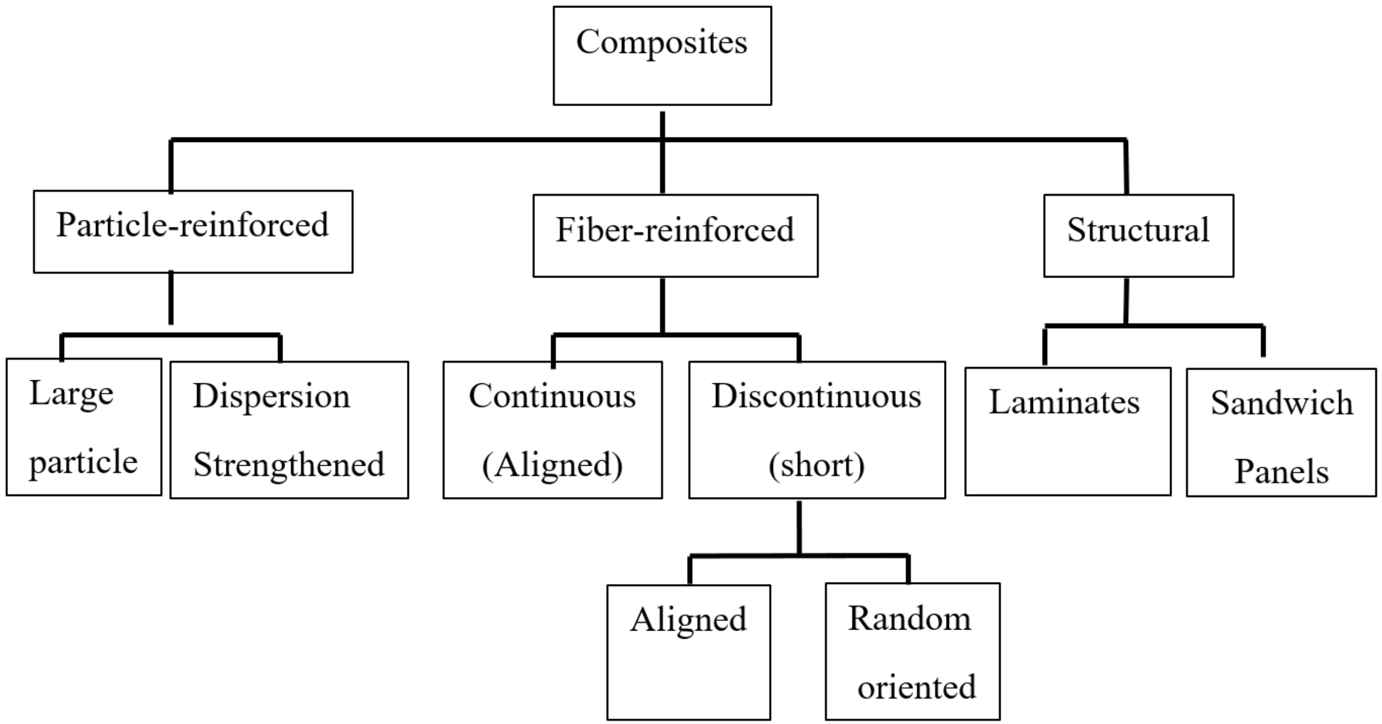


Figure 2.4: Classification composite based on reinforcement materials (Callister, G, and Rethwisch 2011)

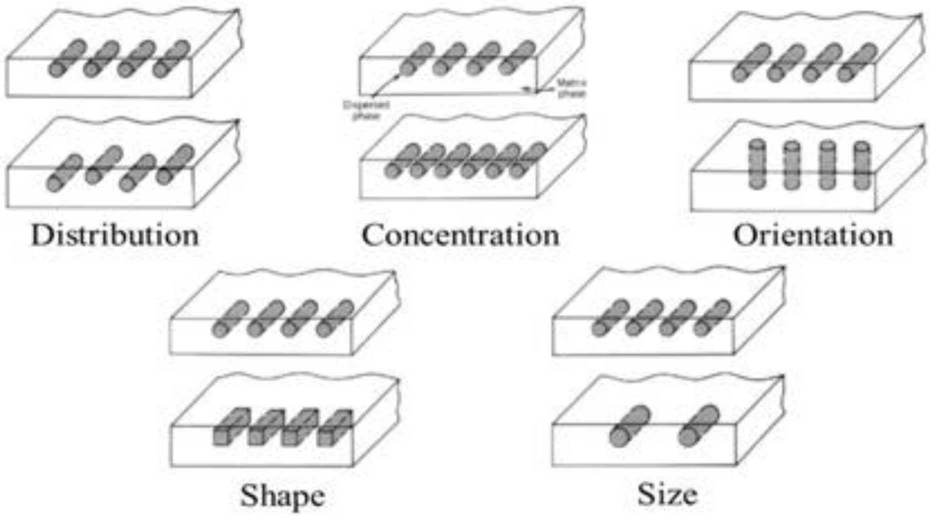


Figure 2.5: Schematic diagram of various geometrical and distinctive characteristics of particles of the dispersed phase (Flinn and Trojan 1990).

2.5 Aluminium Metal Matrix Composites (ALMMC)

Aluminium matrix composites (ALMMCs) have potentials for various applications due to their excellent mechanical and tribological properties. The addition of reinforcements into an Aluminium as matrix improved the stiffness, specific strength, wear, creep and fatigue properties as compared to the conventional engineering materials. An Aluminium and its alloy have attracted most attention as based in MMC. Therefore, ALMMC is widely used in aircraft, aerospace, automobiles and various field (Ramnath et al. 2014).

Aluminium wrought is a light metal group with low density, high corrosion and easy fabrication process. Aluminium alloys are used in advanced applications due to their combination in high strength, low density, machinability, availability and its cost-effectiveness compared to competing materials. The melting point of an Aluminium is high enough to satisfy many applications, yet it is low enough to render composite processing at a reasonably convenient rate. Aluminium also has a high strength-to-weight ratio as well as high resistance to corrosion (Davis J.R 1999). Aluminium is used in advanced applications because of their combination of high strength, low density, durability, machinability, availability and cost-effectiveness. However, the scope of these properties can be extended by using Aluminium matrix composite materials (ALMMCs) (Callister, G, and Rethwisch 2011).

Table 2.1 illustrates findings from a list of researchers who fabricated ALMMCs reinforced such as Alumina (Al_2O_3), Silicon Carbide (SiC), Boron Carbide (B_4C), Silicon Carbide (SiC), matrix magnesium oxide (MgO), Graphite and Sillimanite (mud soil from India). An Aluminium and its wrought as a matrix can accommodate a variety of reinforcing agents and stir casting was the fabrication method as shown in Table 2.1.

The reinforcement for ALMMC should be stable at specific working temperatures, and it is also non-reactive. Furthermore, the most commonly used reinforcements are Alumina (Al_2O_3), Silicon Carbide (SiC), Boron Carbide(B_4C), Fibers and Zircon. Table 2.2 illustrates that the mechanical and tribological performances of ALMMC depend on reinforced materials. In reference to Table 2.2, Boron Carbide (B_4C) was used to increase its hardness, but not for wear resistance. Silicon Carbide (SiC) was used as reinforcement; it can increase all mechanical and tribological properties in ALMMC except for impact toughness (Ramnath et al. 2014).

Another study relating to MMC, where AL6061 (3 samples) and other metals were used as a matrix and varieties of reinforcements were used as a filler material and shown in Table 2.3 (Callister, G, and Rethwisch 2011). The comparison of findings was made on ALMMC, using AL6061 as matrix and Carbon(C), Boron (B), Silicon Carbide (SiC) as reinforcement

Matrix.

An example is a pair of AL6061 with Carbon to AZ31Mg with Carbon. The findings showed that the tensile modulus and tensile strength were slightly better by using AL6061 as a matrix material. Moreover, the tensile strength improved significantly when Boron was used as a reinforcement material in Al6061(Callister, G, and Rethwisch 2011).

Table 2.1: Summary of ALMMCs

Matrix	Reinforcement	Reference	Fabrication method
Aluminium alloy 6063	SiC	(Kashan 2010)	Stir casting method
Pure Aluminium	SiC	(Singla et al. 2009)	
Aluminium alloy Cu-Zn-Mg (700series)	Alumina (Al_2O_3)	(Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar 2011)	
Aluminium alloy	SiC	(Sozhamannan1, Prabu, and V. S. K. Venkatagalapathy 2012)	
Al 6061	Graphite & SiC	(N, Nagaral, and Auradi 2012)	
Al 6063	Alumina (Al_2O_3)	(Pandey et al. 2017)	
AL 7075	SiC	(Balaji, Sateesh, and Hussain 2015)	
AL 2219	Boron Carbide(B_4C)	(Ravindranath et al. 2017)	
Al 6061	TiC	(Pandey et al. 2017)	
Aluminium alloy AL-Si (LM30)	Sillimanite	(S. Sharma, Nanda, and Pandey 2018)	

Table 2.2: The overall finding of ALMMC by the chemical components (Ramnath et al. 2014)

Reinforced material	Characteristic in ALMMC
Alumina (Al_2O_3)	• Increase in vol. fraction of Al_2O_3 decrease the fracture toughness of ALMMC. • Good compressive strength and wear resistance of ALMMC • Using the hot pressing method for fabrication, it showed high tensile strength but low tensile ductility.
Zircon	• Zircon, as reinforcement showed better wear resistance than that of Alumina reinforced to ALMMC. • Method of fabrication was powder metallurgy.
Fibres	• Fibres can satisfy the desired conditions and transfer strength to the matrix constituent, which influences and enhances their properties as desired. • Excellent bonding between Al as matrix and fibre was observed. • Most of the findings used wettability for enhancing and reducing damage on fibre.
Boron Carbide (B_4C)	• Increase in hardness but did not improve the wear resistance of ALMMC.
Silicon Carbide (SiC)	• There is an increment in SiC ratio, and it increased the tensile strength, hardness, density and wear resistance of ALMMC but decreased its impact toughness. • It has higher wear resistance than Al_2O_3 reinforced in ALMMC

Table 2.3 Properties of several Metal-matrix Composites Reinforced with Continuous(Callister, G, and Rethwisch 2011).

Fiber	**Matrix**	**Fiber content (Vol.%)**	**Density (g/cm3)**	**Longitudinal Tensile Modulus (GPa)**	**Longitudinal Strength (MPa)**
Carbon	6061 Al	41	2.44	320	620
Boron	6061 Al	48	-	270	1515
SiC	6061 Al	50	2.93	230	1480
Alumina	380.0 Al	24	-	120	340
Carbon	AZ31 Mg	38	1.83	300	510
Borsic	Ti	45	3.68	220	1270

The choice of AL 6061 as a matrix with three different reinforcement materials as well as different volume percentage is also represented in the given findings:

i. Al6061 is used as a matrix using different fibre as well as its percentage volume, which is entirely different in tensile strength, without correlation.

ii. Three (3) different matrices and three (3) different fibres with three (3) different percentage volume were used. It has clearly shown that the increase of the percentage volume will increase the tensile strength of the MMC.

Table 2.4 shows that the mechanical properties of two MMCs using Aluminium as a matrix with two different reinforcements, which are SiC and Graphite. The results of the mechanical properties of the MMCs were much better as compared to Steel and Aluminium. The table also revealed that the ultimate tensile strength and Young's Modulus were significantly increased when SiC was used as a filler material.
(Kaw 1997). Therefore, AL 6061 is an excellent choice as a matrix for a new ALMMC due to its basic properties; which could easily be applied through alloy, temper and fabrication process.

The ratio of the wrought Alloys families for Al 6061 consisted of Aluminium, Manganese and Silicon of as 98.4%, 1.0% and 0.6% respectively. Magnesium provides substantial strengthening and improvement of the work-hardening characteristic of Aluminium. Also, Aluminium can accommodate a variety of reinforcing agents. The Typical properties for pure Aluminium (high-purity > 99.95%) and Aluminium alloy AL6061 shown in Figure 2.5 (Davis J.R 1999). The mechanical properties of AL6061 showed in table 2.5 such tensile strength, thermal expansion and elongation depended on its heat treated but not for pure Aluminium.

Table 2.4: Mechanical Properties of metal matrix Composites and Monolithic Material (Kaw 1997)

Property	Unit	SiC/ Aluminium	Graphite/ Aluminium	Steel	Aluminium
Specific gravity	-	2.6	2.2	7.8	2.6
Young's Modulus	GPa	117.2	124.1	206.8	68.95
Ultimate Tensile Strength	MPa	1206	448.2	648.1	275.8
Coefficient of thermal expansion	$^{o}C^{-1}$ or $1/^{o}C$	12.4	18	11.7	23

Table 2.5: Mechanical properties of Aluminium alloy Al 6061 and pure Aluminium (Davis J.R 1999)

No	Characteristic	Al 6061	High-purity >99.95% Al
1	Density	2.71g/cm^3	2.699g/cm^3(solid), 2.357g/cm^3(liquid at 973K)
2	Melting Point	580^{o}C	933.5.2^{o}C
3	Thermal expansion	23.5x10-6/K (20-100^{o}C)	23x10^{-6}/K at 293K
4	Tensile strength	110-152Mpa (0) ; 180(T1); 179(T4) ; 260 -310(T6)	90 MPa
5	Elongation	14-16% (0) , 16% (T1), 9-13%(T6)	-
6	Modulus elasticity	70-80GPa	-

2.6 Utilizing Agro-Industrial Waste in Composites

A new trend of technology included utilising new natural resources (natural fibre) as reinforcement materials to produce new composites. The composites with good strength to weight ratio are becoming essential in modern engineering designs especially for automotive and aerospace applications, where improved machine efficiency and reduced fuel consumption are critical requirements to be satisfied (Alaneme and Olubambi 2013).

Lately, the researchers utilized different types of agro waste, such as Fly ash, Coconut shell ash, Rice Husk Ash (RHA), Palm oil fuel ash(POFA), empty fruits branch (EFB), palm oil seeds, Palm oil shell, Palm fiber, palm oil clinker (POC), coconut ash, sugarcane bagasse as reinforcement for new production of composites (Mavhungu et al. 2017). Praveen's findings showed the correlation of density of the new MMC reduced with an increased in bamboo leaf ash(BLA) content in comparison Al-4.5% Cu Alloy(B. P. Kumar and Birru 2017). Table 2.6 shows ALMMCs and PMC used agro waste as reinforcement with the addition of bamboo leaf ash (BLA), groundnut shell(GS), Aloe Vera (AV) and also fly ash (charcoal) as continuous-natural fibre materials.

Table 2.6: The utilisation of the Agro - waste in ALMMC and PMC

Matrix	Reinforcement	Reference
AL 356	Fly ash	(Itskos et al. 2012)
Pure Aluminium	fly ash	(Shanmughasundram, Subramaniam, and Prabhu 2012)
Al-Si alloy	RHA and fly ash	(Senapati, Nanda, and Satapathy 2016)
Pure Aluminium	RHA and Alumina	(Alaneme and Olubambi 2013)
Al 6063	Fly Ash	(Mohammed Razzaq et al. 2017).
Epoxy polymeric	fly ash	(Pappu and Vijay 2017)
Pure Aluminium	fly ash(FA) and Aloe Vera AV	(Gireesh et al. 2018)

Figure 2.7 illustrates that the fly ash and Red mud are considered as an Industrial waste by-product. The fly ash was produced in a thermal power plant by the combustion of the coal. Red mud, which was known as bauxite residue is also waste by-product. Red mud is produced during the production of Alumina from bauxite through Bayer process. It is a caustic insoluble waste generated after bauxite digestion at elevated pressure and temperature(Chandla, Kaushik, and Jawalkar 2017).

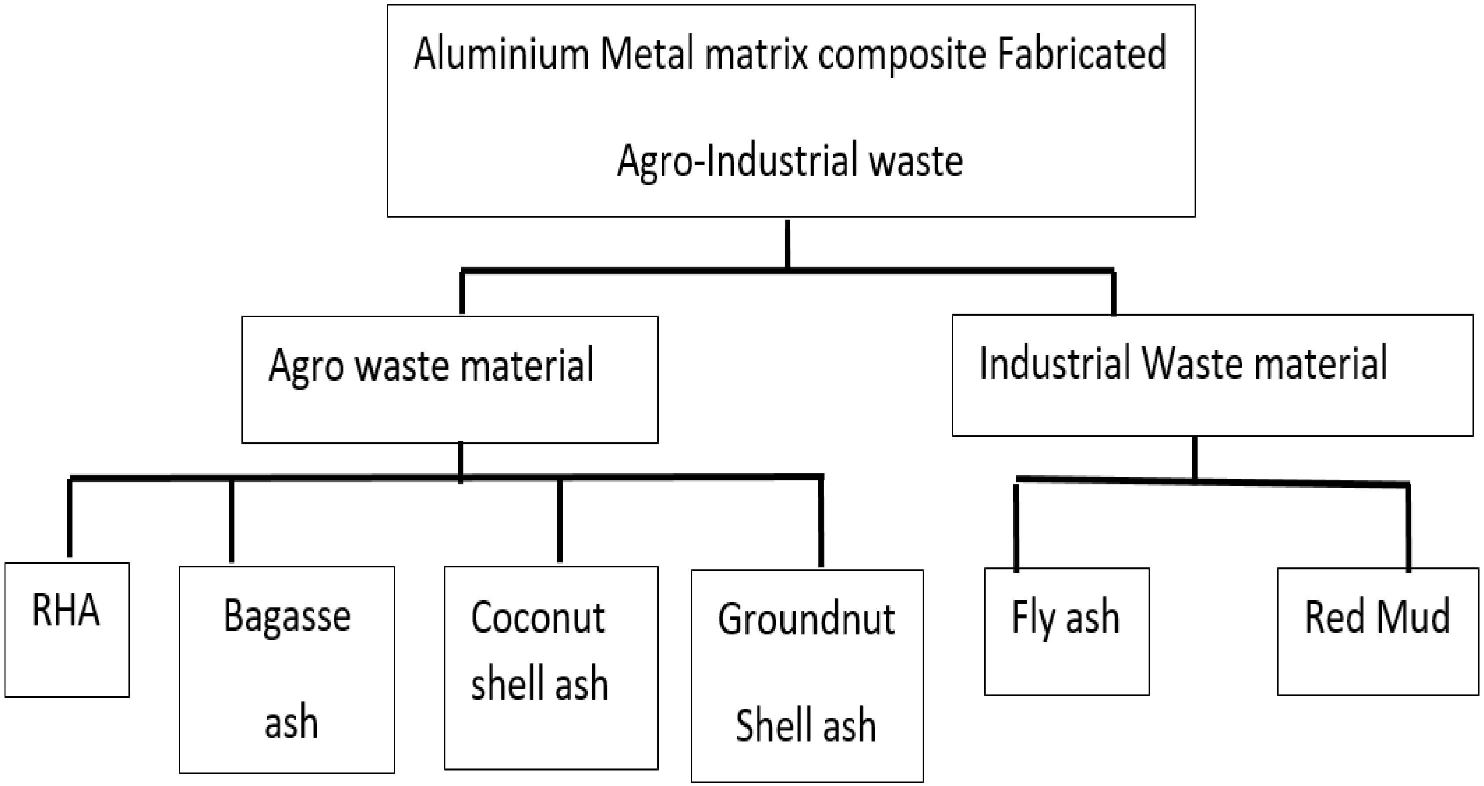


Figure 2.7: Classification of ALMMC fabricated from Agro-Industrial waste(Chandla, Kaushik, and Jawalkar 2017)

It mainly consists of Silicon dioxide (SiO_2), iron oxide (Fe_2O_3) and Aluminium oxide (Al_2O_3), along with the same minor constituents as illustrated in Table 2.7. It showed that the chemical composition of the each of agro-industrial waste contain two to three common the chemical contents in them. Agro Industrial waste ashes offer unique properties, such as low density, higher melting point, refractories, low cost and availability. A distribution of other refractory oxides such as Alumina (Al_2O_3) and Hematite (Fe_2O_3), which makes them a good choice for reinforcement. Among all the agro-industrial waste, RHA having the highest Silica dioxide(SiO_2) (Chandla, Kaushik, and Jawalkar 2017).

As mentioned in chapter 1, Malaysia is the second largest producers, and exporters of the palm oil and about 70% of the volume from the processing of fresh fruits bunch was removed as waste in the form of empty fruits bunches (EFBs), fibres, seeds and shells, as well as liquid effluent from the Palm oil factory. The agriculture waste commonly used as electrical power generation but the cost of disposal and as well as pollution (air and water) of the waste become a major issue. The ash is the last product after all part of the palm oil waste goes to burning process from boiler called Palm oil fuel ash (POFA). So far, POFA had utilised as reinforcement to improve the strength of a concretes. Some results showed that the strength of concrete increased by increasing the POFA content (Zeyad et al. 2016). Another finding was found by Abdul Munir that the concrete strength was decreased and loss of compressive strength with the addition of POFA (Munir et al. 2015). Industrial waste ashes offer unique properties, such as low density, higher melting point, refractoriness, low cost and availability, good amount of Silica dioxide (SiO_2).

Table 2.7: Chemical composition of the constituents (Chandla, Kaushik, and Jawalkar 2017)

Constituents	Chemical composition(%)												
	SiO_2	MgO	AL_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	MnO	ZnO	TiO_2	SO_3	CuO	FeO
Coconut Shell Ash	45.05	16.20	15.60	12.40	0.57	0.52	0.45	0.22	0.30				
Sugarcane Bagasse	66.43	1.13	6.19	0.57	2.23	4.55				0.28	5.37		
Fly Ash	51.40	1.72	29.65		2.82	1.57				2.54		4.86	5.39
Groundnut shell Ash	41.42	3.51	11.75	12.60	11.23	11.89	1.02	0.23		0.63			
Rice Husk Ash	97.09	0.83	1.14	0.38	0.07	0.18	0.09				0.15		
Red Mud	11.53		48.50	48.50	3.96		7.56	0.17		5.42			

The chemical composition of the POFA from Malaysia and Thailand, clearly shown that Silicon dioxide (SiO_2) have range weight percentage from 50 to 70%, the Alumina is varied according to the location. Dominic had researched the chemical composition of the POFA around Johor, Pahang and Carey. The findings showed that silicon dioxide (**SiO_2)** varies from 49% to 72% and it does not contain any Alumina (**Al_2O_3)** (Galau and Ismail 2015)**.** According to Hassan's finding the POFA from Malaysia and Thailand having 66.91% and 55.7% of **SiO_2** respectively (Thomas, Kumar, and Arel 2017)**.** Sanawung's finding shown the **SiO_2** in the POFA that was 55.4% (Sanawung et al. 2017. The reinforcement of light metal opens up the possibility of application of POFA in areas where weight reduction has the priority, and the precondition is the improvement of the component properties (Bhandare and Sonawane 2013).

The mechanical and tribological properties of MMCs increased when the agro waste materials were having Alumina (Al_2O_3), Silica (SiO_2), and Silicon Carbide (SiC). Therefore, the chemical composition analysis of the Agro-Industrial waste to be reinforced for selected matrix need to be identified (Chandla, Kaushik, and Jawalkar 2017). The focus of the study is to explore possible use of light, cheap and abundant reinforcement materials to improve mechanical and tribological performance of the composite materials.

2.7 Fabrication Methods of the MMC

Fabrication methods of the metal matrix composites (MMCs) depend on the type of matrix as well as the reinforcement material. MMCs are materials with less density and higher specific properties such as tensile strength and hardness. Preetkanwal studied the most common fabrication techniques of the MMCs at large scale industrial level. The synthesis of the MMCs depended on many factors including the matrix temperature during processing, extent and reinforcement loading and desired degree of the materials. Refer to Figure 2.7; there are two categories of the states of fabrication of the composites liquid and solid state (Bains, Sidhu, and Paya 2015).

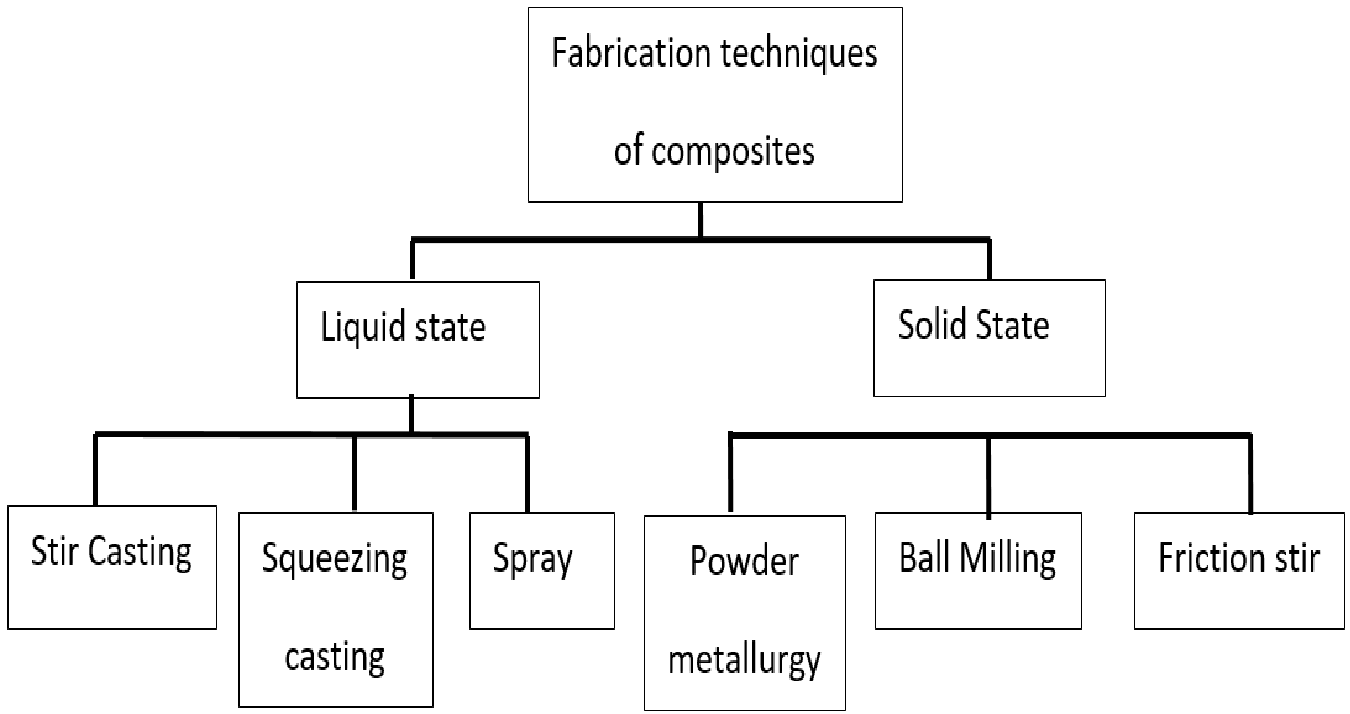


Figure 2.7 Fabrication techniques of the Metal Matrix Composites

2.7.1. Liquid State Methods

The mixing or fabrication of MMC was done when the matrix is in a liquid state. There are three methods under liquid state; stir casting, squeezing and spray casting. Normally the product of the fabrication is non-homogeneity due to mixing the reinforcement materials by random metal stirred, the flow chart for the general liquid state for fabrication as in Figure 2.8. At first, the metal and ceramic need to pre-heating then mixed in a furnace by using metal stirrer. Die casting, permanent mold casting or sand casting were the choices of the casting of the specimens for the mechanical or tribological test.

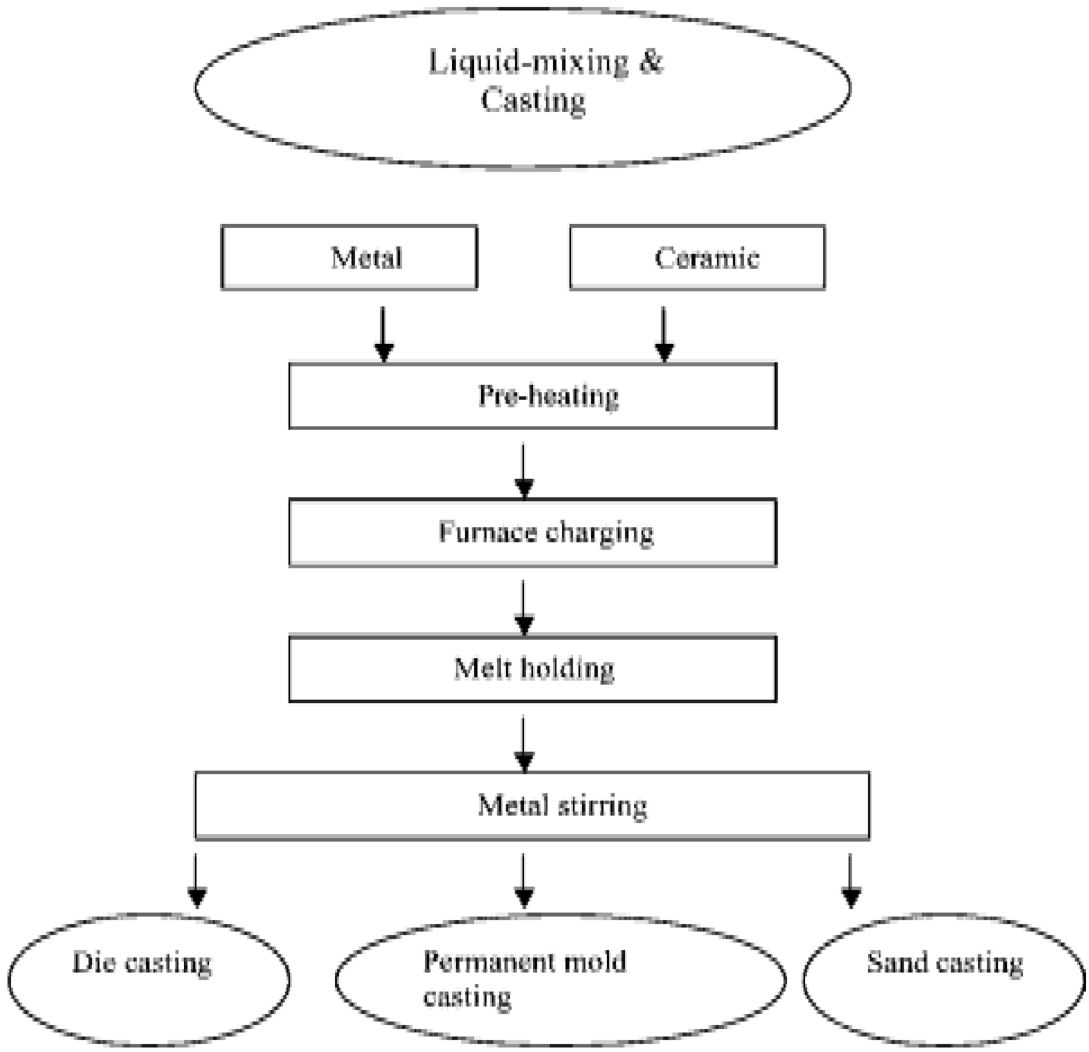


Figure 2.8: Flow chart of Liquid State Casting Process
(V. K. Sharma, Singh, and Chaudhary 2017)

2.7.1.1 Stir Casting Method

The stir casting process, reinforcement is added into the liquid molten matrix, and then it solidifies as an MMCs as shown in Figure 2.9. The method is simple, economical, and applicable for mass production. Poor interfacial bonding, wettability, and non-uniform reinforcement distribution are observed to some extent (Mistry and Gohil 2018).

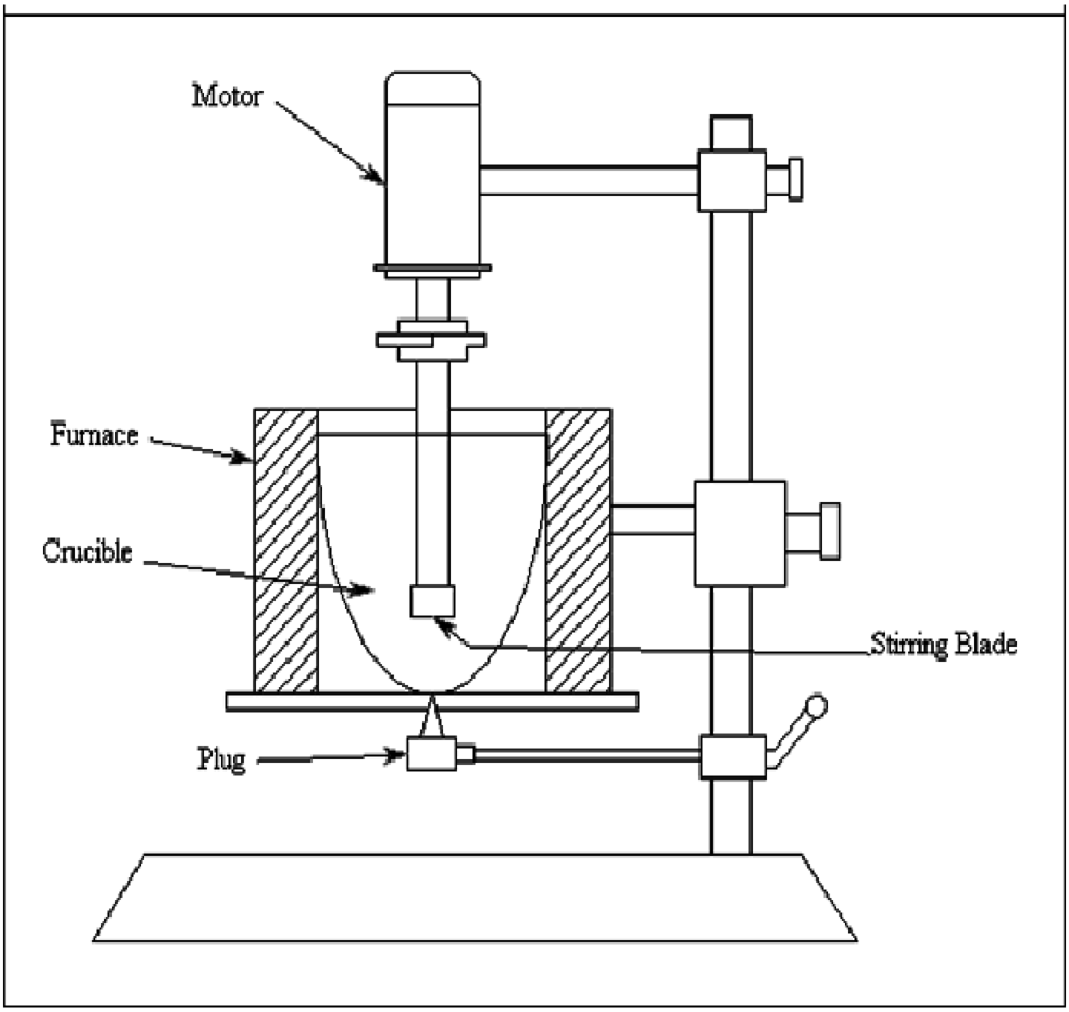


Figure 2.9: Schematic diagram of the stir casting machine
(Algur, K, and Chikmeti 2014)

2.7.1.2 Squeeze Casting (SQ Process)

Molten metal is forced under pressure into particulate pre-form to produce MMCs. The matrix material with the required additives is melted in a crucible, and the reinforcing element is preheated separately. Finally, molten metal is poured on to reinforcement, and simultaneously, a pressure is applied through a ram as illustrated in Figure 2.10. The main benefits of this process are the minimum interfacial reaction of the matrix with reinforcement, low shrinkage, and the ability to fabricate complex shapes (Mistry and Gohil 2018).

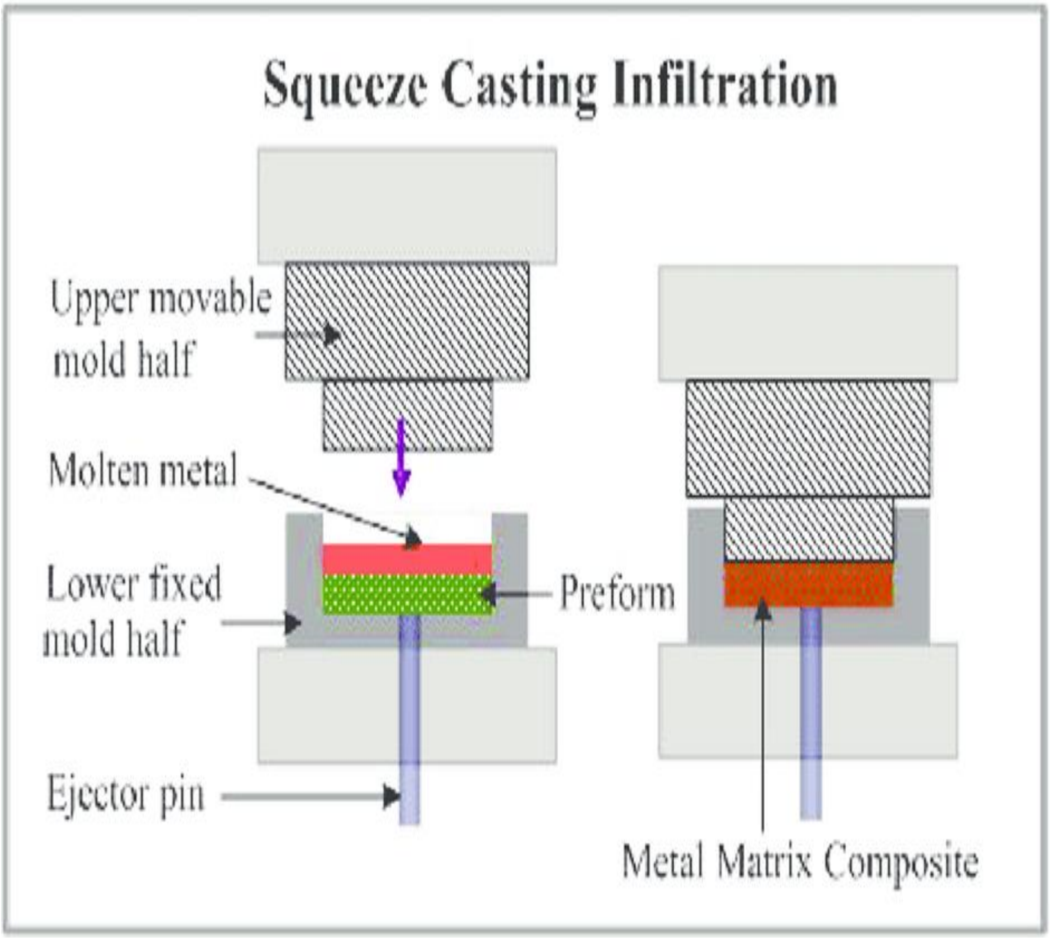


Figure 2.10: Schematic Diagram of Squeeze Casting Technique (Mistry and Gohil 2018).

2.7.1.3 Spray Casting / Spray Co-Deposition

Melted metal and liquid stream are atomised; a fine solid powder is formed due to the rapid solidification of the metal. The state technique is modified by co-depositing the reinforcing element with the matrix as shown in Figure 2.11. The higher production rate and lower, solidification time promote a minimum reaction of the matrix with reinforcement. Particles distribution in the composites depends upon the size and percentage of the reinforcement (Mistry and Gohil 2018).

2.7.2. Solid State

Well establish methods in solid-state processes included powder metallurgy, ball milling and friction stir. The MMCs fabricated possesses more homogeneous microstructure to compare to those fabricated by casting technique (Bains, Sidhu, and Paya 2015).

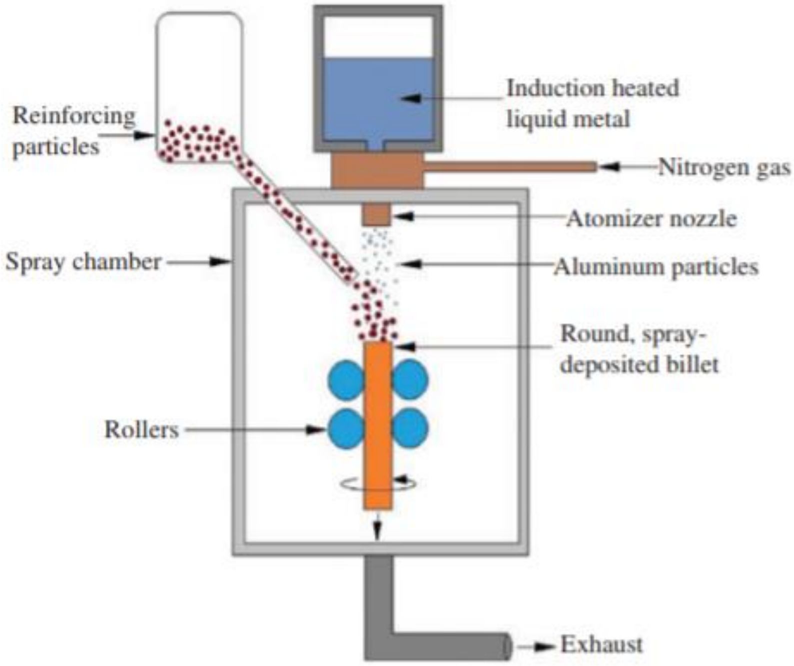


Figure 2.11: Schematic diagram of Spray casting (Mistry and Gohil 2018).

2.7.2.1 The Power Metallurgy

The power metallurgical processes involved pressing and sintering or forging of the powder mixtures and composites powders (Karner, 2006). The flow chart of the Powder metallurgy shown in Figure 2.12 and the schematic diagram in Figure 2.13

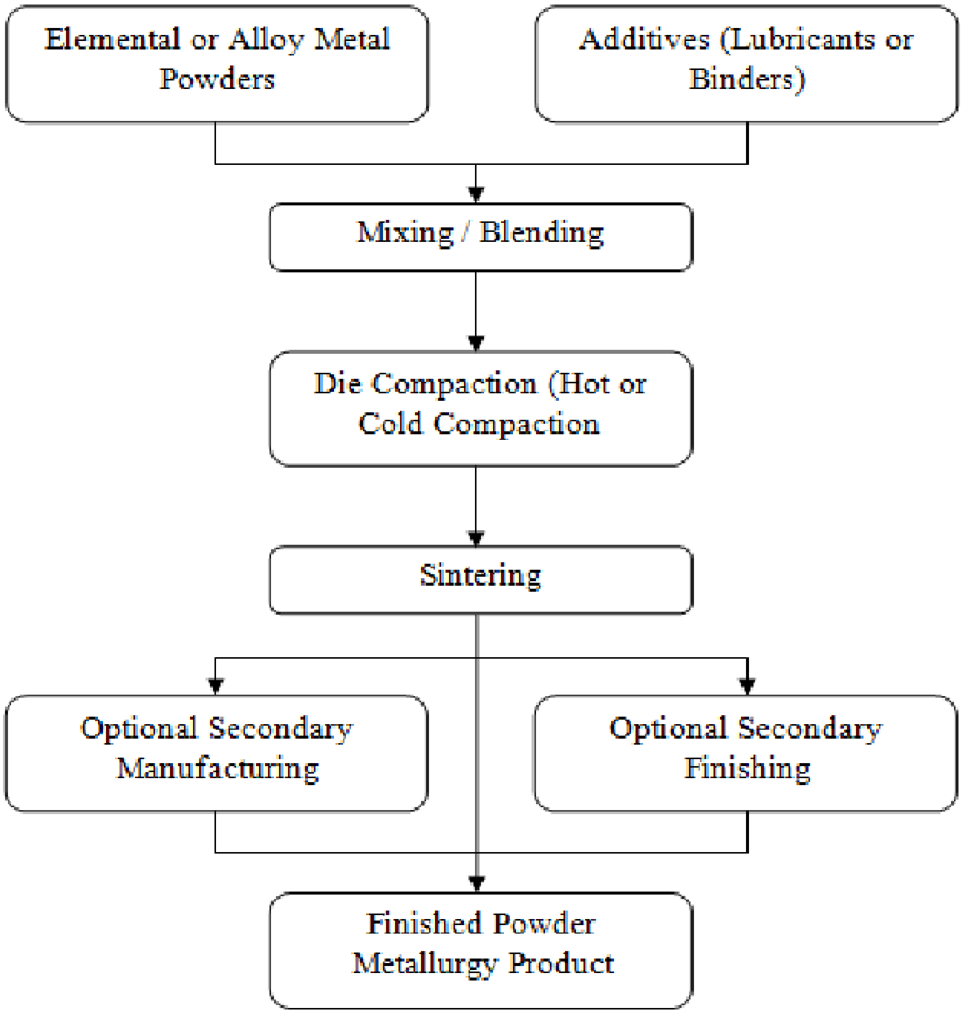


Figure 2.12: Flow chart of powder metallurgy process (Abd Rashid et al. 2014)

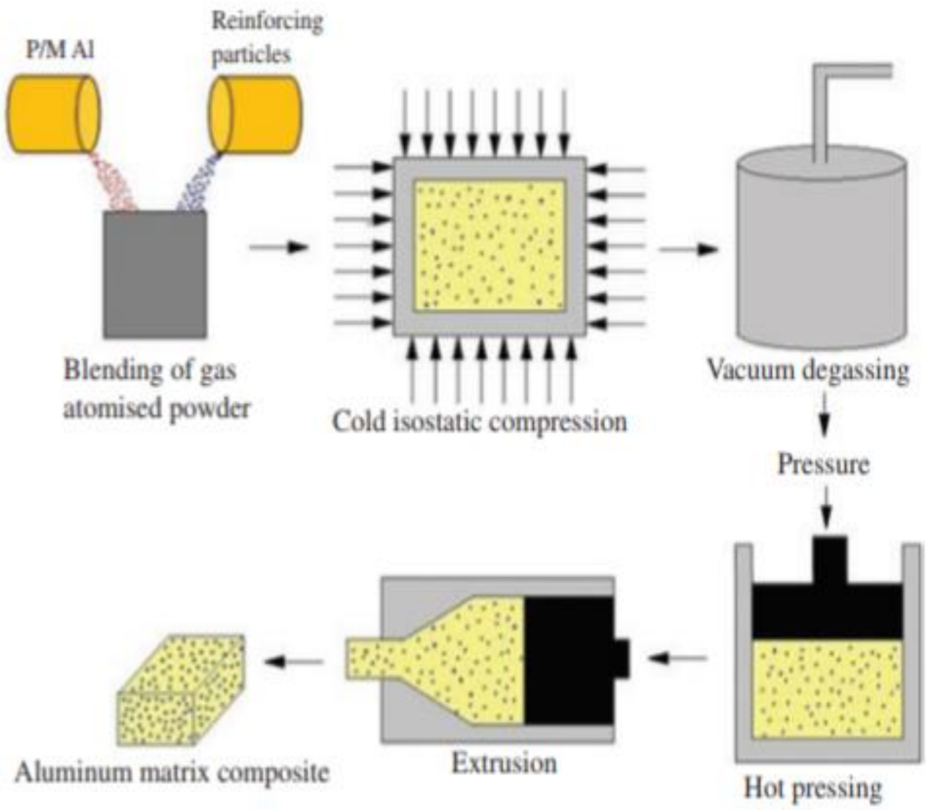


Figure 2.13: Schematic Diagram of Powder Metallurgy technique
(Mistry and Gohil 2018).

2.7.2.2 Ball Milling Process

Ball milling is a selected process to prepare composites of graphene nanoplatelets (GNPs) and epoxy. The findings mostly focus on enhanced the properties due to thermal. The reinforced materials normally uniformly dispersed in the composites (Guo and Chen 2014).

2.7.2.3 Friction Stir Processing

Friction stir processing (FSP) is solid-state processing which works on a single work-piece instead of joining two pieces together. The addition of a small number of nanoparticles significantly enhanced material properties. The stirring motion can uniformly disperse the nano-size particles in MMC. However, they have a tendency to agglomerate in clusters, in friction stir processing, the synergistic effect of stirring, extrusion and forging resulted in refinement of grains, reduction of reinforcement particles size, uniformity in particles distribution, reduction in microstructural heterogeneity and elimination of defects(Mistry and Gohil 2018).

2.7.3 The Choice of the Fabrication Method of MMC

Uniform mixing of reinforcement in the matrix should be ensured in the MMC fabrication method (Sijo and Jayadevan 2016). Table 2.8 shows the summary of the production of MMCs; the matrix, its reinforcement and fabrication method related to the studies. Concerning Table 2.8, the literature review showed that the most popular choice of fabrication of MMC for Aluminium alloy as a matrixis stir casting method. Stir casting of composites first started by S. Ray in 1968. The author introduced the Alumina particles into molten Aluminium while stirring (Ray 1969). Stir casting is generally preferred over other methods due to its applicability, simplicity, flexibility and a large quantity of production over other manufacturing methods.

It is also suitable because it reduced the final cost of the product and allowed substantially sized components to be fabricated (Bhandare and Sonawane 2013). During the stir casting process, major problems associated are non-uniform particles mixing and entrapments of oxides and other impurities into the molten matrix from the environment. In order to overcome these problems, reinforcement particles preheating was done and to reduce the formation of oxides, inert gases such as argon, helium was respectively used(Kumar R., J., and L. 2014). The particles' uniform distribution in the molten matrix mainly depends on density, geometry, position and speed of the mechanical stirrer, melt temperature and wetting condition of the particles with the melt.

Table 2.8: The summary of MMCs and their fabrication method

Matrix	Reinforcement	Reference	Fabrication (Fabrication method)
AL 7075	SiC	(Balaji, Sateesh, and Hussain 2015)	Stir casting
ZR2.5Nb	SiC	(Shedbale et al. 2017)	Stir casting
Aluminium alloy Al-4.5% Cu	Bamboo leaf ash (BLA)	(B. P. Kumar and Birru 2017)	Stir casting
Magnesium sheet	CNT	(Isaza Merino et al. 2017)	Sandwich technique
AL 2219	Boron Carbide	(Ravindranath et al. 2017)	Stir casting
Al 6061	TiC	(Pandey et al. 2017)	Stir casting
Aluminium	Fly ash	(V. K. Sharma, Singh, and Chaudhary 2017)	Stir casting
Al 6082	Fly ash & SiC	(Reddy and Srinivas 2018)	Stir casting
Nickel	RHA and Sugarcane	(Dele-Afolabi et al. 2018)	Powder method
Aluminium alloy AL-Si (LM30)	Sillimanite	(S. Sharma, Nanda, and Pandey 2018)	Stir casting
Aluminium LM6	SiO_2	(Hamouda et al. 2007)	Induction furnace
Aluminium alloy 6063	SiC	(Kashan 2010)	Stir casting
Pure Aluminium	SiC	(Singla et al. 2009)	Stir casting
Pure Aluminium	(Fe_3O_4,	(Bayraktar and Katundi 2010)Supmeca, 2010	Blended powder compacted
Aluminium alloy Cu-Zn-Mg (700series)	Alumina (Al_2O_3)	(Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar 2011)	Stir casting
Aluminium alloy	SiC	(Sozhamannan1, Prabu, and V. S. K. Venkatagalapathy 2012)	Stir casting
Pure Aluminium	Alumina (Al_2O_3), & magnesium oxide (MgO)	(Mohsin and Dixit 2017)A.R.I. Khader et. al., 2011	Stir casting
Al 6061	Graphite & SiC	(N, Nagaral, and Auradi 2012)	Stir casting
Al 6063	Alumina (Al_2O_3)	(Rathod and Purohit 2013)	Stir casting
Aluminium alloy	SiC	(Pargunde et al. 2013)	two steps of stir casting

Wettability is the ability of a liquid to spread on a solid surface, which is another problem associated with MMCs. Magnesium (Mg), Calcium (Ca) and Titanium (Ti) are generally added to the molten matrix to ensure the wettability. Amongst them, Magnesium (up to 2wt.%) is added to molten Aluminium to reduced wettability (Nirmal, Hashim, and Ahmad 2015) (Agarwal, Patnaik, and Sharma 2013).

In general, the incorporation of the reinforcement in the matrix was responsible for the improvement in some mechanical and tribological properties of the MMC. The factors were due to the uniform distribution of the reinforcement in the molten matrix mainly depends on density, geometry, position and speed of the mechanical stirrer, melt temperature and wetting condition of the particles with the melt matrix.

2.8 The mechanical and tribological properties of the ALMMCs

The Flexural properties of Aluminium metal matrix composites are preferred over other materials due to its properties like greater strength, improved hardness improved wear resistance, reduced density and etc. (Ramnath et al. 2014). Researched on MMC's attracted the researches more as they become one of the most important structural materials depending on the requirement (Gireesh et al. 2018). Effective of utilization the reinforcement materials in industries reduce cost and size materials while increasing the performance in the strength , corrosion resistance, easy fabrication process and etc.(Elanchezhian et al. 2018). The automotive industry is subjected to increasingly restrict fuel economy requirement by customers, demanding improved comfort and safety. The development of advance material parts with improved performance and efficiency (Mavhungu et al. 2017). The research on some of the properties of materials (refer to ALMMCs) which critical for aircraft are tensile strength, hardness and impact strength (Bidari et al. 2017). Another the flexural properties of the ALMMCs, was carried out on hot forged for the preparation of the specimens according to ASTM standards (Narayan and Rajeshkannan 2017). The overall mechanical and tribological properties of ALMMCs increased when high strength ceramic particles as reinforcement are added to ductile Aluminium (Sozhamannan1, Prabu, and V. S. K. Venkatagalapathy 2012). Table 2.9 showed, in the summary of their findings of MMC, that most mechanical and tribological properties improved compared to base metals. The findings showed that when pure Aluminium or any of its wrought (2000, 6000 and 7000) is used as the matrix material and reinforced with Alumina (Al_2O_3), Titanium Carbide (TiC) Graphite (Gr), Silicon Carbide (SiC) and Sillimanite, the ALMMCs enhance the mechanical and tribological properties (Phanibhushana, Chandrappa, and Niranjan 2017) .

Focusing on the utilisation of the Agro-Industrial waste as reinforced materials in ALMMC, Table 2.10 showed the findings of mechanical and tribological properties. Fly ash as an industrial waste by-product become a top of the list in Table 2.10 as reinforcement to ALMMC. The choice to used fly ash (FA) as reinforcement in ALMMCs because of its low density, availability and presence of a good amount of silica or silica dioxide (SiO2) and Alumina (Al_2O_3) content, as mentioned in Table 2.7 (chemical composition) of the agro waste. The Fly ash (FA) as reinforcement to ALMMCs can alter cost as well as improved mechanical and tribological properties. Table 2.11 also showed that the mechanical and tribological properties increased when the reinforcement of the size and percentage volume used, at 2-100 µm and 2-30 % respectively (N. K. Chandla et al., 2017).

Referring to findings (Table 2.9 and 2.10) shown, the mechanical and tribological properties of the ALMMCs depended on the selected Aluminium alloy as matrix and nature or types, volume or weight fractions or percentage, distribution and orientation of the reinforcement. The mechanical and tribological properties of the ALMMCs are influenced by the nature of fibre factor, homogeneity, fibre-matrix interface, diffusion process, the presence of porosity and agglomeration (Clyne and Withers 1995).

Table 2.9: Summary of the mechanical and tribological properties AL MMC

Matrix	Reinforcement	Reference	Remarks
Aluminium alloy 6063	SiC	(Kashan 2010)	◆ Increase in the hardness by the decrement of SiC and the optimum, at 15 % SiC
Pure Aluminium	SiC	(Singla et al. 2009)	◆ Uniform dispersion of reinforcement in the ALMMC ◆ Increase in hardness: the impact strength by an increment of the composition of SiC
Aluminium alloy Cu-Zn-Mg (700series)	Al_2O_3	(Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar 2011)	◆ There were increases in all mechanical properties by the increase of an Alumina. ◆ Tensile strength increased only up to 10% of alumina and elongation up to only 12%.
Aluminium alloy	SiCp	(Sozhamannan1, Prabu, and V. S. K. Venkatagalapathy 2012)	◆ The Charpy impact test for a composite that matrix is Al-10% reinforced by SiCp slightly increased with an increment in the processing temperature. ◆ The test results revealed that the distribution of the particles in the matrix was seen in SEM
Al 6061	Graphite & SiC	(N, Nagaral, and Auradi 2012)	◆ The hardness increase by increasing the wt. % of SiC ◆ The hardness reduced by increasing the by wt. % of graphite ◆ SiC and graphite increased its dry sliding by wt. %
Al 6063	Al_2O_3	(Rathod and Purohit 2013)	◆ The tensile strength, yield strength, and hardness increased with increase in V% of Al_2O_3
AL 7075	SiC	(Balaji, Sateesh, and Hussain 2015)	◆ The density of ALMMC was higher that AL 7075 alone. ◆ Results produced a uniformed distribution of ALMMC. ◆ The hardness increased with increase in SiC and max at 10% of SiC. ◆ The tensile strength of ALMMC is better than AL 7075 alone. ◆ The tensile strength of reinforcement by SiC was better than Alumina.
AL 2219	Boron & Graphite	(Ravindranath et al. 2017)	◆ The wear rate increase by increased load and sliding distance.
Al 6061	Titanium Carbide (TiC)	(Pandey et al. 2017)	◆ Wear rate reducing in linear form increased the vol. fraction of TiC. ◆ The mean reduced linearly by vol. fraction of TiC.
AL6061	SiC	(Sijo and Jayadevan 2016)	◆ The hardness, tensile strength and impact result increased by increased in wt. % of SiC from 5 % to 15%.
Aluminium alloy AL-Si (LM30)	Sillimanite	(S. Sharma, Nanda, and Pandey 2018)	◆ Uniformed distribution by SEM ◆ Wear loss reduced by sliding distance ◆ Low values of applied load & sliding distance, the abrasive wear was predominant ◆ At higher applied load and longer sliding distance, the adhesive wear was the main reason for the material loss.
AL alloy	Al_2O_3 & Graphite	(Radhika, Subramaniam and Venkat Prasat 2011)	◆ The BHN of the MMC increased with increment % of reinforcement content

Table 2.10: The utilisation of the Agro-Industrial waste in ALMMC with their findings

Matrix	Reinforcement	Reference	Remarks
AL 356	Fly Ash(FA)	(Itskos et al. 2012)	◆ The tensile strength was reduced by the increment vol.% of fly ash ◆ The tensile strength increased by the size of fly ash.
Pure Aluminium	Fly Ash(FA)	(Shanmughasundram, Subramaniam, and Prabhu 2012)	◆ The hardness and compressible strength of new composites were found to increase with increased fly ash content but decreased when contains above 20wt% of fly ash.
Al-Si alloy	RHA and Fly Ash(FA)	(Senapati, Nanda, and Satapathy 2016)	◆ MMC reinforced by fly ash shows better properties of tribology properties than RHA.
Pure Aluminium	SiC and groundnut shell (GSA)	(Alaneme, Bodunrin, and Awe 2016)	◆ Overall the mechanical and fracture properties better compared to composite reinforcement by RHA and BLA
Al 6063	Fly Ash(FA)	(Mohammed Razzaq et al. 2017)	◆ The bulk density of ALMMC reduced by increased % of the fly ash ◆ The Charpy impact strength reduced by increased % of the fly ash
Pure Aluminium	fly Ash (FA) and Aloe Vera AV	(Gireesh et al. 2018)	◆ The ultimate tensile strength of AMC-AV is higher compared to that AMC-FA.

2.8.1 Tensile Strength

The tensile strength is the most common mechanical properties of the materials. The wrought of Aluminium alloy, such as 6000 and 7000 were chosen as matrix and is reinforced by Alumina (Al_2O_3), Silicon Carbide (SiC) and Graphite (GR). Table 2.11 shows that most tensile strength of ALMMCs increased by aggregating the volume or weight portion of reinforcement materials,(Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar 2011;Niranjan et al. 2017;Sijo and Jayadevan 2016) and for some, it is increased by the size of the reinforcement (Meena et al. 2013).

The main factor of the increased the tensile strength of the AL MMCs is sufficient amount of reinforcement added to the metal matrix during fabrication. The amount of reinforcement is to make sure that the function of the matrix is to hold the fibres as reinforced materials together as well as to protect the fibres. If the volume or weight of the reinforcement percentage is more than matrix capacity, then the tensile strength decreased(Ling 1999).

The microstructures of the ALMMC specimens in Figure 2.14 showed a different percentage of Alumina as a reinforcement material. The findings have shown that the tensile strength of ALMMC increased as Alumina increased from 2. 5% to 10%, but after 15% of Alumina added the tensile strength decreased. Figure 2.15(d) revealed the findings that the black agglomeration more compared to the others (a), (b) and (c) (Muhammad Hayat Jokhio et al., 2011).

Table 2.11: Summary of reported work on AL MMC from Agro-Industrial waste

(Chandla, Kaushik, and Jawalkar 2017)

Reinforcement Material	Matrix Material	Wt./ Vol.%	Particle size (μm)	Reinforcement Density (g/cm^3)	Improved as reported properties
Rice Husk Ash	AlSi10Mg	3-12	50-75	0.3-1.6	UTS-(167-174) MPa BHN-(60-80)
	A356.2	2-8	37-63		UTS-(285-312) MPa BHN-(70-83)
	Aluminium Can	4-12	53-75		UTS-(230-271) MPa BHN-(54-60)
Sugarcane Bagasse Ash	Al–Cu–Mg	2-10	-	1-7-2.2	UTS-(152-229) MPa HRB-(43-70)
	Al-7% Si alloy	5-30	-		UTS-(168-178) MPa HRV-(74-92)
	Al-10% Si alloy	10-30	-		UTS-(165-180) MPa BHN-(73-82)
Coconut Shell Ash	Al-Si-Fe alloy	3-15	-	1.6-2-2	Wear rate (3.5 $x10^{-3}$ g/m - 7.2 x 10^{-3}g/m) @ 10-50 N load. BHN-(65-78)
	AA-6063	3-12			UTS-(58-85) MPa HRB-(35-42)
Groundnut Shell Ash	Al-6063	3-12	-	1.7-2.6	UTS-(135-158) MPa VHN-(55-70) UCS-(175-250)MPa
	Al–Mg–Si alloy	6 and 10	-		UTS-(130-160)MPa
	al-4.5% cu	5-15	2-10	2.2-2.82	UTS-(110-120)MPa UCS-(550-780)Mpa
	Al 6061 alloy	10-20	25-100		UTS-(122-134)MPa
Fly Ash	Aluminium	5-20	0.1-100		TS-(578-588)MPa HRA-(53-69)
Red Mud	Al-7075 alloy	2-8	-	2.4-2.8	UTS-(118-60) MPa UCS-(57-47) BHN-(121-70)

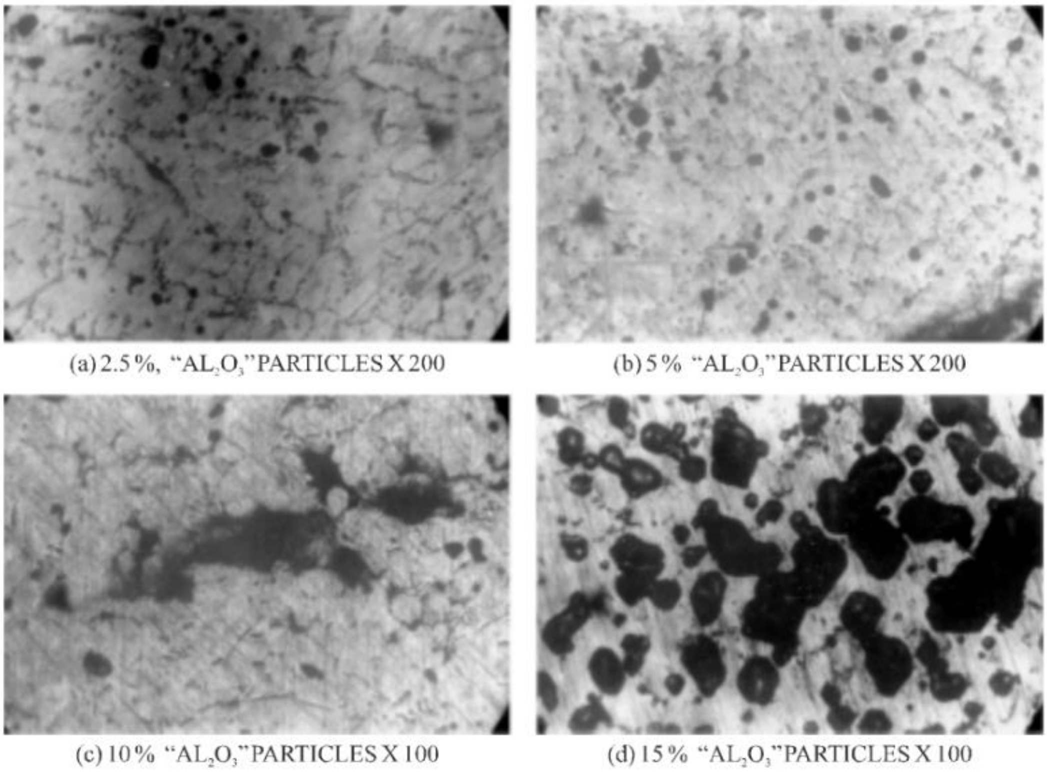
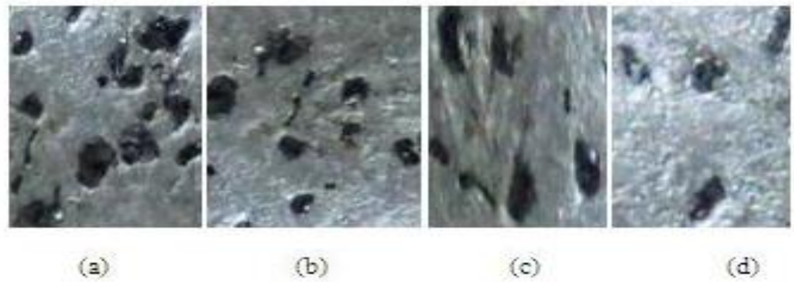


Figure 2.14: The microstructure of ALMMC specimen reinforced by different % Alumina (Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar 2011).

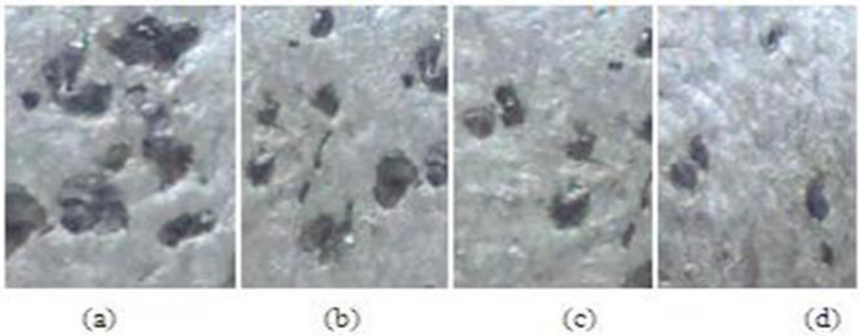
2.8.2 Impact Strength

Another important mechanical property of the ALMMC is the impact strength or toughness of the material. The total amount of energy that a material can absorb, and it is directly related to the brittleness of the material and brittle material tend to have lower absorption rates compared to ductile materials like copper and Aluminium. Similar factors to tensile strength, the impact strength is also influenced by sizes and volume or weight percentage or portion to their matrix (Ling 1999). The impact strength of ALMMC decreased with the increase in reinforced particulate size (220mesh, 300mesh and 400mesh) and increased with increase in weight fraction (5%, 10%, 15% and 20%) of SiC particles.

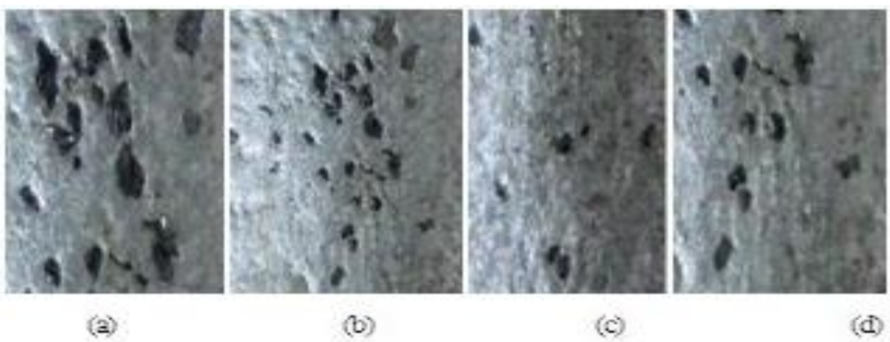
The maximum impact strength about 37.01 Nm has been obtained at 20% weight fraction of 400mesh size of SiC particles, refer to figure 2.15 (d). The micrograph of AL/SiC in Figure 2.17, the MMC's sample from the cylindrical cast bar was taken for different sizes and weight fraction of SiC particles shown in Figure 2.15. A 0.5% HF solution was used to etch the samples, to see the distribution of SiC particles in ALMMC. Optical micrographs showed a reasonably uniform distribution of SiC particles (Meena et al. 2013).



i) For size 220 mesh: (a)wt. 5%SiC, (b) wt. 10%, (c) wt. 15%, (d) 20%



ii) For size 300 mesh: (a)wt. 5%SiC, (b) wt. 10%, (c) wt. 15%, (d) 20%



iii) For size 400 mesh: (a)wt. 5%SiC, (b) wt. 10%, (c) wt. 15%, (d) 20%

Figure 2.15: The microstructure of the specimens of ALMMC reinforce by wt. % and the sizes of the reinforcement of SiC (Meena et al. 2013)

2.8.3 Hardness of the MMCs

An essential property of engineering materials is hardness; it is based on resistance to permanent deformation, in the form of penetration or indentation. The hardness is the measure of material's resistance to localised plastic deformation, and the microstructural of the composite is explained distribution of the reinforcement material in the matrix to reveal the hardness result and the wear behavior that measures the weight loss of the composites under certain conditions as well as the coefficient of friction for the composites. The penetration distance of material has represented the hardness of the material. The findings indicated that the lesser the penetration, the harder the materials (Black, A, and Kohser 2008). Table 2.17 shows the finding relating to the hardness of the ALMMC. Mostly, the findings showed that the hardness increased by increasing the volume or weight percentage of the reinforcement materials except that Jenan and Preshant showed that the hardness decreased by increasing the reinforcement materials (Kashan 2010).

Shedbale had studied the effect of particle volume fraction, particle size and particle distribution on the indentation behaviour of MMC using extended finite element approach. The MMC consists of matrix ZR2.5Nb reinforcement by Silicon Carbide (SiC) for different volume fraction, size and shape of SiC as reinforcement. The present simulations observed that the mean indentation depth decreased with the increase in particle volume fraction, and decreased with a decrease in particle sizes (Shedbale et al. 2017).

It is clearly shown in Table 2.12 that all findings showed that the hardness of MMC increased by increasing the percentage of reinforcement. Maximum 15% of the volume or weight percentage of reinforcement can be added to the matrix for fabrication of the ALMMC. Figure 2.16 showed the microstructural (SEM) of 3 specimens of MMC, where magnesium sheet as matrix and CNT with three different weight percentages as reinforcement. Figure 2.16 (a) with 0.25 wt. % and b) 0.5w. % CNT, the interface clearly shown on the specimen. However, the 1.0wt. % interface was blurred. The author concluded that the outstanding properties could be only explained if a good interfacial bonding between MWCNT and matrix exists (Isaza Merino et al. 2017).

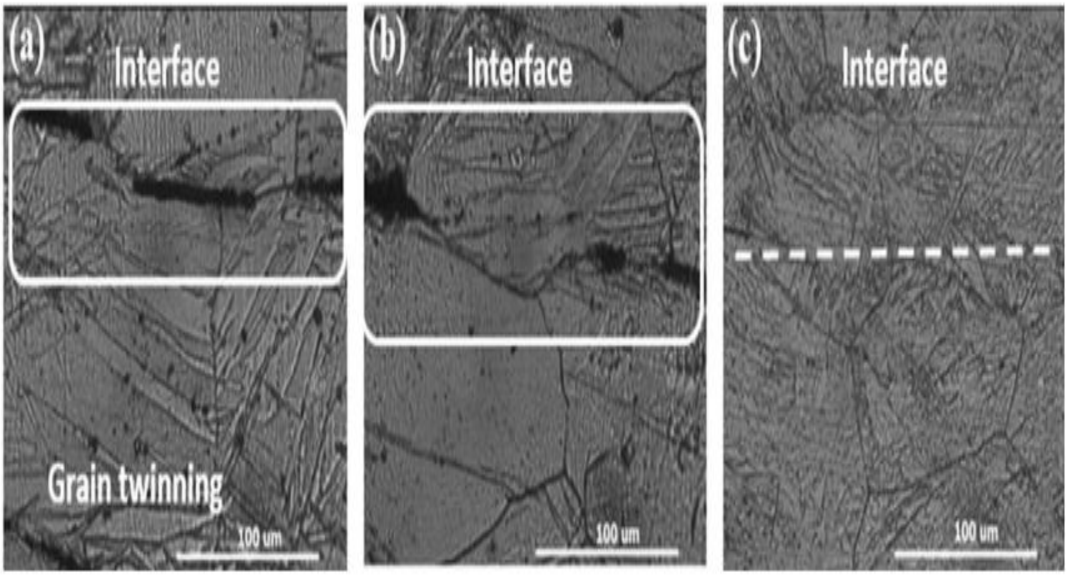


Figure 2.16: The microstructure of specimens of magnesium sheet reinforced with CNT0.25 wt.%, b) 0.5wt.% and 1.0wt.% (Isaza Merino et al. 2017) .

Table 2.12: The hardness of ALMMCs by its reinforcement materials

Matrix	Reinforcement	Reference	Remarks
Aluminium alloy 6063	SiC	(Kashan 2010)	◆ The decree use of SiC achieved in the increase of the hardness and reached its optimum at 15 % SiC.
Pure Aluminium	SiC	(Singla et al. 2009)	◆ Increased in the hardness was achieved by the increasing of the composition of SiC
Al 6061	Graphite & SiC	(N, Nagaral, and Auradi 2012)	◆ The hardness increased by the increase of wt. % of the SiC ◆ The hardness reduced by the increase of the wt. % of graphite
Al 6063	Al_2O_3	(Rathod and Purohit 2013)	◆ The hardness increased by the increase in V% of Al_2O_3
AL 7075	SiC	(Balaji, Sateesh, and Hussain 2015)	◆ The hardness increased by the increase of SiC and reached its optimum at 10% of SiC.
ZR2.5Nb	SiC	(Shedbale et al. 2017)	◆ The mean indentation of MMC is reduced by the increase of Vol.% and decreased by particles sizes.
AL6061	SiC	(Sijo and Jayadevan 2016)	◆ The hardness result increased by the increase in weight % of SiC from 5 % to 15%.
AL alloy	Al_2O_3 & Graphite	(Radhika, Subramaniam and Venka Prasat 2011)	◆ The BHN of the MMC increased with the increase % of reinforcement content.
AL 6063	SiC	(Meena, Manna, and Banwait 2013)	◆ The HRB increased by the increase of reinforced particulate sizes, as well as the weight fraction.
Aluminium alloy 356	fly ash	(Itskos et al. 2012)	◆ Their hardness increased as their fly ash content increase

2.8.4 Wear Behaviour

The tribological properties of the material illustrated the gradual loss of material that is due to friction during the relative motion of bodies and is caused by interfacial mechanical force (Fisher 2009). The wear resistance and strength of a material can also be evaluated by assessing its “hardness” as an important property, which affects wear resistance of any metal (Radhika N. and R. 2014). The composites properties provide exciting opportunities for designing an exceedingly large variety of materials with property combinations that cannot be met by any of the monolithic conventional metal alloys, ceramics, and polymeric materials. The wear mechanism of composites can be measured by its wear rate by temperature, sliding distances, sliding velocity, duration/time of rubbing and load. The analysis of the coefficient of friction μ of the materials showed the correlation between the hardness of the material to mass or volume loss of the sample. The higher the value of the coefficient of friction μ, the harder the materials (Callister, G, and Rethwisch 2011).

Author used two loads applied to the specimen of ALMMC with 2N and 5N, and the 2N illustrated better results, which was less of weight lost during wear mechanism test. The findings showed that the reduced the weight loss of the ALMMC by increasing the percentage of the melon shell as reinforced material (Abdulwahab et al. 2017). The reduction of the ALMMC area (same as mass or weight loss with known density) decreased with the increment in particulate sizes (220mesh, 300mesh and 400mesh) and increased with the increment in weight fraction (5%, 10%, 15% and 20%) of SiC particles (Meena et al. 2013). Sharma’s findings showed that the wear resistance increased by the increase in the percentage of fly ash as reinforcement and Aluminium as the matrix (V. K. Sharma, Singh, and Chaudhary 2017). Saravanakumar fabricated the ALMMC using Aluminium alloy AA2219 as matrix and reinforced by Graphite powder (Gr). The worn out surface due to dry sliding showed that the wear rate decreased by increasing of % of the Gr (Saravanakumar, Sivalingam, and Rajesh 2018).

The finding of ALMMC consisted of AL 2219 as matrix and reinforced by 8% of Boron, and 3 % of Graphite was shown that the wear rate increased by increasing the applied load and sliding distance. Figure 2.17 showed the microstructure of the worn out surface ALMMC after completing the sliding distance.

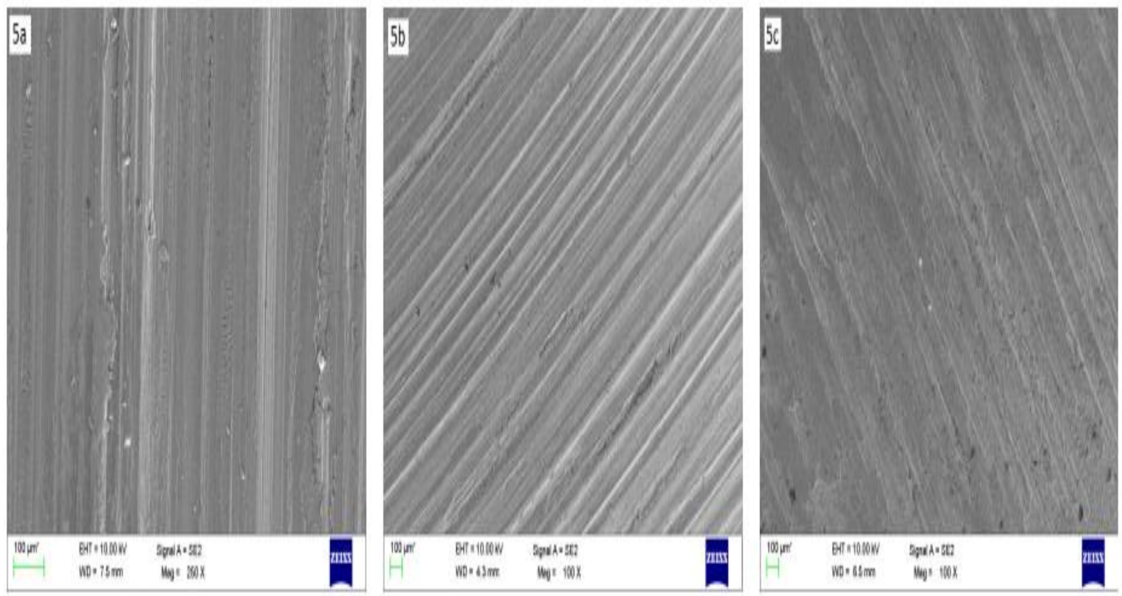


Figure 2.17: Worn out surface ALMMC consisted of AL 2219 as matrix and 8% of Boron and 3 % of Graphite (Ravindranath et al. 2017)

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The findings revealed good bonding with no evidence of debonding at the particle-matrix interface from the worn out surface of the alloy and composite (Ravindranath et al. 2017). The author found that the ALMMC that consisted of AL 6061 as the matrix and reinforced by SiC and Al_2O_3; the wear rate was reduced by the increase in volume content of reinforcement materials (K, S.T., and K 2011). Figure 2.18 (a) showed the COF is reduced by increasing the load for three samples of composites The author mentioned that this may be due to softening of the surface of the composite caused to frictional induced heat between sliding surface. Figure 2.18b (b) showed the sample II and III having negative value. This may be due to the oxide layer, which acted as a protective shield by preventing the metal to metal contact. The information of microstructure will reveal the performance of the mechanical and physical properties of the materials as well as the new product of MMC (Xavier and Suresh 2016).

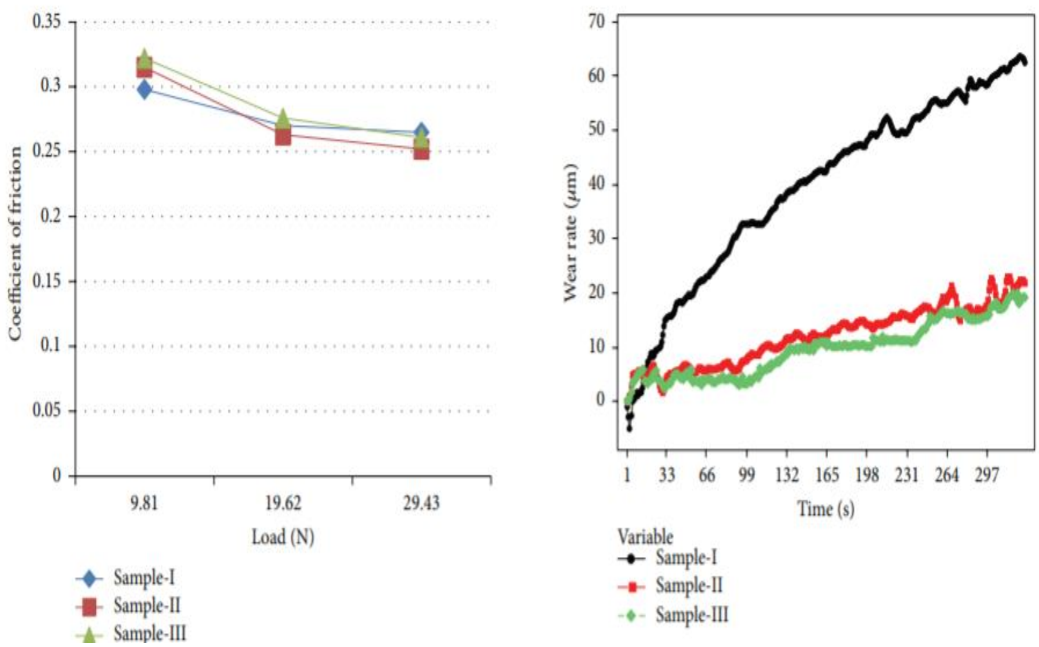


Figure 2.18(a): The COF of the three samples of composites by the load (Xavier and Suresh 2016)

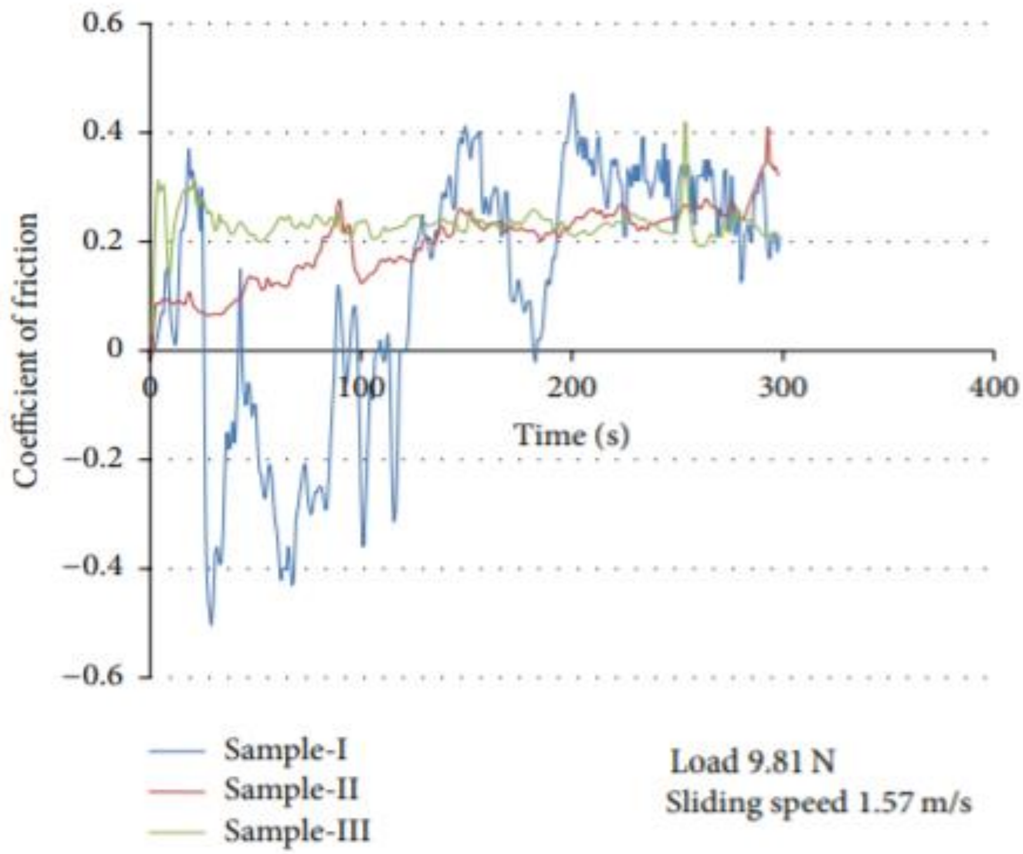


Figure 2.18(b): The COF versus sliding time of the three sample of composites (Xavier and Suresh 2016)

2.9 Summary

Through a detailed review on classification Metal Matrix Composites (MMC), it revealed that the Aluminium metal matrix (ALMMC) reinforced by agro-Industrial waste through stir casting method for fabrication could be successfully done. The information and behaviour of different agro-industrial waste may assist to further investigate on the development of ALMMCs. So far fly ash, rice husk ash, bagasse ash, groundnut ash and other agro-industrial were used/ as reinforcement to pure Aluminium or Aluminium alloy as matrix to ALMMCs. POFA as recorded in Table 2.6. Mostly POFA only used as reinforced in new product of the concrete (Hamada et al. 2018) (Thomas, Kumar, and Arel 2017); POFA never used as reinforced material to formed MMC. The broad conclusion had been drawn for taking the challenge and opportunity to study the possibility of new ALMMC by utilising the Agro-Palm oil fuel ash (POFA), as follows:

- Aluminium alloy is widely used in industrial structure parts requiring a certain strength and very important is high corrosion resistance. AL 6061 was the choice of the matrix for a new MMC's due to its basic properties; which could be easily applied through alloy, temper and fabrication process.

- Utilizations of the Agro-Industrial waste can solve the problem of storage and disposal of ash, which a serious issue related to the environment. The chosen local POFA as a reinforcement material for a new ALMMC is due to it being one of the most common Agro-Industrial waste in Malaysia.

- Studies have shown that the percentage of Alumina (Al_2O_3), Silicon (SiO_2) and Silicon Carbide (SiC) as reinforcement in ALMMC had proven the increase of the mechanical and tribological properties. Therefore, the chemical composition of POFA needs to be identified prior to fabrication.

- The incorporation of Agro-Industrial waste in ALMMC proved their worth as weight saving and cost-effective material, as well as also responsible for the improvement in some of the mechanical and tribological of the composites such as density, hardness, tensile strength, impact and wear.

- In order to investigate the correlation of mechanical and tribology properties of ALMMCs, the variable of the three (3) different sizes and also three (3) different volume percentage of the POFA will be chosen.

- Economic utilisation of the POFA could enhance the energy efficiency of Malaysia as the country is the second highest of Palm oil production in the world. The possibility also provides alternative engineering materials in composites application.

- The outcome may be an added value option for a palm oil factory in managing the waste, the cost of disposal of the waste as well as the solution to air and water pollution. These solutions will be the long term solution for palm oil factory as well as global for agriculture countries.

CHAPTER 3: EXPERIMENTAL PROCEDURE

3.0 Introduction

Preparation of the new specimen of the MMC's depends on types of matrix and its reinforcement material. The study of the preparation of the mixing process clearly stated in the literature review, in order to produce the new product of MCC's accordingly. Lately, Aluminum has become an economic competitor in engineering and would play a role as an automotive material. An Aluminum was the choice as the Matrix due to its basic properties; could easily be applied through alloy, temper and fabrication process. Moreover, its light compared to steel in which its density is one third that of steel. Aluminium also has a high strength-to-weight ratio as well as high resistance to corrosion. The mechanical, physical and chemical properties of aluminium alloys depend on its chemical composition and microstructure (Davis J.R 1999).

3.1 Experiment Procedure

The two selected materials to be MMC's are Aluminium alloy that is AL6061 as matrix and palm oil fuel ash (POFA) as a reinforcement material. The literature review shows that the suitable fabrication method is stir casting method. Figure 3.1 shows the general steps of the experiment procedure, starting from the preparation of the materials that were matrix and reinforcement materials until the analysis of the mechanical and tribological properties of AL MMC.

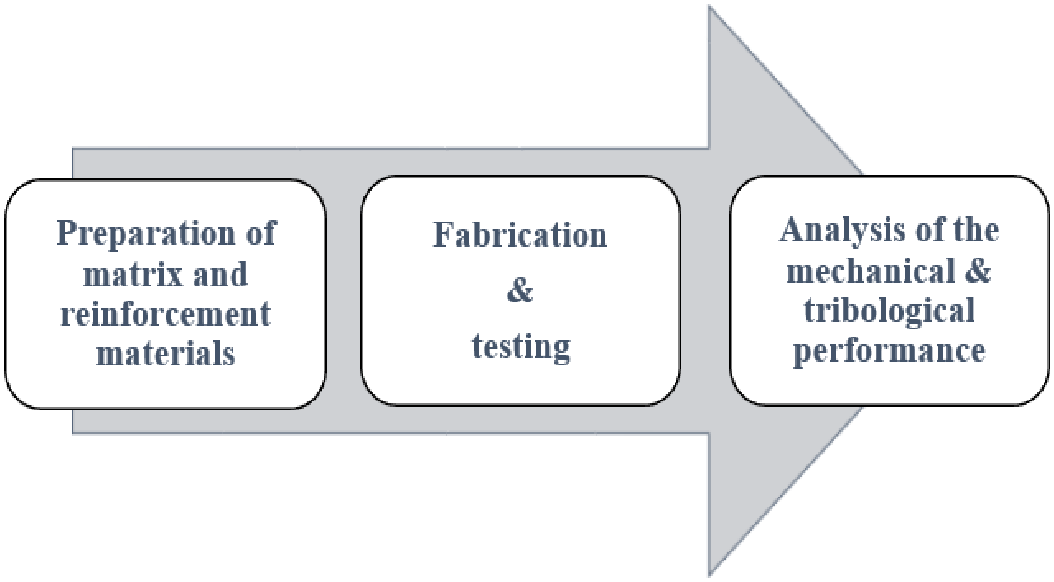


Figure 3.1: The general three steps of the experimental procedure for the production of ALMMC

The detail of the experimental procedure was shown in figure 3.2, starting from the preparation of the matrix and reinforcement materials, followed by fabrication parameters of the ALMMC and final stage is mechanical and tribological testing their properties.

3.1.1 Aluminium 6061

The AL 6061 was chosen in which Magnesium and Silicon are the principles alloying elements. Substantial strengthening and improvement are made apparent through the use of Magnesium, which provided the work-hardening characteristic of Aluminium. The Al 6061 consisted of Aluminum, Manganese and Silicon as 98.4%, 1.0% and 0.6% respectively(Davis J.R 1999).

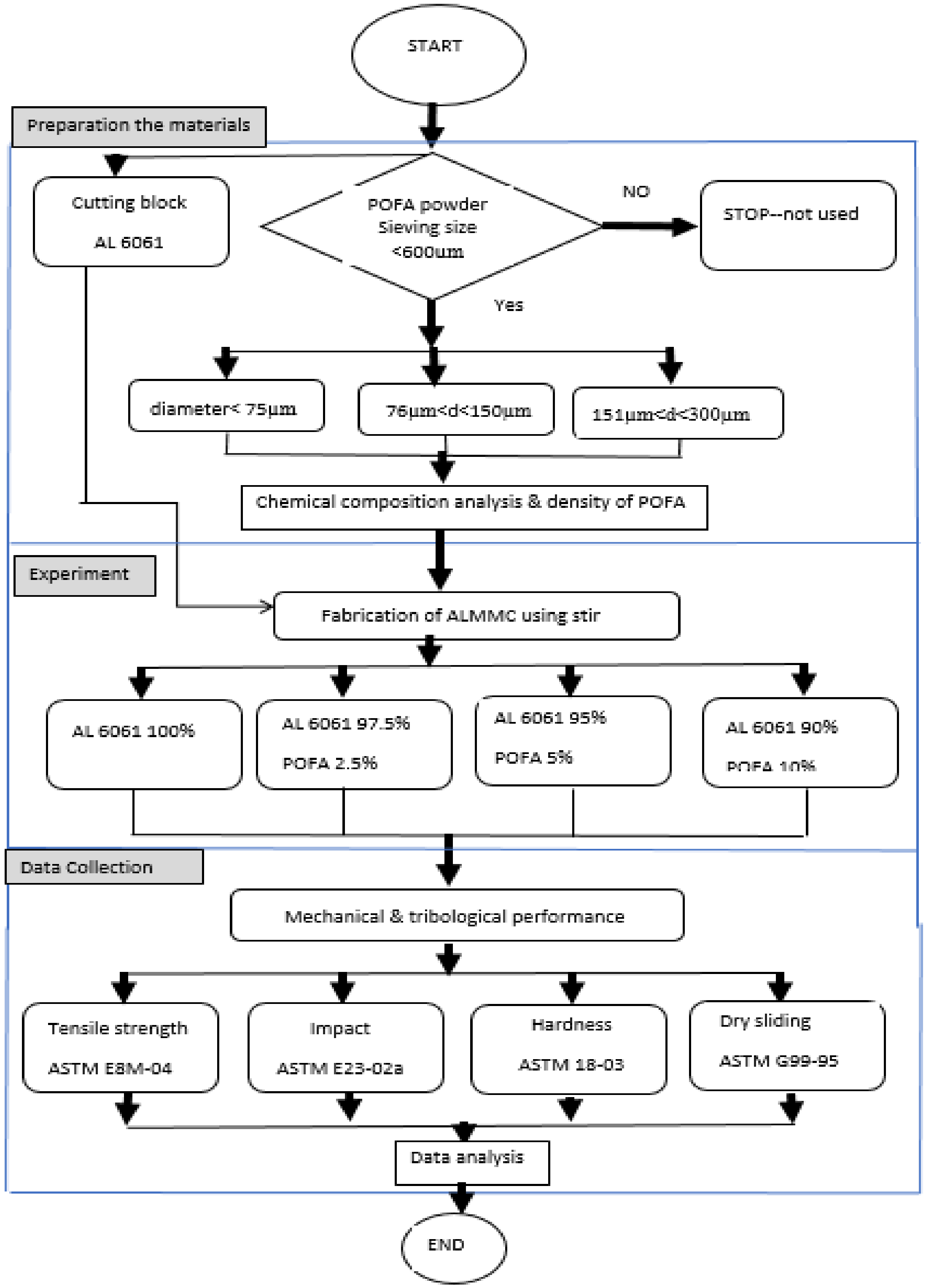


Figure 3.2: The experiment procedure of the production of AL MMC

3.1.2 Palm oil fuel ash (POFA)

Palm Oil Fuel Ash (POFA) was collected from the Palm oil factory had separated their wastes into four categories, there are four (4) types of Agro-industrial waste produced by palm oil industries, i.e. fibres, kernel or shell, empty fruit bunches and seeds. Figure 3.3 shows the palm oil waste.

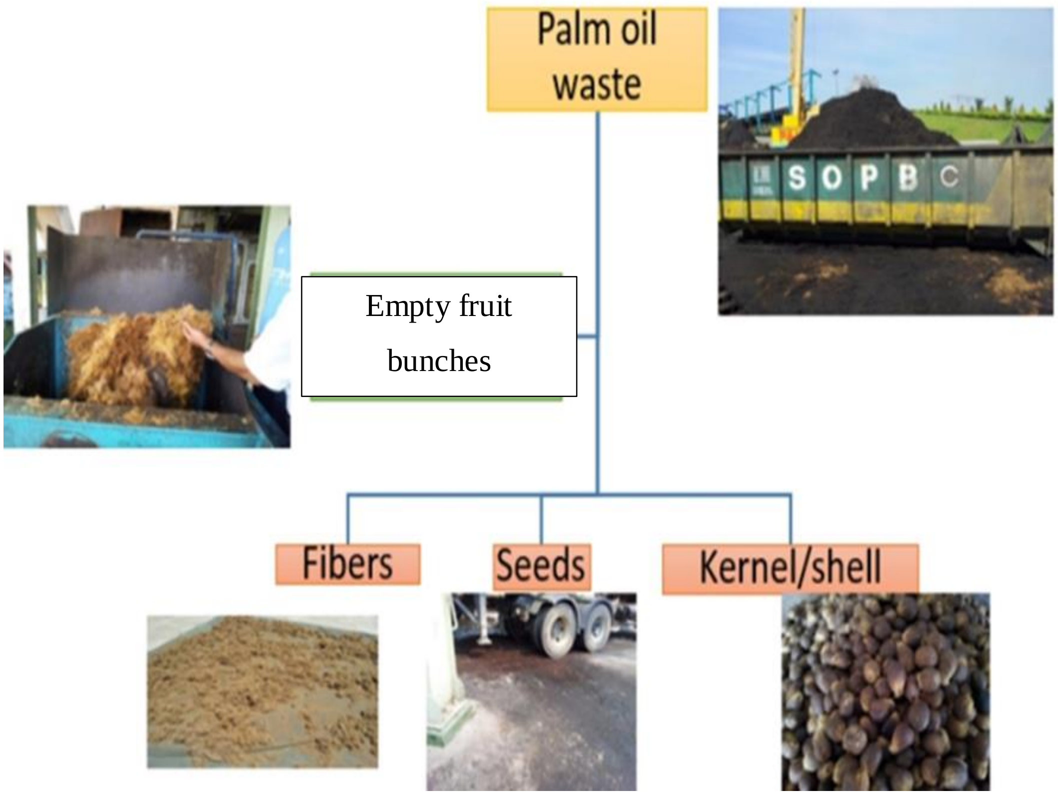


Figure 3.3: The palm oil waste has four types and are separated waste

The obtained POFA (fibres and empty fruits bunches) is relatively moist when it was released from the chamber. At first, the raw POFA was dried under the sun. Then it was sieved using 600µm size, more than the size will release as not used as shown in Figure 3.4.

Figure 3. 4: POFA after sieving with 600µm filter

After that POFA smaller size than 600µm was grinded by using grinder machine (with parameter100mm steel ball at 150rpm). As a result, the size of the POFA reduced as well as the surface area increased. Finally, the grinned POFA was heated at 200^{o}C for 2 hours before sieving. For this project three sizes of sieving that are 300µm, 150µm and 75µm, therefore the POFA sizes collected are less than 75µm, between76µm to 150µm and 151µm to 300µm. The complete sieving process is shown in figure 3.5. Precaution need to be made, where the process should be done on a sunny day. POFA is easily become moisturised by the humid weather, so avoid the process during the raining season to make sure that the dried POFA then will be ready for fabrication.

The chemical composition and the density of the POFA by different sizes need to be determined. The step is crucial as info to reveal the data analysis of the ALMMCS.

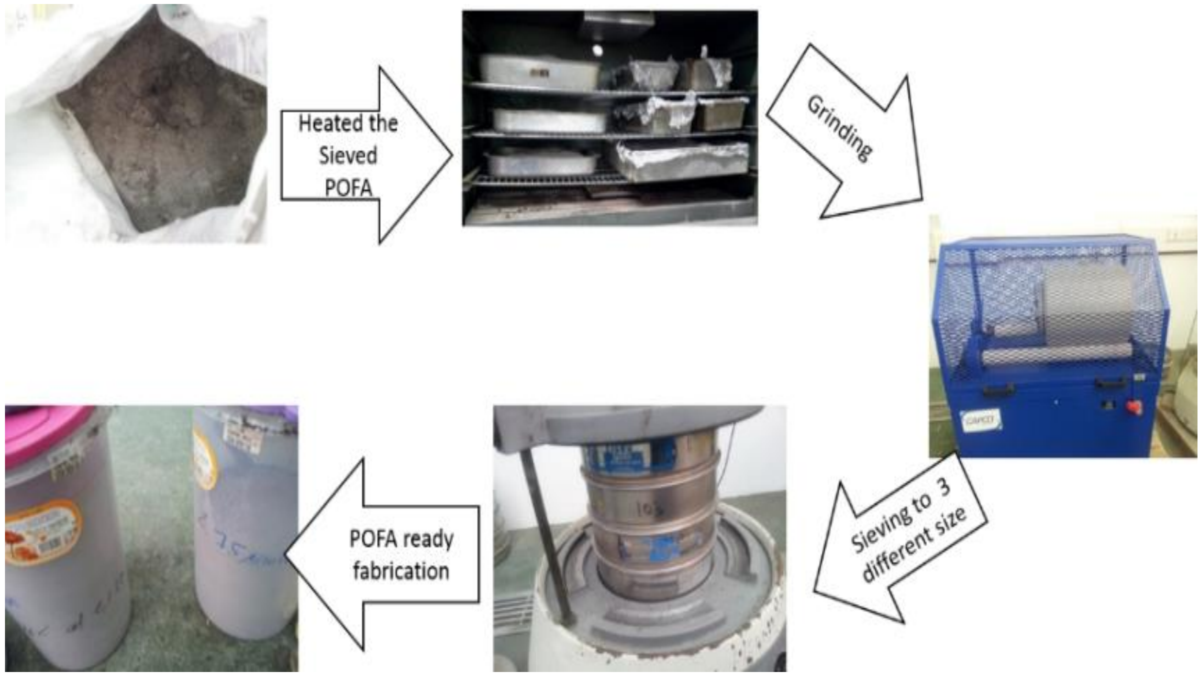


Figure 3. 5: Sieving process of the POFA

3.1.3 The Chemical Composition and Microstructural Analysis of the POFA

The chemical compositions of the POFA were identified before the fabrication process using the XRF (X-ray Fluorescent-model EDX 720) as shown in Figure 3.6. The chemical composition of the POFA as reinforcement material will provide to analyze the mechanical and physical properties of new ALMMCs. The step to identifying the chemical composition such as SiC, SiO_2, Al_2O_3 or other chemicals that can reveal the increase or decrease the mechanical and tribological performance of the new product of ALMMC. The detail result of the chemical composition of the POFA as a reinforcement material and AL6061 as a matrix will be discussed in Chapter 4.

The microstructural analysis of ALMMC's was conducted by using Gemini SEM 500 (Scan Electron Microscope -Carl Zeiss Microscopy GmbH) as shown in Figure 3.7.

Figure 3. 6: XRF machine for chemical composition of the POFA.

Figure 3.7: Gemini SEM 500(Carl Zeiss Microscopy GmbH) for chemical and microstructural analysis of the specimens.

The next step is the preparation of the parameters for the fabrication of new ALMMC with AL 6061 as matrix and POFA as a reinforcement material.

3.2 Preparation of the Fabrication of the AL MMC Composites

The step of identification of the parameters become prerequisites before the fabrication procedure of the ALMMCs. Clearly shown in Figure 3.8 the parameters of POFA as a reinforcement material for new ALMMC are as follows:

i) Three (3) different sizes, less than 75µm, between76µm to 150µm and 151µm to 300µm.
ii) Density for each size of POFA
iii) Three (3) different volume portion or each size of POFA

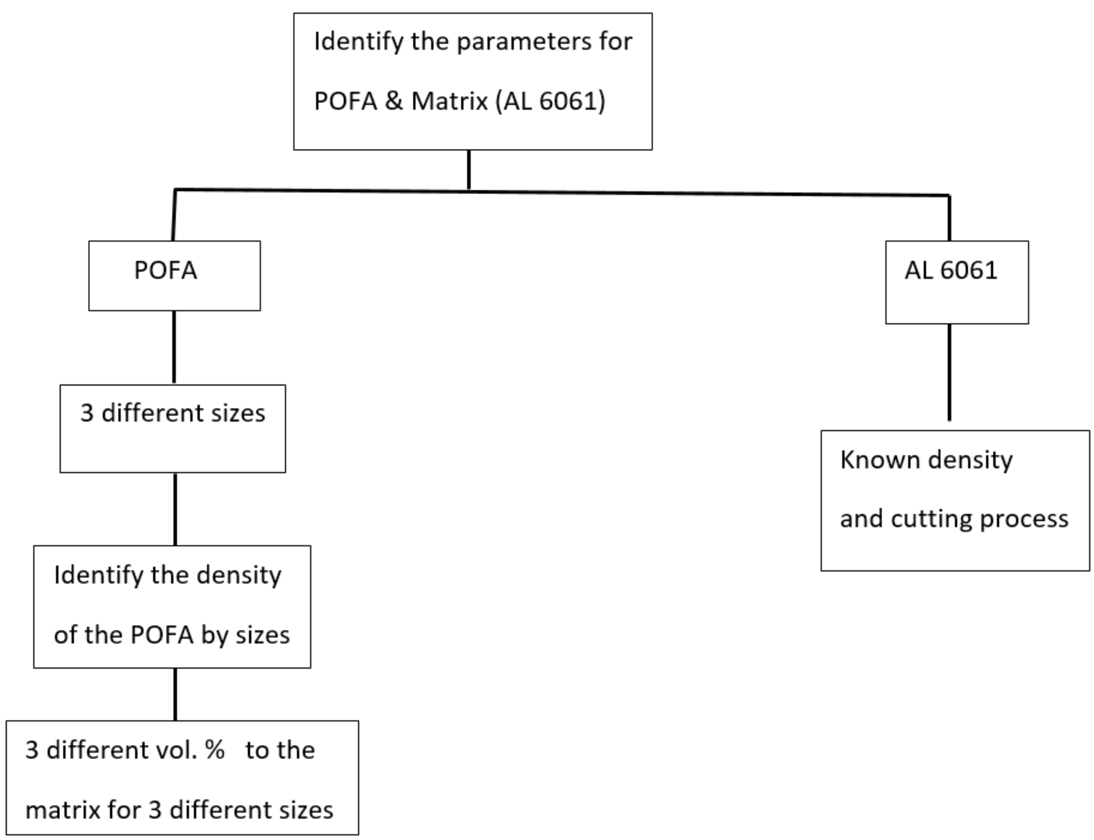


Figure 3.8: Experiment and fabrication of the ALMMC

The density of the POFA of different sizes is shown in figure 3.9. It was observed that 76µm to 150µm sizes of POFA provided the highest density which is 0.88 g/cm^3. In order to determine the optimum mix of the POFA and AL6061, the POFA volume percentage was chosen from 0% as a reference and followed by 2.5 vol.%, 5.0vol.% and 10vol.%.

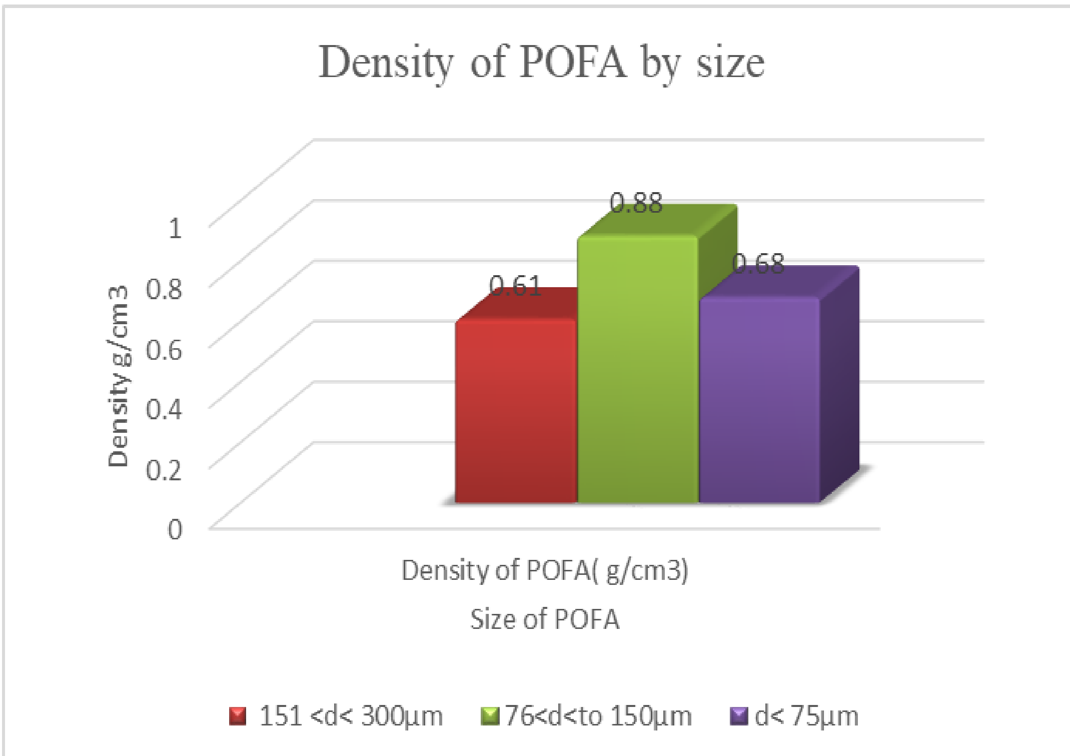


Figure 3.9: The density of POFA for different sizes

The different density of POFA by its sizes was due to the chemical composition. The details of chemical composition of POFA by different sizes was stated clearly on chapter 4 (refer to Table 4.2, 4.3 and Figure 4.2) shows the correlation of density of POFA and the percentage weight of SO_3 (Silicon trioxide). Table 3.1 shows the list of specimens with a different volume percentage of POFA together with the percentage volume of AL6061 to be prepared for fabrication. Due to the dissimilar density of the POFA for different sizes, the calculation of POFA volume needs to be prepared before fabrication due to the mass of the AL 6061 block.

Table 3. 1: List of the samples for the mechanical and physical properties

	Sample Name	*Al6061*	*POFA*
0 Reference sample	*Al-MMC 100*	*100%*	*0%*
Sample type 1 (POFA diameter<75μm)	*Al-MMC 120*	*97.5%*	*2.5%*
	Al-MMC 150	*95%*	*5%*
	Al-MMC 110	*90%*	*10%*
Sample type 2 (POFA diameter 76 to 150μm)	*Al-MMC 220*	*97.5%*	*2.5%*
	Al-MMC 250	*95%*	*5%*
	Al-MMC 210	*90%*	*10%*
Sample type 3 (POFA diameter 151 to 300μm)	*Al-MMC 320*	*97.5%*	*2.5%*
	Al-MMC 350	*95%*	*5%*
	Al-MMC 310	*90%*	*10%*

3.2.1 Fabrication of the ALMMC

Stir casting method was used to fabricate AL MMC samples. Before starting the fabrication, matrix materials were cut to a smaller size as shown in Figure 3.10. At first, the AL6061 block was to be put in the stir casting machine, then set the temperature of the melted at 780^{o}C for AL6061. Figure 3.11 shows the AL 6061 was melted at 780^{o}C in the stir casting furnace. At the same time, different weight percentage and sizes of the POFA were preheated at 200^{o}C. Then the heated POFA was added slowly with the melted Al 6061 to ensure the homogeneity of the composite.

After mixing with a stirrer for 10min, the molten mixture will have released in the container that withstands the heat about 800ºC. The specimen was left at room temperature for cooling, shown in Figure 3.12.

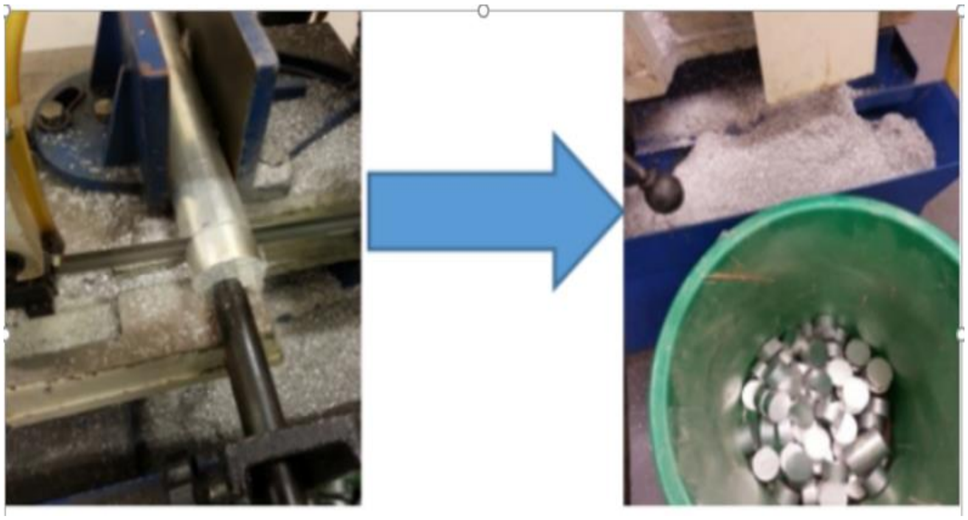


Figure 3. 10: Small blocks of AL 6061

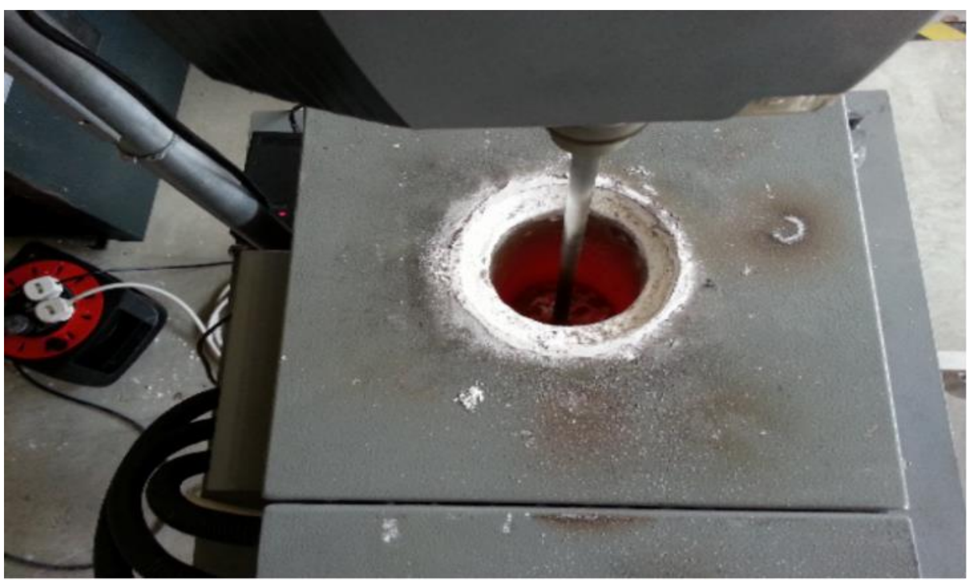


Figure 3. 11: Stir casting machine at temperature 780ºC

Figure 3. 12: The raw sample of new AL MMC

Then the specimen in Figure 3.12 was being cut according to the ASTM test stated in section 3.2.2 for further investigation.

3.2.2 Testing for Mechanical Properties

Testing the mechanical and tribological performances were lead the outcomes of the product, leads the conclusion of the studies. In this study, the tensile, impact, hardness tests and wear behavior or dry sliding of the ALMMC will be conducted at room temperature condition. The specimens were cut as follows:

For Mechanical properties:	using ASTM E 8M-04 for tensile strength, E 23-02a for impact and E 18-03 for Rockwell hardness test.
For tribological properties:	using ASTM G99-95 standard for wear dry sliding test.

3.2.1 Tensile Strength

In order to determine the tensile strength, the specimen was prepared according to the ASTM E 8M-04 standard as shown in figures 3. 13.

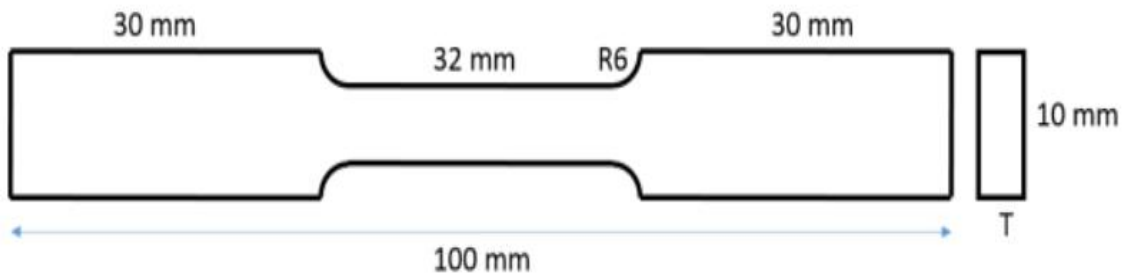


Figure 3. 13: Tensile strength specimen dimension

Figure 3. 14 shows the three (3) actual specimens were prepared for each parameter, vol.% and the size of the POFA. The detail parameters of the mixture of the between matrix (Al 6061) and POFA was stated in Table 3.1. Reference sample also prepared as Al-MMC 100; without POFA that was 100 vol. % of AL 6061. The samples of ALMMC prepared accordingly by increased the vol. % of POFA by 2.5%. 5% and 10%. There are 3 (three)samples will be cut accordingly using ASTM for the vol.% stated above, then the average value of the tensile strength will be recorded and analysis will be done for all specimen accordingly.

Figure 3. 14: Tensile test specimens

3.2.2 Izod impact test

In order to determine the impact energy, there are 3(three) the specimens were prepared according to the ASTM E 23-02a standard as shown in figure 3. 15. The test will be repeated for 3(three) times and the average value impact energy of ALMMCs by Vol. % of POFA will be discussed in Chapter 4.

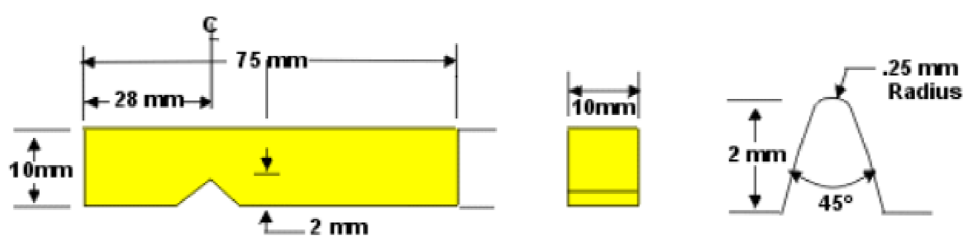


Figure 3. 15: Izod Impact specimen dimension (ASTM E 23-02a)

The Izod impact test machine model MAT/IT3U in Figure 3. 17 was used to measure the impact on new MMCs product, and the test for all the specimens with different volume percentage and sizes of POFA added as reinforcement in AL6061. The test specimen was placed to receive the blow of the moving mass, a moving mass that has sufficient energy to break the specimen placed in its path, and a device for measuring the energy absorbed by the broken specimen. The temperature of testing affects the impact properties of most materials. Therefore temperature during testing needs to be recorded. The pendulum needs to rise to the latched position at the same time the pointer also need to adjust to the negative side of zero. After pendulum released, then allow it to cycle and the value indicated by the pointer (ASTM E23-02a). The average result of the impact of the new MMC was tabulated and discussed in result and discussion section in chapter 4.

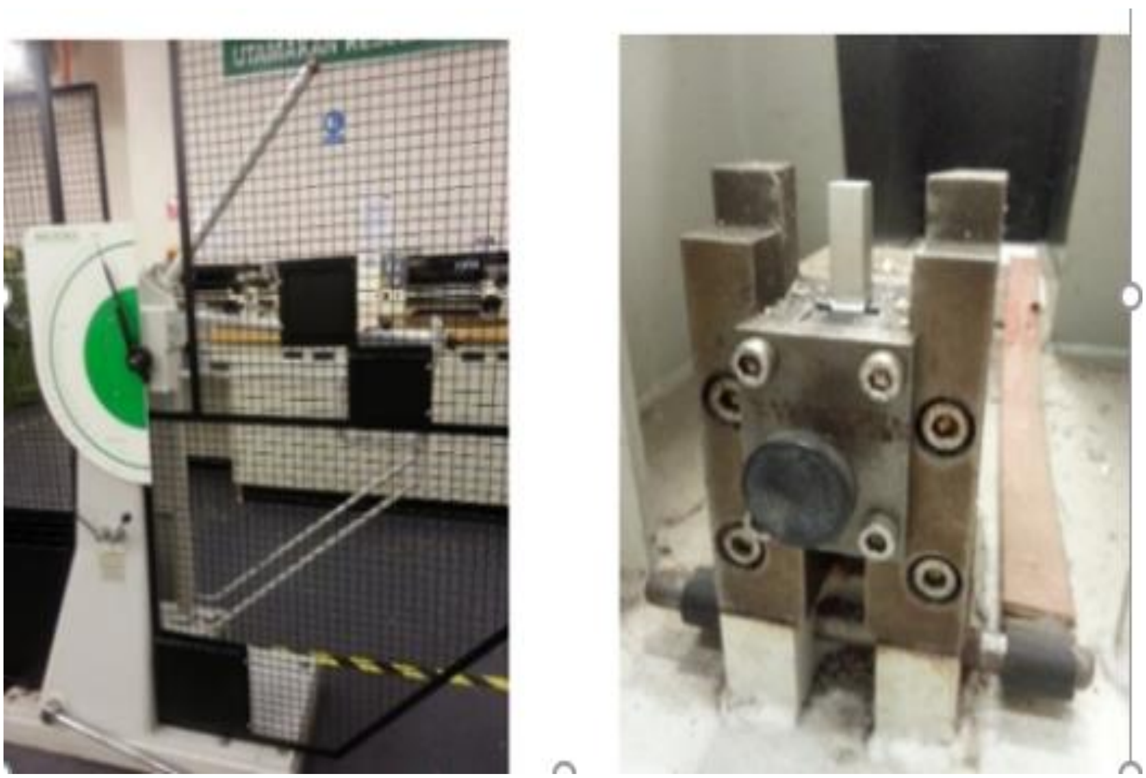


Figure 3. 16: Izod Impact test machine

3.2.3 Rockwell Hardness Test

The Rockwell hardness is a measure of the permanent penetration of load and indicates the Rockwell hardness number. The number indicates the depth of plastic or permanent penetration on the specimen refers to figure 3. 18.

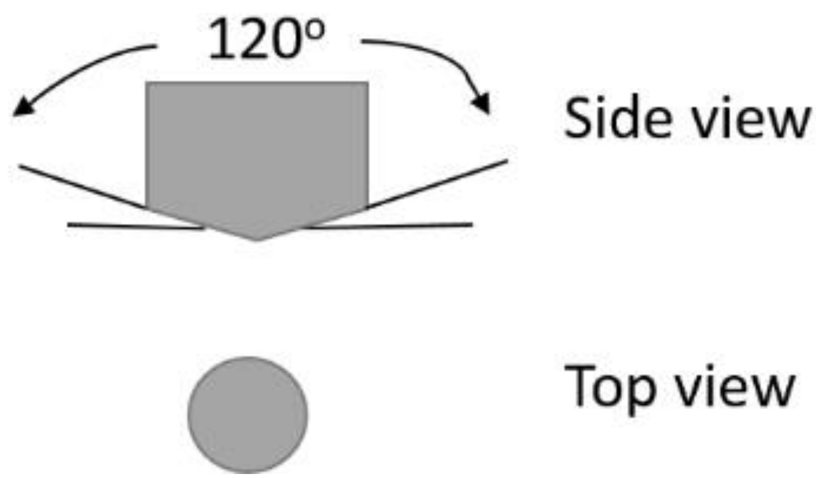


Figure 3. 17: Shape of indentation for side and top view

The hardness of the specimen was measured using model LEQLO50070 according to ASTM E 18-03 standard as shown in figure 3. 19. The Rockwell hardness value had been determined through an indentation produced under a static load of 100kgs and has been applied with indenter or penetrator size of 1/16 inch on the disk specimens. Before testing, the specimen size was prepared at 30mm diameter with a thickness of 5mm and continued to be polished to obtain a smooth surface finish.

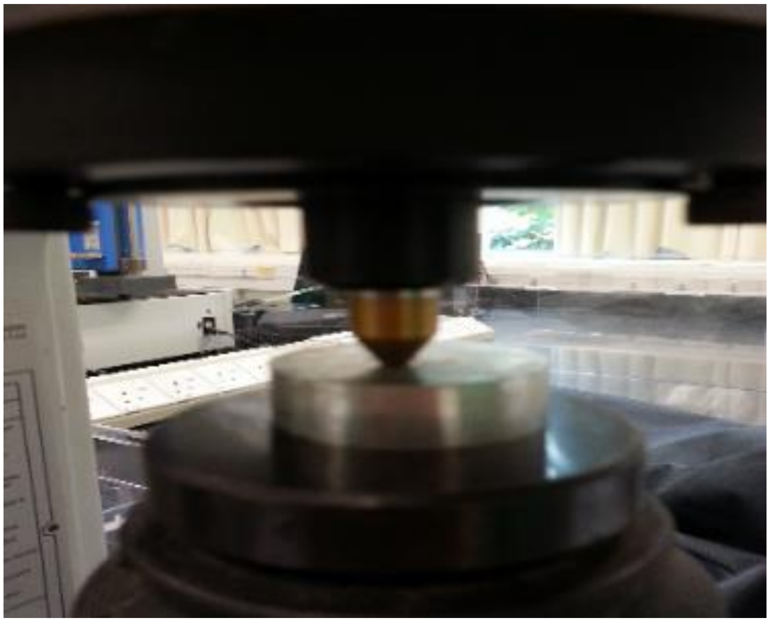
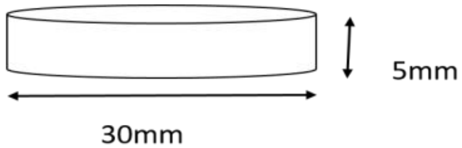
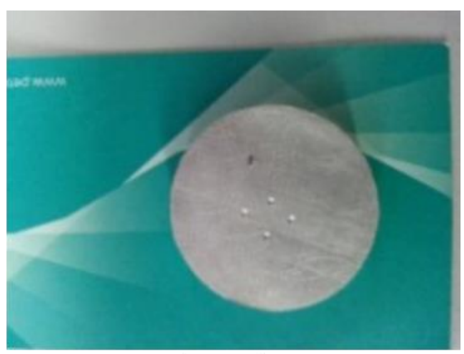


Figure 3. 18: Rockwell hardness test machine

Figure 3. 20 (a) shows the dimension of the specimen for the Rockwell hardness test and figure 3. 20 (b) is the specimen surface after the test. The result of hardness (HRB) was recorded and discussed for different percentage and different sizes of POFA in chapter 4.



(a)



(b)

Figure 3. 19 (a) Dimension of Rockwell hardness specimen (b) Effect on the sample of Rockwell hardness

3.2.4 Ball-On-Disk Wear Dry Sliding Test

The ball-on-disk tribometer, model NZM 7045-71 fulfil ASTM G99-95 standard for wear dry sliding test. The specimens were cut into the specific dimensions using ASTM G99-05 for wear test. The specimen of the new AL MMC is a flat circular disk with 50mm diameter and 8mm thickness. A carbide ball with 10mm diameter was positioned perpendicular to a flat circular disk with 50mm diameter and 8mm thickness dimensions as shown in figure 3. 20. The wear dry sliding tests were conducted at room temperature using the carbide ball-on-disk with the size of 10mm. The applied load was 10N. The mass loss of the new sample of ALMMCs was recorded for total distance travelled 900m. The schematic configuration of ball-on-pin is shown in figure 3. 21.

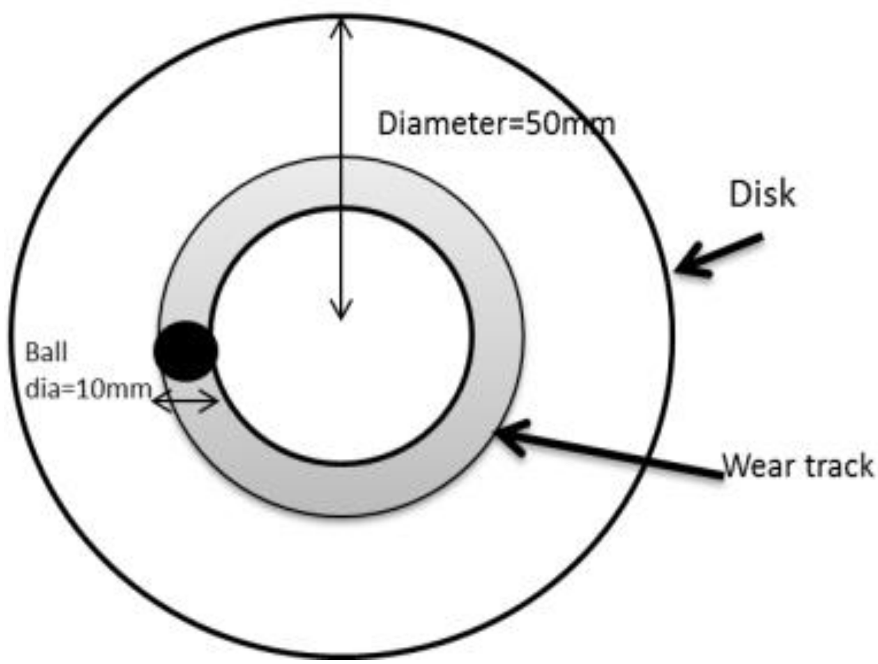


Figure 3. 20: Schematic dimension of the specimen for wear dry sliding

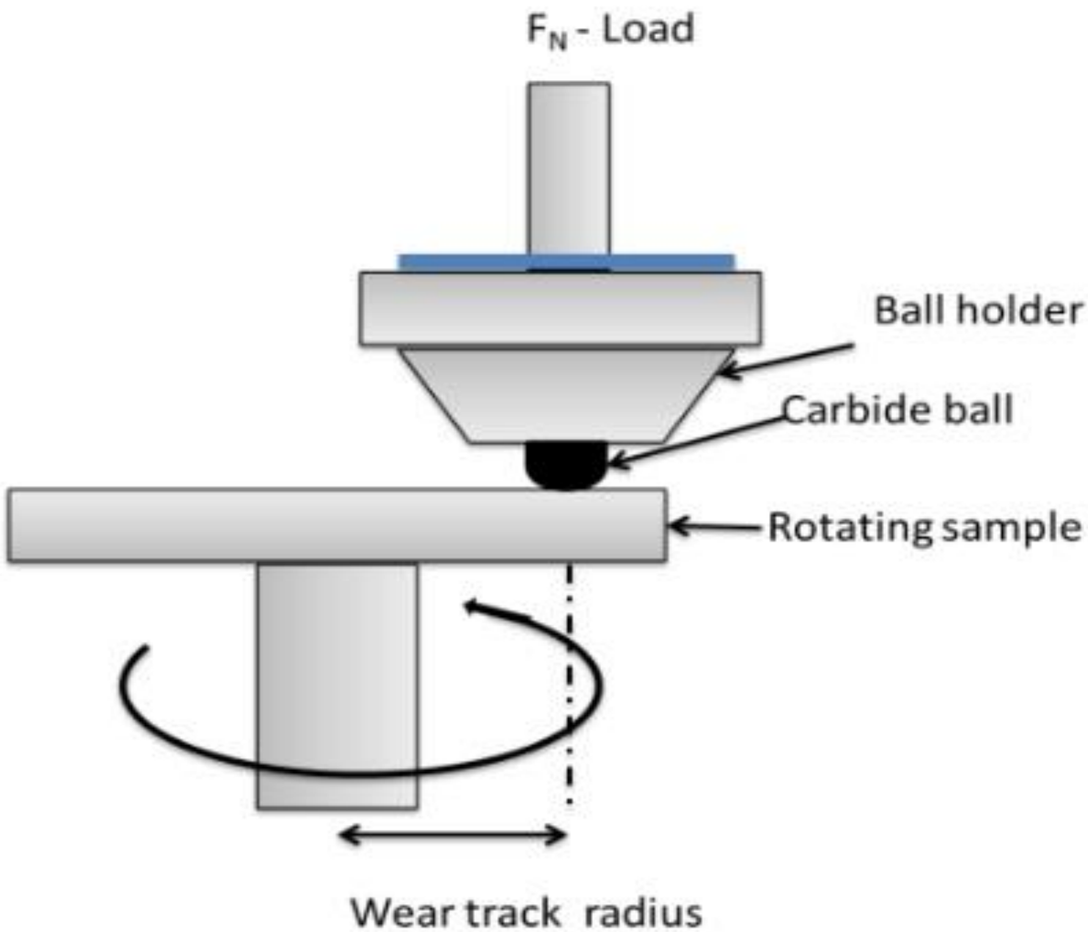


Figure 3. 21: Schematic configurations of Carbide ball on new AL MMC disk

(Al 6061+ POFA)

The dry sliding method was applied to measure the weight loss and coefficient of friction for the specimens. Samples were cleaned by acetone and were thoroughly dried before and after the wear test to determine the weight loss. Figure 3.22 shows the carbide ball with its holder together with the wear dry sliding specimen after the test.

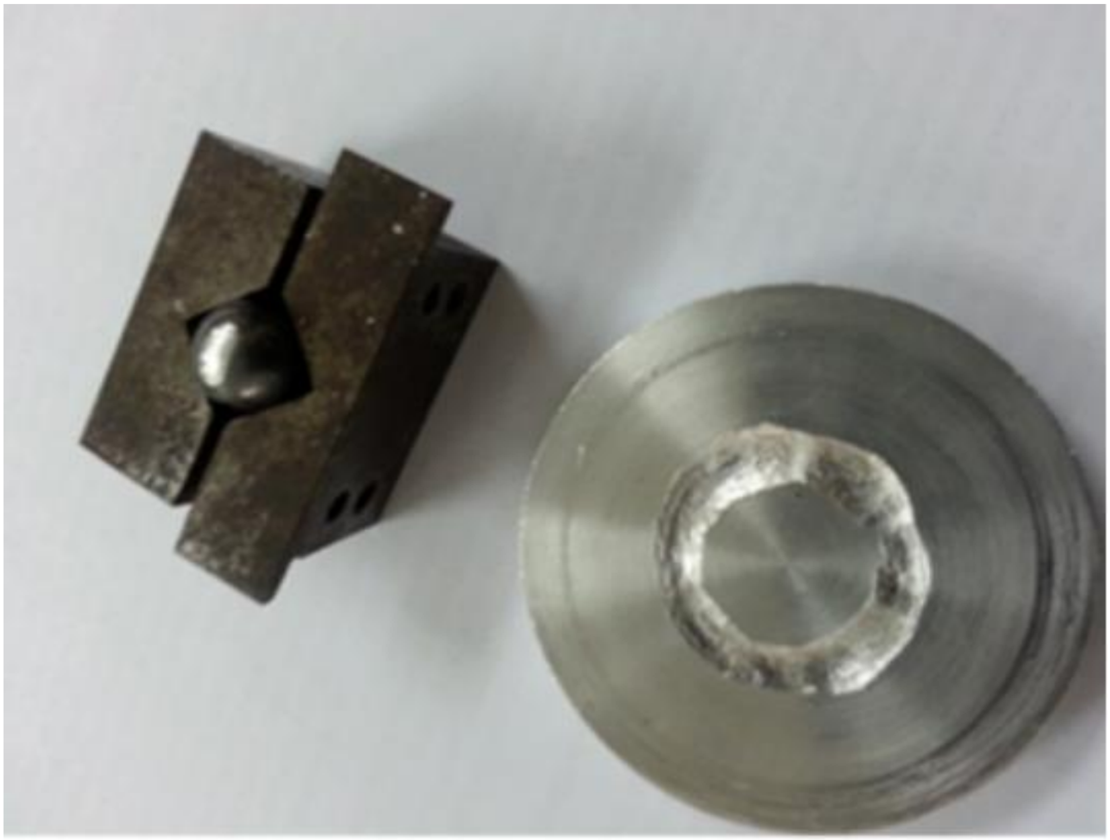


Figure 3. 22: Carbide ball with the holder and the specimen after dry sliding test wear.

3.2.5 Microstructural Characterization using Scanning Electron Microscope (SEM)

Microscopic examination of the specimen is a study to identify the defect, homogeneity, porosity and bonding and chemical composition of the materials. The microstructural analysis of the specimens was conducted by using model INCAX-act Scanning Electron Microscopy (SEM). The result of microstructure indicated the surface condition when force was applied to it. The SEM will provide a comprehensive metallurgical analysis for both wear track and debris of the samples. The microstructural analysis also was done for the fractured unpolished specimens (Izod impact test) by using

Gemini SEM 500(Carl Zeiss Microscopy GmbH) from Malaysia Nuclear Agency, Bangi as shown in figure 3.23.

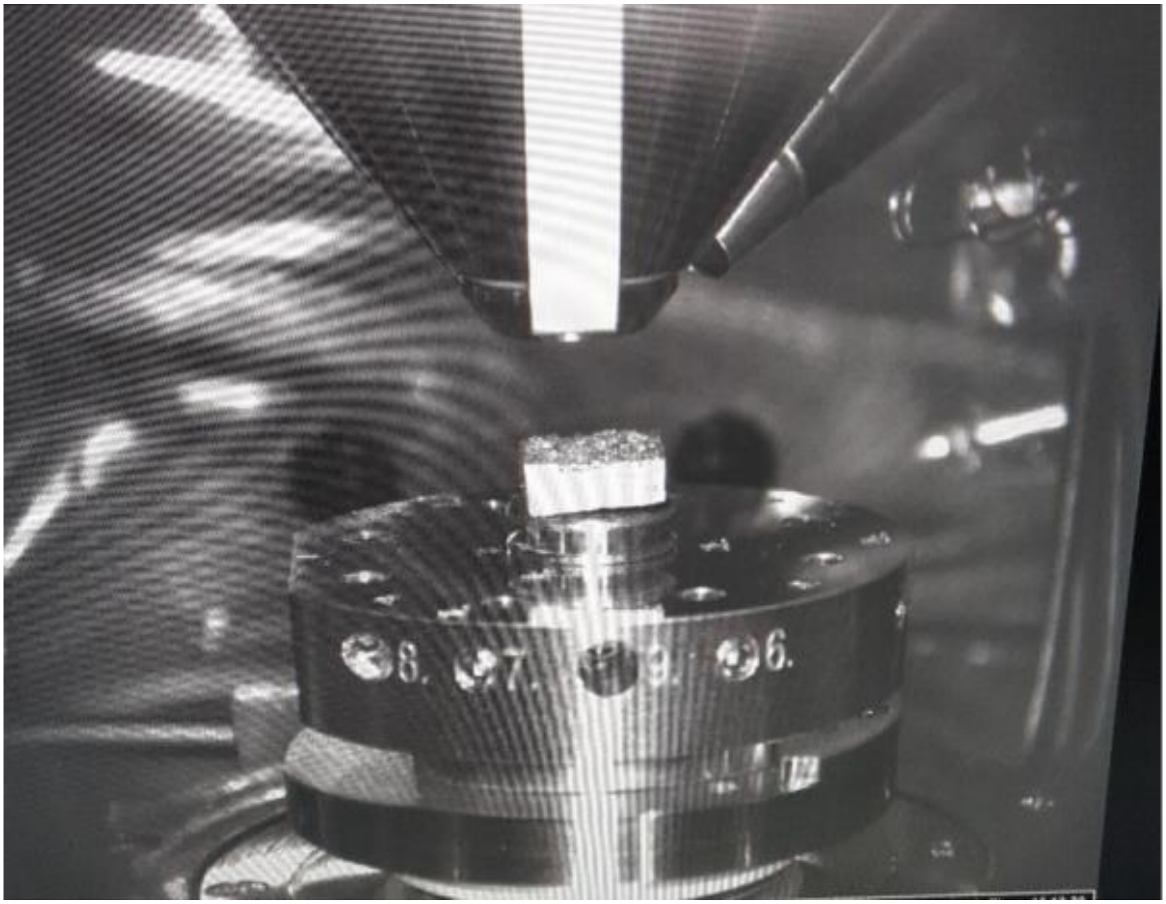


Figure 3. 23 Specimen in the Gemini SEM 500(Carl Zeiss Microscopy GmbH)

The detailed analysis of all the mechanical and tribological performance of the AL MMCs which consist of Aluminium alloy (AL 6061) as the matrix and reinforcement by POFA will be discussed in chapter 4.

CHAPTER 4: RESULTS AND DISCUSSION

4.0 Introduction

The method of fabrication of the composite materials that is MMC depends on the chosen matrix and reinforcement material. In this case, the chosen matrix is an Aluminium alloy (AL 6061), that is the light (low-density) metals and also of commercial importance. The suitable fabrication method for any Aluminium alloy fibres is usually using stir casting method. The reinforcement is POFA; it is considered as fibres. Starting with the identification of the chemical composition of the POFA as reinforcement as well as the AL 6061 as matrix before the fabrication the MMCs. Then this was followed by the result of the mechanical and tribological properties. The mechanical properties result of a AL MMC are the impact, hardness and tensile strength, and the tribological properties were the weight loss as well as the coefficient of friction and the Scan Electronic microscopy image (SEM) of a MMC to revealing the finding.

4.1 The Chemical Composition of the Al6061 and POFA.

Before the fabrication of the ALMMC using stir casting machine, both the chemical composition of the matrix that is Al6061 and POFA as a reinforcement material, needed to be identified.

4.1.1 Chemical content of AL 6061

Aluminium alloys are the light (low-density) metals and alloys of commercial importance based on Aluminium, Magnesium and Silicon. It is clearly shown in Table 4.0 that the chemical contents in the Aluminium alloy 6061 was recorded by percentage in weight (wt. %). The chemical contents of AL 6061 were determined from reference specimen which indicated without addition of POFA.

Table 4.0: Chemical content in the AL6061

Element	Al	C	O	Mg	Si	Fe	Ag	Cu
Weight %	60.1	22.0	4.7	4.6	3.9	2.0	2.1	0.4

Compared the chemical content of the AL6061 by other researcher shown in Table 4.1 (Arun Kumar and Swamy 2011).

Table 4.1: Chemical composition of AL 6061 (Arun Kumar and Swamy 2011)

Element	AL	Mg	Si	Fe	Cu	Zn	Mn	Cr	Be	V
Weight %	Balance	0.920	0.750	0.280	0.220	0.060	0.040	0.070	0.003	0.010

4.1.2 Chemical Composition of POFA

The palm oil fuel ash (POFA) is the reinforcement to the MMC. The chemical composition of the POFA on various parts of the palm oil waste was identified. With reference to the Table 4.2, the chemical contents of the POFA varies for each preparation process, i.e. different sizes, duration of the burning process, etc. The overall result of all the nine samples in Table 4.2 showed none from the nine samples had Alumina (Al_2O_3) even the fibre from the boiler, raw fibre by normal burning, fruits bunches heated or not, heated for 2 hours or 4 hours, with different size of POFA. The amount of the Silicon dioxide (SiO_2) content in nine POFA samples of was not the same. The biggest sizes of POFA (151μm to 300μm) from fruit bunches component having highest SiO_2, it is about 34% for both conditions that was heated 2 hours or 4 hours at temperature of 200°C. It is also showed that the POFA from the boiler, which needed to continue burning to have 33% of Silicon dioxide (SiO_2) compared to burned POFA from raw fibre about 20%.

Table 4.2: Chemical compositions of the POFA from Sarawak Oil Lambir, Miri Sarawak

No	Sample	Total weight of the sample (gram)	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric Oxide (Fe_2O_3)	CaO	P_2O_5	K_2O	SO_3	TiO_2	MnO	Others
1	POFA from boiler (continue normal burning process)	10.46g	33.302		8.933	26.730	6.701	20.430	2.144	0.610	0.523	CuO-0.239, SrO-0.154, ZnO-0.122, Rb2O-0.070, NiO-0.032, Y_2O_3-0.008, Br-0.028
2	POFA from raw fiber (normal burning)	5.87g	19.918		6.178	26.222	5.988	32.288	2.897	0.403	0.515	Sc2O3-0.387, CuO-0.238, SrO-0.105, ZnO-0.226, Rb2O-0.104, ZrO2-0.072, NiO-0.034, Y_2O_3-0.005, Br-0.028
3	POFA from fruit branches (151<d< 300µm) heated for 4 hrs for 200°C	15.73g	34.163		12.677	23.724	6.385	18.906	1.465	1.179	0.610	CuO-0.226, SrO-0.160, ZnO-0.146, Rb2O-0.074, Y_2O_3-0.013
4	POFA from fruit branches , (76< d<150µm) heated for 4 hrs for 200°C	13.8g	3.978		0.805	11.630	1.170	73.020	1.663	0.200	0.272	Cl -6.894, CuO-0.096, SrO-0.079, Br-0.037, ZrO2-0.005, ZnO- 0.0, Rb2O-0.144, Y_2O_3-0.005
5	POFA from fruit branches (d< 300µm) heated for 2 hrs for 200°C	11.59g	5.240		1.009	12.352	1.559	72.064	1.515	-	0.318	CuO-0.107, Cl-5.356, SrO-0.091, ZnO-0.185, Rb2O-0.160, NiO-0.032, , Br-0.043
6	POFA from fruit branches (76< d<150µm) no heat	11.42g	5.091		0.821	12.014	1.269	71.554	1.670	-	0.272	Cl – 6.786, CuO-0.098, SrO-0.079, ZnO-0.159, Rb2O-0.149, Br- 0.038,
7	POFA from fruit branches (< 75µm) heated for 4 hrs for 200°C	11g	3.445		0.764	11.707	0.951	73.917	1.487	-	0.262	Cl- 6.756, CuO-0.098, SrO-0.071, ZnO-ZrO2-0.007, Rb2O-0.128, La2O3-0.369
8	POFA from fruit branches (151<d< 300µm) heated for 2 hrs for 200°C	12.26g	33.753		12.336	25.324	6.592	18.197	1.185	0.957	0.611	SrO-0.174, ZnO-0.146, Rb2O-0.080, Y2O3- , BaO-0.251, ZnO-0.146
9	POFA from fruit branches (< 300µm) no heat	7.63	6.266		0.876	10.893	1.6	71.745	1.608	-	0.277	CuO-0.085, SrO-0.082, ZnO-0.160, Rb2O-0.150, Br-0.040

The continuous burning process result cannot be reliable chemical composition due to inconsistent process of burning due to Malaysian weather. Therefore, the selected POFA from fruit bunches was the one having the same conditions; they were heated for 4 hours at temperature of 200°C for three different sizes that are shown in Table 4.3. In general, the bigger the size of POFA, more percentage of SiO_2 content, same finding to Ferric tri oxide (Fe_2O_3) content. The details of SiO_2 content in POFA; the size of 151µm to 300µm the SiO_2 content was 34.163%, compared to the other two sizes of the SiO_2 content was minimal, that is 3.978% and 3.445%. The Fe_2O_3 content in POFA was 12.677% for the highest size and followed by 0.805% and 0.764%.

Table 4.3: Selected POFA to be reinforced for new MMC

No	Sample	Total weight of the sample (gram)	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric Oxide (Fe_2O_3)	CaO	P_2O_5	K_2O	SO_3	TiO_2	MnO	Others
1	POFA from fruit branches (151<d< 300µm) heated for 4 hrs for 200°C	15.73g	34.163		12.677	23.724	6.385	18.906	1.465	1.179	0.610	CuO-0.226, SrO-0.160, ZnO-0.146, Rb2O-0.074, Y_2O_3-0.013
2	POFA from fruit branches , (76< d<150µm) heated for 4 hrs for 200°C	13.8g	3.978		0.805	11.630	1.170	73.020	1.663	0.200	0.272	Cl -6.894, CuO-0.096, SrO-0.079, Br-0.037, ZrO2-0.005, ZnO- 0.0, Rb2O-0.144, Y_2O_3-0.005
3	POFA from fruit branches (< 75µm) heated for 4 hrs for 200°C	11g	3.445		0.764	11.707	0.951	73.917	1.487	-	0.262	Cl- 6.756, CuO-0.098, SrO-0.071, ZnO- ZrO2-0.007, Rb2O-0.128, La2O3-0.369

Table 4.4 was shown their correlation between POFA density (result from chapter 3 was used to prepared the sample of ALMMC) and SO_3 content in the POFA. The medium sizes of the POFA (76 µm to 150µm) be the highest POFA density among three of the POFA sizes and same as the SO_3 content. Therefore, the mass of the SO_3 content is the one be contributed to the density of the POFA. Histogram in Figure 4.1 shows clearly shown their correlation.

Table 4.4: POFA Density and SO_3 (wt.%) For different size of POFA

POFA Size (μm)	Density of POFA(g/cm^3)	SO_3(wt.%)
less than 75	0.61	1.465
76-150	0.88	1.663
151-300	0.68	1.487

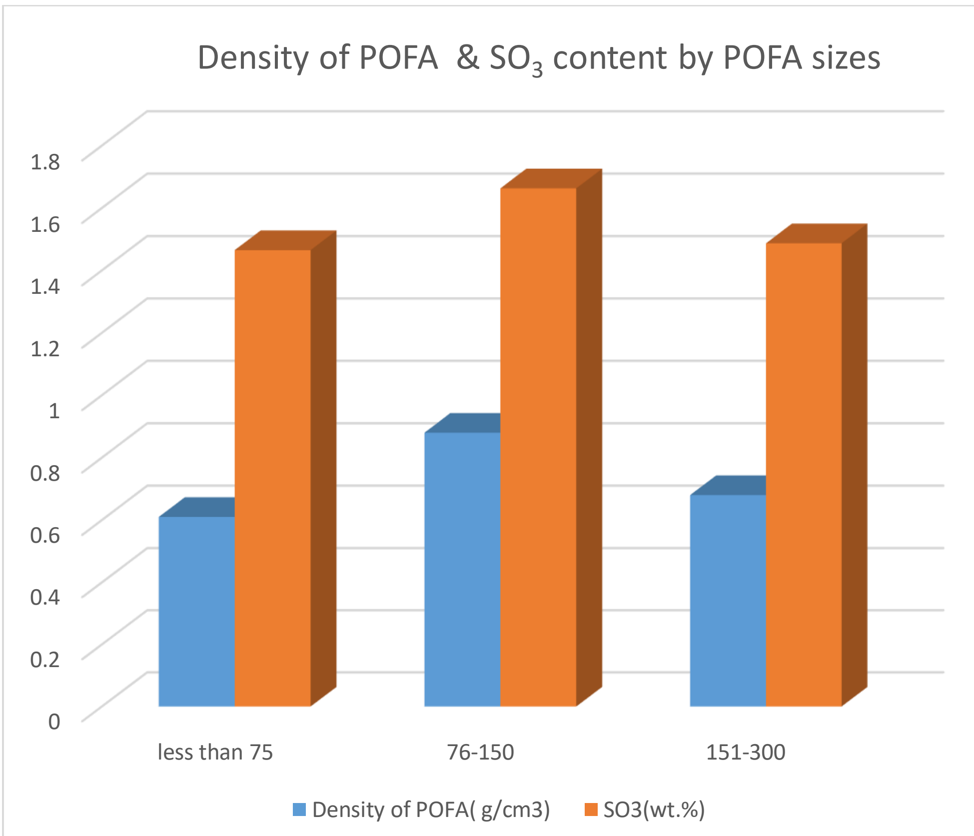


Figure 4.1: Correlation between the density of POFA and SO_3 content in POFA

The microstructure of POFA for different sizes shown in Figure 4. 2, 4.3 and 4.4. The colors in microstructure analysis obviously shows that the different sizes POFA has the different weight percentage (wt. %) of chemical contents and non-uniformed distributed.

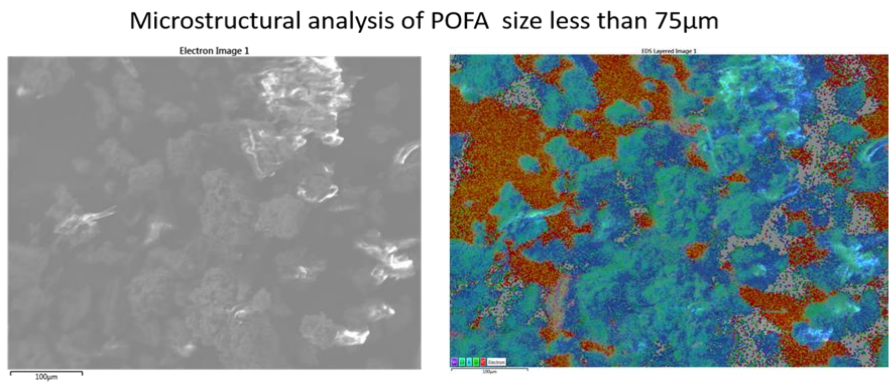


Figure 4. 2: Microstructure of POFA sizes less than 75µm

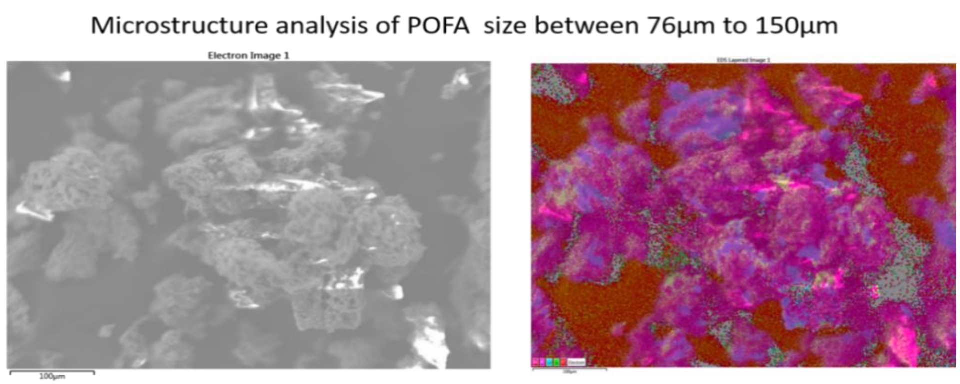


Figure 4.3: Microstructure of POFA sizes between 75µm to 150µm

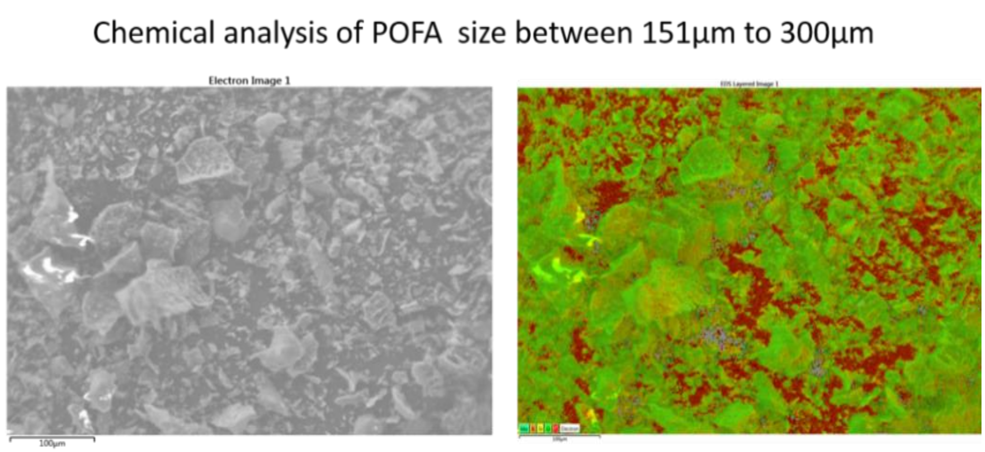


Figure 4. 4: Microstructure of POFA sizes between 151µm to 300µm

Compared to the other findings of the chemical composition of the POFA; the Alumina is one of the important contents besides Silicon dioxide (SiO_2). The comparison on chemical composition on POFA by Thomas also showed the Silicon dioxide (SiO_2) were 43% to 65% with a small percentage in Alumina that is about 2% to 11% (Thomas, Kumar, and Arel 2017). Compared to other location that is from Penang, the chemical composition of POFA is 67% Silicon dioxide and 6 % Alumina (Salami et al. 2017). The primary composition of POFA is Silicon Dioxide (SiO_2) which ranges from 43% to 71%; it is shown that POFA particles with good pozzolanic properties could produce high-quality concrete. The Alumina content was about 0.9% to 11% (Hamada et al. 2018). The previous finding showed that Silicon dioxide (SiO_2) is one of the reinforced fibres that increases the strength of the concretes as part of the composites.

The above findings showed that the chemical composition of the POFA is differed from one location to the another location. This is due to the different chemical contents of the soil where the palm oil trees are planted in the plantation. A large variety of the chemical composition of the POFA also was due to different conditions such as burning temperatures, burning quantity of the palm oil parts from different factories, and other similar factors. In general, the bigger the size of POFA, more percentage of SiO_2 content, same finding to Ferric trioxide (Fe_2O_3) content. The findings shown that the correlation between POFA density and the SO_3 content in The POFA, hence the mass of the SO_3 content is the one be contributed to the density of the POFA.

4.2 Density of proposed ALMMC

The theoretical value density of AL6061 is 2.7g/cm^3 (Karthick et al. 2017)consider as ALMMC without reinforcement of POFA compared to the ALMMC with reinforcement varies by sizes and volume percentage (vol.%) of POFA. Figure 4.5 shows the variation of ALMMC density by the volume percentage of POFA for three difference sizes. Overall result showed that the density of ALMMC is increased by vol.% POFA up to the 10.vol. % compared to ALMMC without added POFA. In general, the density decrease by the increasing the sizes of POFA in the ALMMC. The big gap of the density value of the ALMMC with 2. 5vol. % of POFA for three (3) difference sizes, may be due to the bigger size of POFA that is 150 to 300 µm having bigger sizes of chemical component with less dense. As a result, the density of ALMMC become so low.

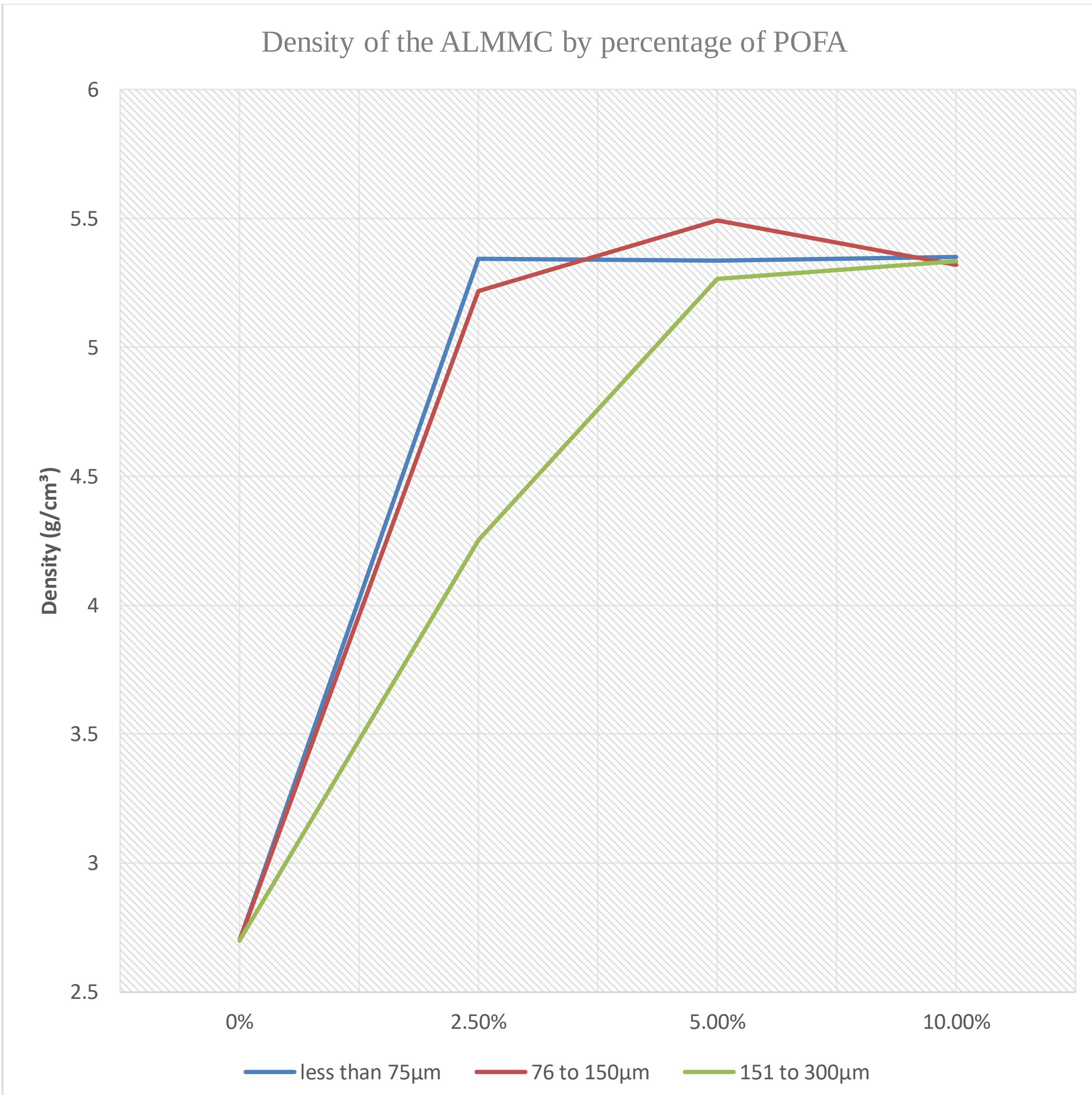


Figure 4.5: Variation of density of AL MMC by the vol. % and the different size of POFA

It was clearly shown that the increasing of the density of ALMMC with POFA was less than 75µm was obviously significant finding with 2.5vol%, but remain the same value even more volume percentage of POFA was added to the AL6061 till 10vol. % (5.4g/cm^3). The other two bigger sizes of POFA that are76µm to 300µm and the size 151µm to 300µm were having the same pattern of increment, but the maximum of the density of ALMMC with 5.0vol% of POFA. The result showed that the maximum density of the ALMMC with the middle size of POFA (76µm to 150µm) increased till 5.0vol. % of POFA added to AL6061. The most significant is all ALMMCs shows density results come to the same point for the mixture of 10% POFA as reinforced material for all sizes.

There was correlation between the density of POFA and density of ALMMC, both are peak at the medium POFA sizes that is 76µm to 150µm. The higher density of POFA as reinforcement material to the ALMMC, then this will contribute to the density of the ALMMC. As mention earlier that the SO_3 content is the one be contributed to the density of the POFA, so the higher the SO_3 content, contributed to the higher POFA density and therefore higher of ALMMC density at 5vol. % of POFA.

Table 4.6: POFA size, density of POFA, SO3 content and density of ALMMC

POFA size	Density of POFA (g/cm3)	SO_3 (wt.%)	Density of ALMMC with 5vol. % (g/cm^3)
151 <d< 300µm	0.607	1.478	5.3
75<d<to 150µm	0.883	1.663	5.5
d< 75µm	0.679	1.465	5.4

The excellent mixture between AL6061 as matrix and POFA reinforcement material depends on the sizes A and volume percentage of the POFA. The result may be due to good bonding process between matrix (AL6061) and reinforcement material (POFA)

Same finding for MMC, which the AL 7075 was chosen as matrix and SiC as reinforcement material was fabricated using stir casting method. The density of MMC increased its density by an increase in the percentage of the filler SiC and Alumina Al_2O_3 from 2%, to 6% (Balaji, Sateesh, and Hussain 2015). Another ALMMC's was a mixture of fly ash from palm oil industry with Aluminium alloy 356, the AMC's density increased when the pressure ratio increase (Rocha and Fabricio 2017). The density and porosity of the AA6061 MMC's increased with increasing weight percentage of the reinforcement that were Al2O3 and red mud (Quader, Murthy, and Reddy 2016). The density of AMMC's consist of BLA(bamboo leash ash) and AL-4.5%Cu alloy reduced with an increased in BLA content (B. P. Kumar and Birru 2017). The density of composites AMC reduced with added the fly ash and Aloe Vera (Gireesh et al. 2018). The density of ALMMCs that the mixture of Al7075 with SiC as reinforcement increases with weight percentage of SiC with heat treated. The finding shown that the condition of heat treated improved the ALMMCs but reduced percentage of porosity (Das et al. 2018). The densities of the ALMMC's of the mixtures of AL 7075 with the SiC as reinforcement material are found improved than their base matrix (Balaji, Sateesh, and Hussain 2015). Al-xGnP Nano composites shows an increased in relative density with an addition of xGnP in Al Matrix. However the density of composites reduced beyond 3wt.% of the xGnP (Nasimul and Kumar 2016). Density of MMC consist of Aluminium alloy (6000 series) as matrix and Multi walled carbon nanotubes (MWCNTS) as reinforcement decreased by 4.17% and 12.8% for 0.25% and 0.50% of MWCNTs respectively compared to Aluminium alloy (Bidari et al. 2017).

4.3 Mechanical and Tribological Properties of the ALMMC

The mechanical properties of AL MMC consist of AL 6061 as matrix and reinforced by POFA that were focused on the tensile strength, impact and hardness tests. The wear properties focus on the dry sliding and friction behaviour on new AL MMCs. Wear is the gradual loss of material that is due to friction during the relative motion of bodies (Fisher 2009). The Coefficient of frictions (μ) and the metallographic of new MMCs on wear track and fracture surface of Izod impact specimen revealed the findings.

Generally, all mechanical and tribological test results of the ALMMC were better than AL 6061 alone, except for a particular condition. The study of the correlation of the weight loss and hardness of new AL MMC will be discussed in this chapter

4.3.1 Tensile Strength

Figure 4.6 shown the variation of tensile strength of the ALMMC to its volume percentage and for the three 3 different sizes of POFA. Generally, the graph indicated that the tensile strength increased by the percentage volume of POFA to a certain limit (maximum point) depending on the size of the POFA. The tensile strength of the ALMMC were increased up to 2.5vol % of POFA added to AL6061 for the smallest size d <75μm and biggest size151μm < d <300μm. Above or more than 2.5vol. %, the tensile strength was decreased. The above findings may be due to the poor rebounding of the reinforcement of the POFA with the matrix that is AL-6061, but compared to POFA size 76μm<d<150μm, the tensile strength of the ALMMC was increased up to 5.0vol % of POFA (refer to Figure 4.6). It can be seen that there was a substantial increase (orange line) in the tensile strength of the new MMC for the POFA with the size of 76μm<d<150μm. The peak of the strength was at the 5vol. % of the POFA and its value was more than 170N/m^2 tensile strength compared to AL 6061 without reinforcement only at 85N/m^2. The above findings shown the correlation between the highest density of POFA, the highest density of ALMMC and the best tensile strength results were used POFA size was 76μm<d<150μm as reinforcement material to the ALMMC with 5vol.% of the POFA.

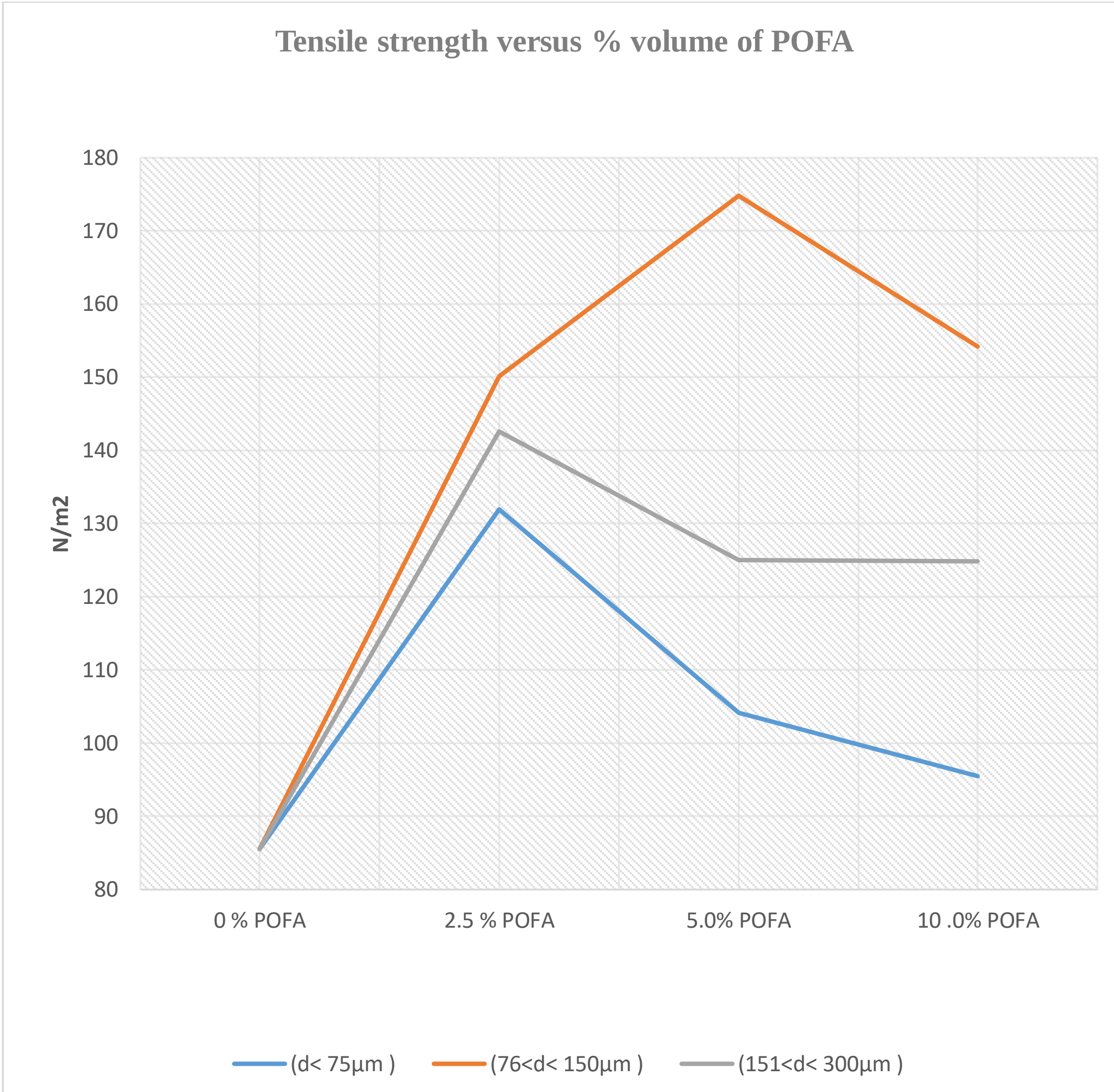


Figure 4.6: Variation of tensile strength versus vol. % of POFA

Refer to Table 4.7, their correlation between sizes of the POFA to the density of POFA, the SO_3 content in the POFA, density of ALMMC and Tensile strength of ALMMC with 5.0vol. % of POFA. The result shown that the ALMMC added with middle sizes of POFA that is 76µm<d<150µm having the highest value of tensile strength value (175N/m^2) at 5vol. % of POFA, may be due to the good bonding between the reinforcement and the matrix. The increasing of the tensile strength of the ALMMC is depend on sufficient amount of reinforcement added to the metal matrix during fabrication. As mentioned earlier, the function of the matrix is to hold the fibres as reinforced materials together as well as to protect the fibers (Ling1999). Compare to the other two (2) sizes of POFA, the tensile strength of the ALMMC was reduced at 5.0vol. % with value of 125N/m^2 and 105N/m^2.

Table 4.7: The correlation between sizes of the POFA to the density of POFA, the SO_3 content in the POFA, density of ALMMC and Tensile strength of ALMMC with 5.0vol. % Of POFA

POFA size	Density of POFA (g/cm3)	SO_3 (wt.%)	Density of ALMMC with 5vol. % (g/cm^3)	Tensile strength with 5vol.% (N/m^2)
151 <d< 300µm	0.607	1.478	5.3	125
75<d<to 150µm	0.883	1.663	5.5	175
d< 75µm	0.679	1.465	5.4	105

It also was seen in the AL-6061 reinforced by fly ash up to 15% that the tensile strength of increased compared to the monolithic alloy (V. Kumar, Gupta, and Batra 2014). Same result for the tensile strength for AL6061 composites, that is, there was increase by wt.% of reinforced of Graphite-SiC (Prashantha et al. 2017). The finding of MMC content AL 6061 reinforced fly ash also produced the same that the tensile strength increase by wt.% of the fly ash (Arun Kumar and Swamy 2011). Same as MMC in which the matrix was ALSi10Mg (Aluminium alloy) reinforced by RHA increased by wt. % of the RHA. There was a decreased tensile strength for MMC new MMC with RHA fraction beyond 12% (Saravanan and Kumar 2013). It may be due to the poor wettability of the reinforcement with the matrix.

There were hybrid composites produced by combining the Silicon Carbide (SiC) and Corn Cob Ash (CCA) to the Al-Mg-SI Alloy; the result of the ultimate tensile strength of hybrid composites decreased gradually in CCA content of the composites (O. babajide Fatile, Akinruli, and Amori 2016) (O. babajide Fatile, Akinruli, and Amori 2016) . Balaji also found out that the tensile strength increased more than the based matrix of new the MMC (a mix of AL 7075 as matrix and SiC as reinforcement material the wear resistance of the MMC is higher (Balaji, Sateesh, and Hussain 2015).

The tensile strength was increased up to 4% of Bamboo leaf ash (BLA) as reinforcement fabricated with an Aluminium alloy Al-4.5 Cu as matrix BLA in the composites. The microstructure reveals his finding of the density and porosity of the MMC (B. P. Kumar and Birru 2017). Even using a sandwich technique for the fabrication of MMC on Magnesium sheet as matrix and reinforcement by a carbon nanotube, the tensile increased concerning unreinforced material. Ramgopal finding showed that the ultimate tensile strength of the MMC using Aluminium alloy Al 6082 as matrix and Fly ash and Silicon Carbide ad reinforcement material by increasing the percentage of SiC in the MMC(Reddy and Srinivas 2018). The result of the ultimate tensile strength of Al 6061 can be increased from 184 to 399Mpa, on the addition of 10%, 15% and 20% Alumina and fly ash by vol. respectively. (Himanshu Chauhan, Irfan 2017).

4.3.2 Impact

The results of the Impact energy of the ALMMC for three different sizes and percentage volume of the POFA as reinforcement material is shown in Figure 4.7. In general, POFA sizes and concentration of the filler can improve the Izod impact energy of ALMMC as compared to pure Al606. It is also showed in Figure 4.7 that the increasing of the impact energy of the ALMMC were be same pattern for the smallest size of POFA (less than 75µm- blue) as well as for the biggest size of POFA (151 - 300µm). Compared to ALMMC reinforced by the middle size of POFA (76 -150µm) size, the result shown inconsistent. The increased of impact energy was from 0 vol. % to 5.0vol. % of POFA but decreased after 5.0vol. % of POFA (blue and grey line). ALMMC reinforced by the smallest size of POFA has given the highest Izod impact energy gain by 35% as compared to the pure Al6061. The result may be due to sufficient mixture of ALMMC between Al6061 as matrix and 5 vol. % of POFA (the smallest size) as reinforcement material. Clearly shown the blue line in the Figure 4.7 that, the Izod impact of ALMMC increased by decrease of POFA sizes.

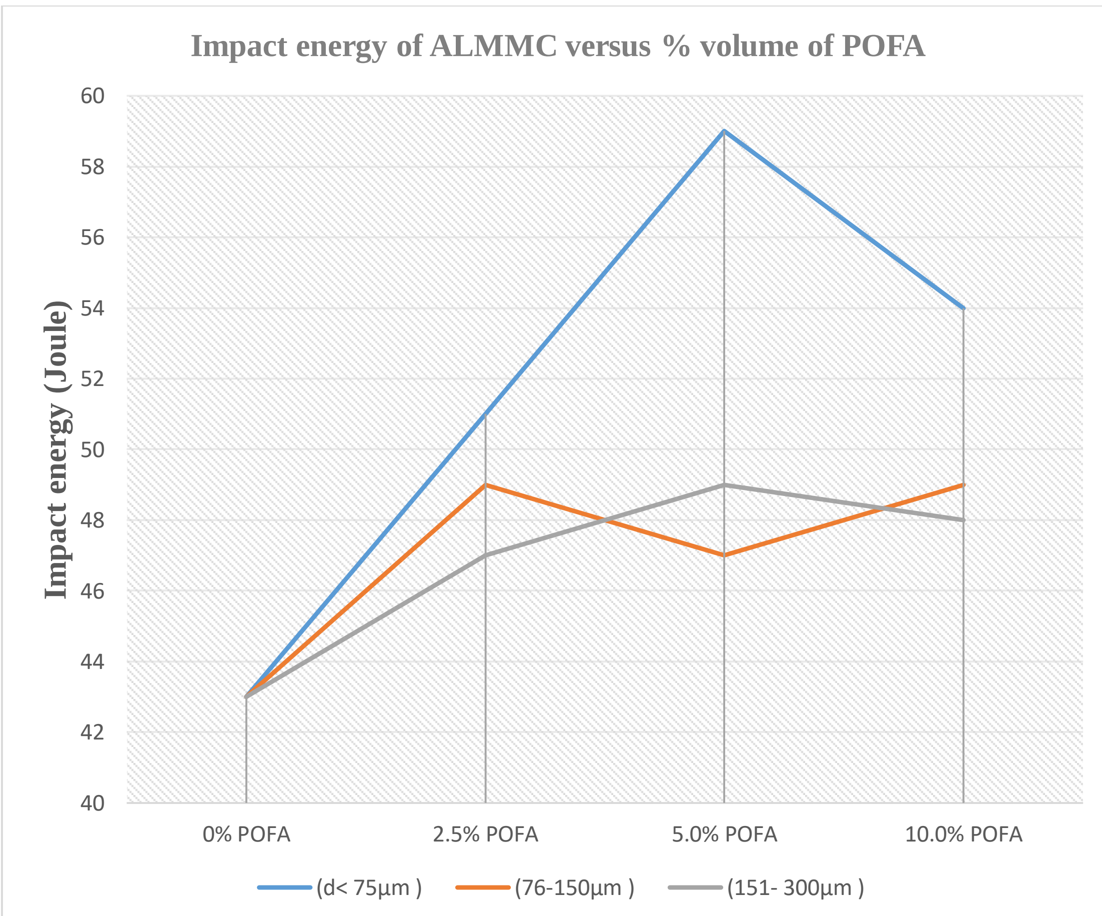


Figure 4.7: Variation of Impact energy of ALMMC for different vol. % and different size of POFA

The same finding of impact strength ALMMC decreased with increased particulate sizes of SiC (220mesh, 300mesh and 400mesh) and increased with increased in weight fraction (5%, 10%, 15% and 20%) of SiC particles (Meena et al. 2013). Hence, the concentration and size of POFA fillers also plays a significant role in order to produce the optimum Izod impact energy (Ling 1999).

The result produced the same pattern for new composites PMC utilizing fly ash (agro waste) as filler material in the epoxy polymer. The result showed that the decreasing size of the fly ash increased the impact energy of the epoxy polymer matrix composites with 10wt.% maximum of the filler (Raja, Manisekar, and Manikanda 2013). Asokan did another utilisation of fly ash as a reinforcement material, and the natural cellulosic polymers as a matrix for new PMC have been found the impact to be better than wood, plastic and have many opportunities for a multifunctional application (Pappu and Vijay 2017). The finding of the impact strength of new Aloe Vera powder used as reinforcement and Aluminium alloy as the matrix was better than of MMC using fly ash as reinforcement (Gireesh et al. 2018).

4.3.3 Metallographic of a ALMMCs

The studies of the microstructure are to excess the structure-property correlation of the material. The result of SEM will explain bonding between matrix and reinforcement material at worn surfaces of the wear track and fractured zone on impact specimens.

4.3.3.1 The Metallographic On Izod Impact Fractured Surface

The figure 4.9 shows the SEM for ALMMC with the chemical composition analysis and clearly shows that all specimens are not homogeneous. The variation of impact results in Figure 4.9. of the ALMMC for different % and different Size of POFA and the best impact test is the smallest sizes of the POFA that was less than 75µm. The microstructure will reveal the result on impact test, for comparison of the microstructure of the AL MMC consist of AL6061 without reinforcement in Figure 4.8.

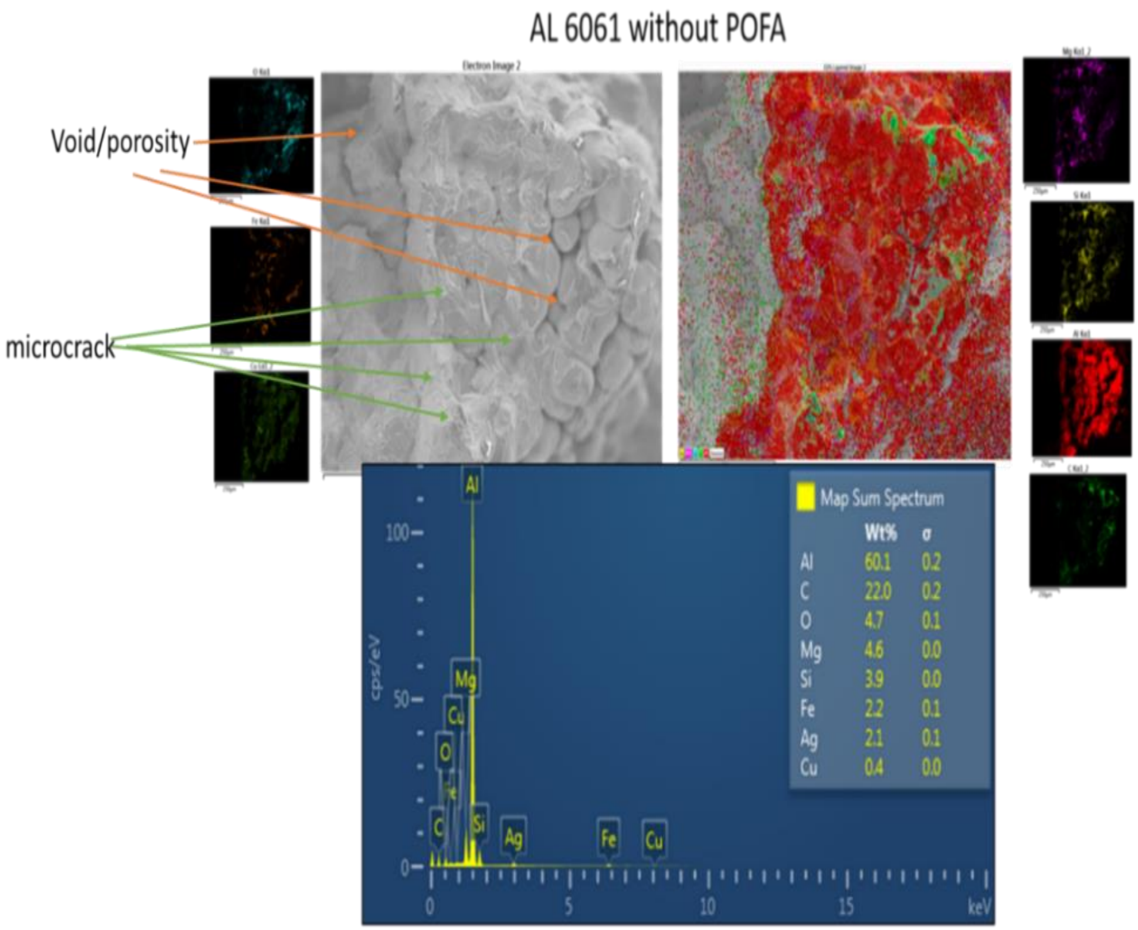


Figure 4.8: Impact fracture surface the AL6061 without POFA with chemical content analysis

The void or porosity is the empty or vacant or unoccupied or gap or space between the matrix and reinforcement which is typically a weak point in the composites. Micro crack in Composites is more complicated than those in homogeneous material. Not much porosity shown in Figure 4.9, compared to a micro crack location on the sample without POFA. Bonding only between chemical content in the AL 6061, therefore not much crack on the sample.

Compared to the sample of the best impact result of AL MMC is from the smallest sizes of the POFA that was less than 75µm with only 5 % of POFA. This sample also was for the best hardness result among 3 of them. The microstructure of the fractured surface on impact specimens above is shown in Figure 4.9. There were many void or porosity between matrix and reinforcement in the sample. Compared to Figure 4.10 for ALMMC with POFA size 76 to 150µm, the impact fracture shows less void or porosity but more micro-crack on the samples. This clearly showed that all microstructure of the ALMMC were not no homogeneous composite material.

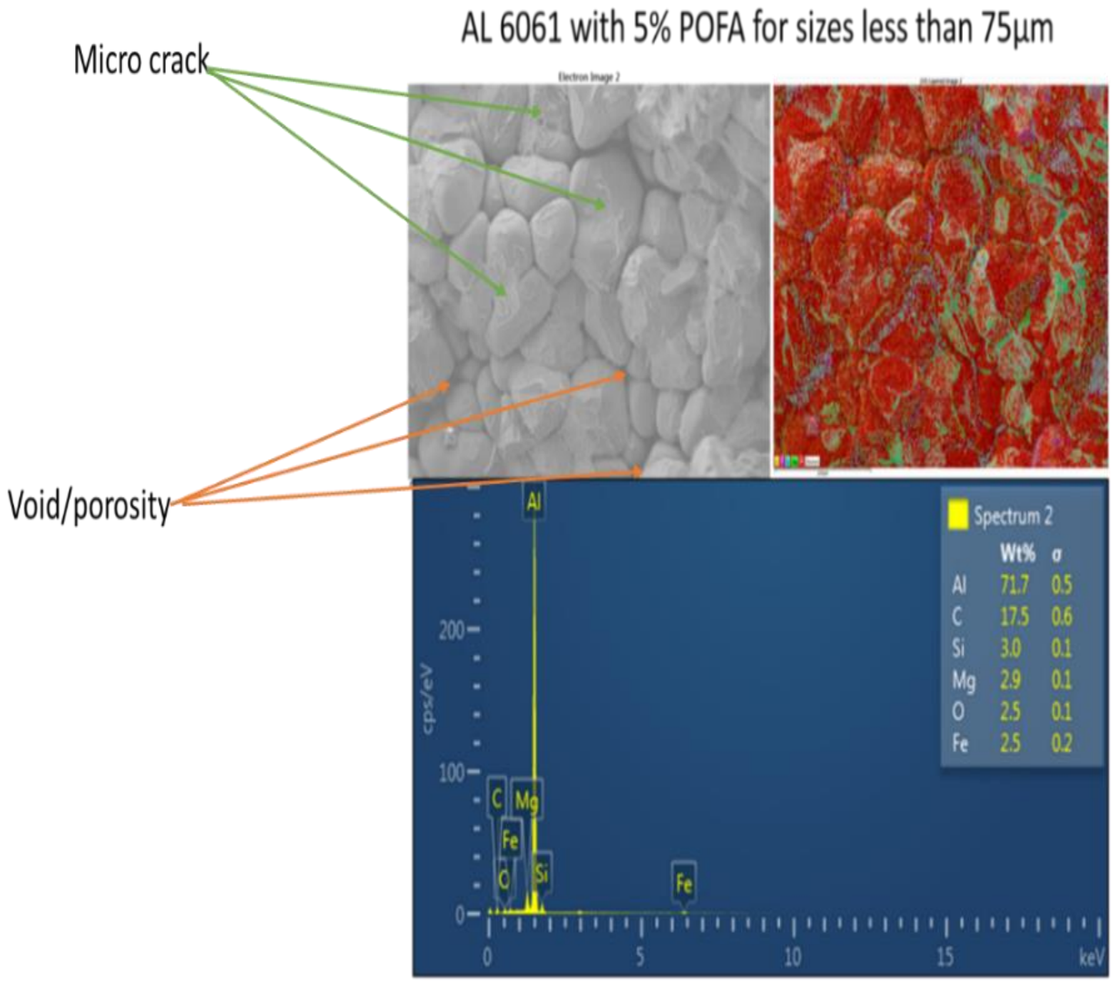


Figure 4.9: Impact fracture surface the AL6061 mixed with 5% of POFA size less than 75µm with chemical content analysis (the best impact result)

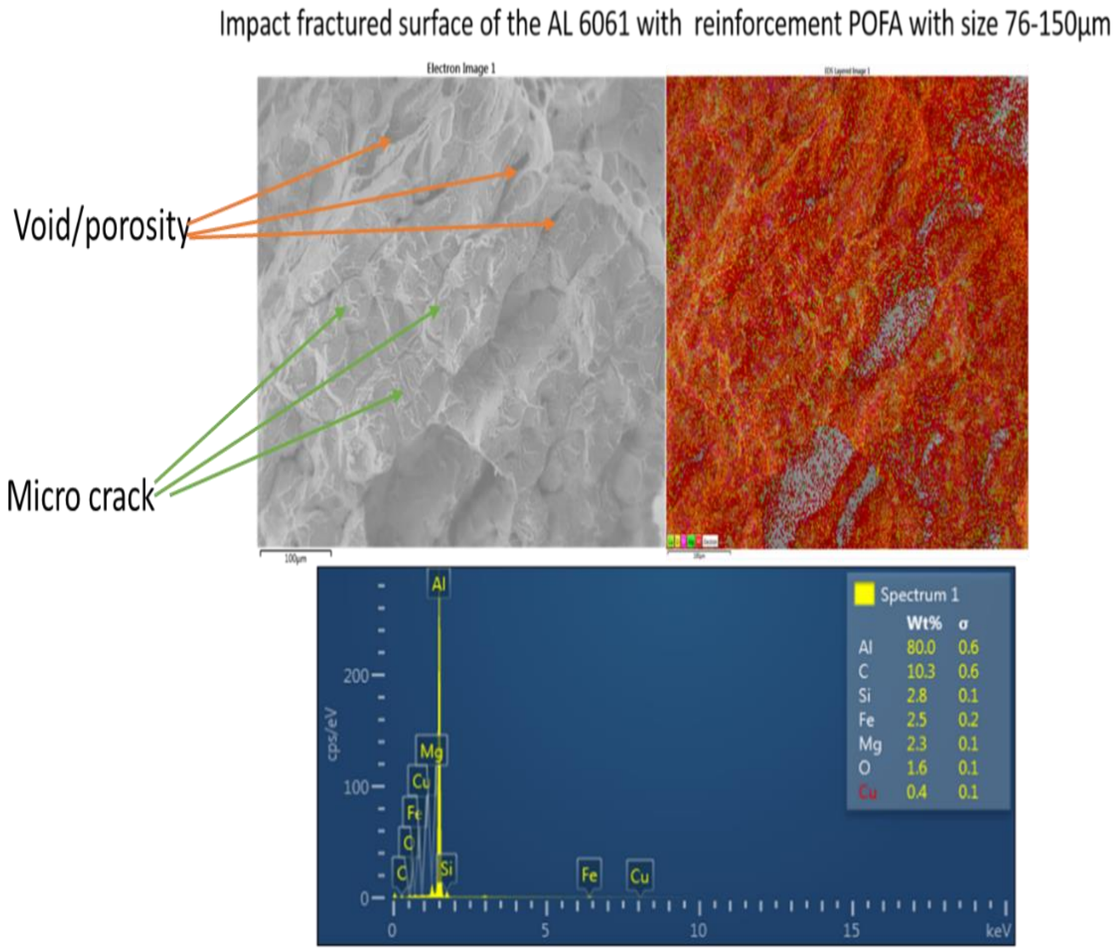


Figure 4.10: Impact fracture surface the AL6061 mixed with POFA size 76-150µm with chemical content analysis (the not consistent result of impact)

4. 3. 4 Hardness

The Rockwell hardness result of ALMMC by volume percentage of the filler shown in Figure 4.11, which the matrix is AL6061 and reinforcement material is POFA. The bar chart showed that not all cases of ALMMC resulted in a gain in hardness by the increase in the percentage of the POFA in the AL6061. Figure 4.11 shows that the blue bar indicated the increased in hardness by the increase the vol. % of the POFA that is up to 5.0vol.%. However, the smallest POFA size of d <75µm gave a consistent hardness gain for all POFA concentration volume variables (2.5%, 5% and 10%). The best hardness gain was the one by 5vol.% of POFA reinforcement to AL 6061which was achieved from above 23HRB to 26.5HRB at 5vol.% of POFA concentration sample.

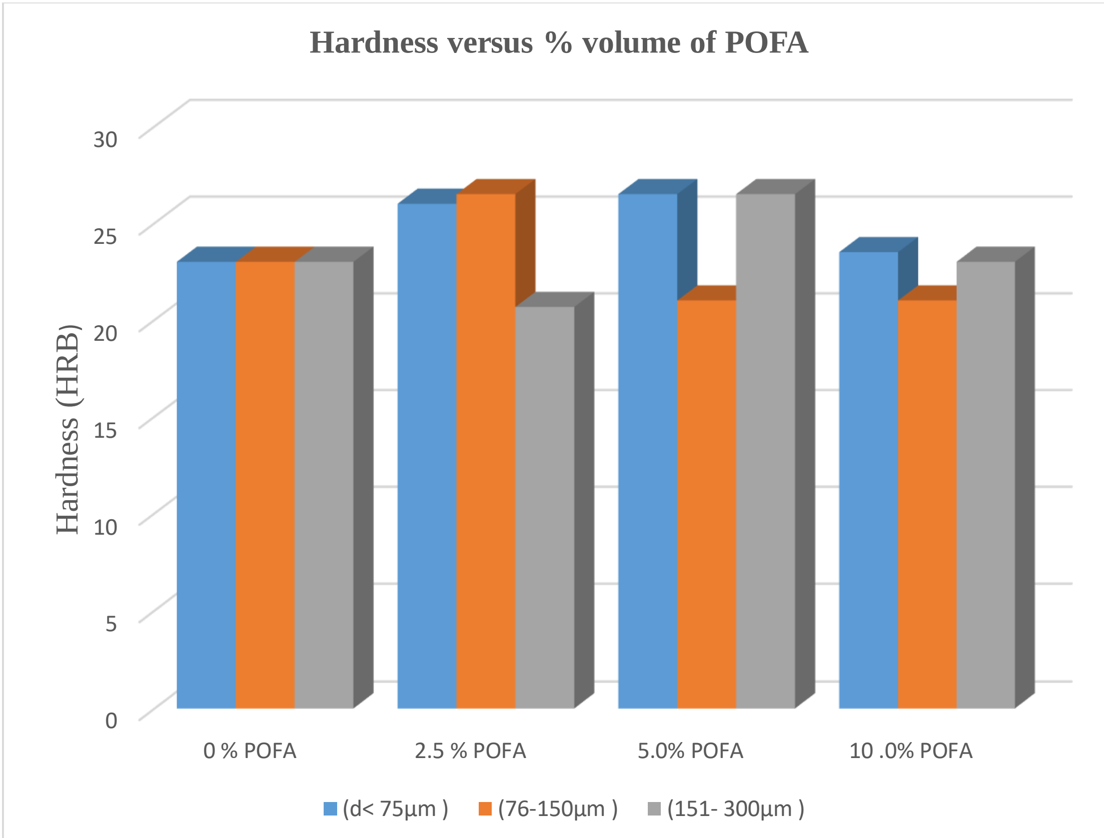


Figure 4.11: Variation of the hardness of ALMMC versus vol. % of POFA

For cases where POFA sizes were more than 75 µm, the result was found unable to produce a consistent hardness gain with some cases resulted in negative hardness gain. From the literature review in chapter 2, similar finding for the polymer matrix composites reinforced by the fly ash, the hardness increased by decreasing the size of fly ash filler(Raja, Manisekar, and Manikanda 2013). Same goes to the results of the hardness strength of new composites which were found to increase with increased fly ash content but decrease for above 20wt% of fly ash (Shanmughasundram, Subramaniam, and Prabhu 2012).

The hardness of Al6061reinforced by SiC composite increased with increased the wt.% of reinforcement while in AL6061-graphite composite the hardness decreased with increased wt.% of reinforcement (N, Nagaral, and Auradi 2012). The finding of hardness for AlSi10Mg matrix Composite reinforcement by (RHA) was also the same whereby the hardness linearly increased by wt.% of the RHA from 3% to 12% (Saravanan and Kumar 2013). The hardness result on matrix hybrid composite consist of Al-Mg-Si alloy reinforced by a ratio of RHA and Al_2O_3 is the opposite. The hardness decreases slightly with an increase in the wt.% RHA (Alaneme and Olubambi 2013). There are hybrid composites produced by combining the Silicon Carbide (SiC) and Corn Cob Ash (CCA) to the Al-Mg-SI Alloy, the result of the hardness of hybrid composites decreased gradually in CCA content of the composites (O. B. Fatile, AkinruliI, and Amori 2014).

Similar findings on new MMC comprised of AL7075 as matrix and SiC as reinforcement has shown that the micro-hardness increased by the filler for about 10% (Balaji, Sateesh, and Hussain 2015). The finding of the MMC consisted of matrix ZR2.5Nb reinforcement by Silicon Carbide SiC for different volume fraction, size and shape and was done by Shedbale. The finding has shown that the indentation decreased by increasing the percentage of volume fraction, of the reinforcement material (Shedbale et al. 2017). The hardness of the new composites contents of Bamboo leaf ash (BLA) as reinforcement fabricated with an Aluminium alloy Al-4.5% Cu as matrix has shown the increase in BLA content compared with the matrix. The maximum hardness was attained at 4% BLA (B. P. Kumar and Birru 2017). Another technique of fabrication of the MMC is the sandwich technique on Magnesium sheet as matrix and reinforcement by carbon nanotube. The hardness was increased concerning non-reinforcement material (Isaza M et al. 2017).

The product of MMC done by Ramgopal which utilized the agro-industrial waste, that was Fly ash and Silicon Carbide as reinforcement material fabricated with Aluminium alloy Al 6082 using stir casting method for fabrication with 2.5%, 5% and &7.5 % of the SiC. The finding has shown the hardness increasing as the weight fraction of SiC and Fly Ash reinforcements increases from 2. 5% to 7.5%. The percentage of SiC in the MMC

(Reddy and Srinivas 2018). The finding of the hardness, tensile strength and impact strength of new Aloe Vera powder used as reinforcement and Aluminium alloy as matrix was better than of MMC using fly ash as reinforcement (Gireesh et al. 2018).

4.3.5 The Wear Behaviour and Friction of New MMC

The studies of the wear rate (weight loss), and friction (coefficient of friction) results for dry sliding wear at room temperature that is 33ºC by using 10N load for a distance of 150m was done on the ALMMC samples. The variation of hardness in Figure 4.11 shows only the mixture with POFA size less than 75µm shows improved consistency compared to other POFA sizes. The hardness of the new MMC was improved until 5.0vol.% and reducing after 5vol. %. Therefore, the best hardness and also the best impact result was selected (POFA size of less than 75 µm) to study the wear and friction behaviour of new MMC. Due to the hardness result, therefore the wear test only focuses on the POFA sizes less than 75µm for a different vol. % that is 2.5%, 5% and 10%. The result clearly shows that the weight loss of the specimen without reinforcing POFA was the highest value that is 0.192gram, then reducing to 0.173g for 5vol. %. After 5vol %, the weight loss increased till 0.182g. This is the lowest weight lost on the specimen with 5 vol. % of POFA.

4.3.5.1 Weight Loss of the Specimens for the Best Hardness of New MMC

The effect of weight loss of the new ALMMC's for dry sliding wear is illustrated in Figure 4.12. The figure shows that the weight the loss of the ALMMC reduced by increasing the vol. % POFA till 5vol.%, increased as the increase above 5vol.% to 10%. Referring to Figure 4.12; it shows the lowest weight loss for new AL MMCs consists of AL 6061 reinforcement by 5vol. % of POFA for the size of less than 75µm.

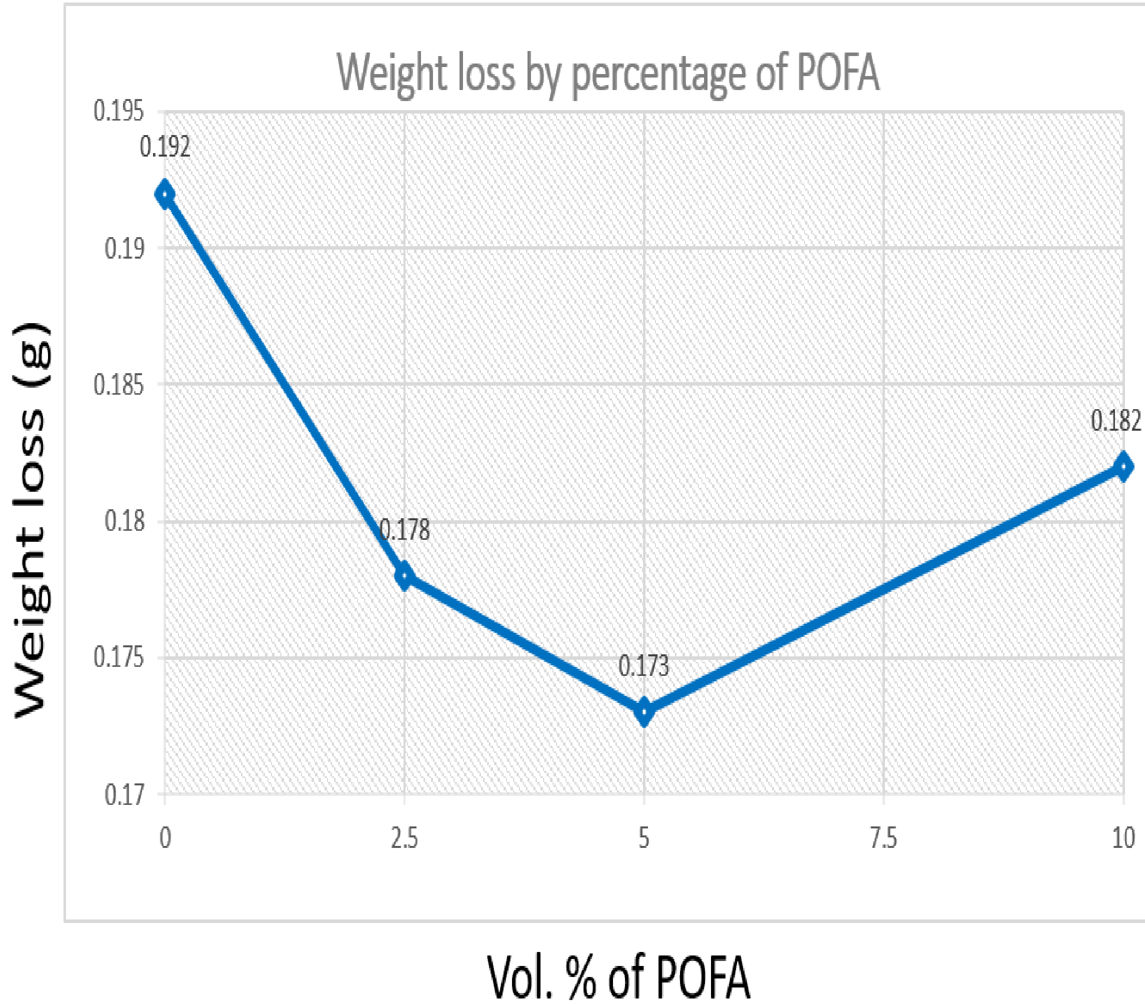


Figure 4. 12: Variation of average weight loss by the volume percentage of POFA for size less than 75µm

The correlation between hardness and weight loss by the vol. % of POFA for dry sliding wear is clearly shown in Figure 4.12, the best hardness of new MMC reinforcement by 5vol.% POFA at the lowest or minimum of weight lost when moving for 150m distances with a 10N load. The result of the best harness for the POFA size less was than 75µm. Compared to the other findings, it was observed that the wear mechanism of the composites transformed from predominantly abrasive wear to a combination of both adhesive and abrasive wear with increase in RHA wt.% (Alaneme and Olubambi 2013). The wear resistance of hybrid MMC's shows a decreasing trend, as Al2O3/SiCp hybrid ceramic powder composites increased with increasing reinforced SiC particle sizes (Altinkok, Özert, and Findik. 2013).

4.3.5.2 The Friction Behaviour of New AL MMC

Friction between carbide ball and ALMMC disk plays a significant role in the dry sliding wear behaviour with the condition at room temperature that is 33ºC by using 10N load for a distances of 900m. The investigation of the Coefficient of frictions (COF-µ) is an important parameter to evaluate the wear resistance between two bodies in contact for a specific condition. The different condition will lead to different results and all the values of the findings. COF of the material was determined using the ratio of friction force to the normal load. The best hardness result from the selected sample which is correlated with the lowest weight loss of the ALMMC was chosen for investigation of the coefficient of friction. Refer to Figure 4.13. The best hardness result correlate d with lowest weight loss is the ALMMC with 5% reinforcement POFA size which is less than 75µm. Therefore, the focus was only on the new MMC with 5% POFA reinforcement, due to the best hardness result as well as the lowest weight loss result.

Figure 4.13: Correlation between hardness and weight loss of new MMC with reinforcement POFA size is less than 75µ

4.3.5.3 Variation of Coefficient of Friction (COF - µ) of the best hardness of the new ALMMC

The variation of coefficient of friction (COF- µ) with sliding distance for a new MMC consisting of AL 6061 as matrix reinforced by 5% POFA is depicted in Figure 4.14. The sizes of POFA are less than 75µ***m***, between 76 to 150µm and between 151 to 300µm versus total sliding distance about 900m. The graph shows that the value of COF for three of the samples at the beginning of the sliding of the COF increased nearly 1.4 for the first 10m of sliding distance but reduced around 1.2 after 20m until 900m. The blue line shows that the COF value is higher among two lines after 400m till 900m that is almost 1.3.

Coefficient of friction versus sliding distance

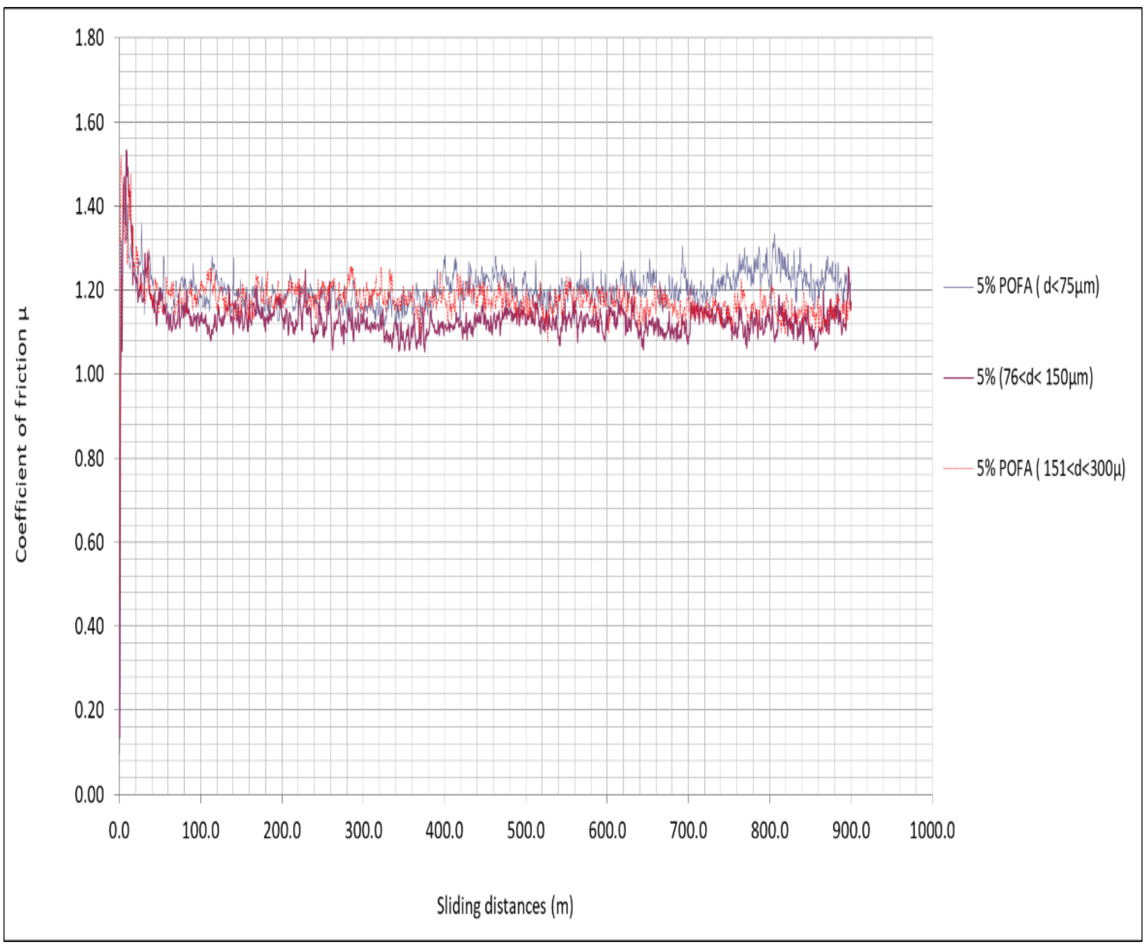


Figure 4.14: Coefficient of friction µ for three different sizes of 5% POFA

Due to the result, Figure 4.15 focuses on coefficient of friction of the best result of hardness and best weight loss that is 5% of POFA sizes that is less than the 75µm.

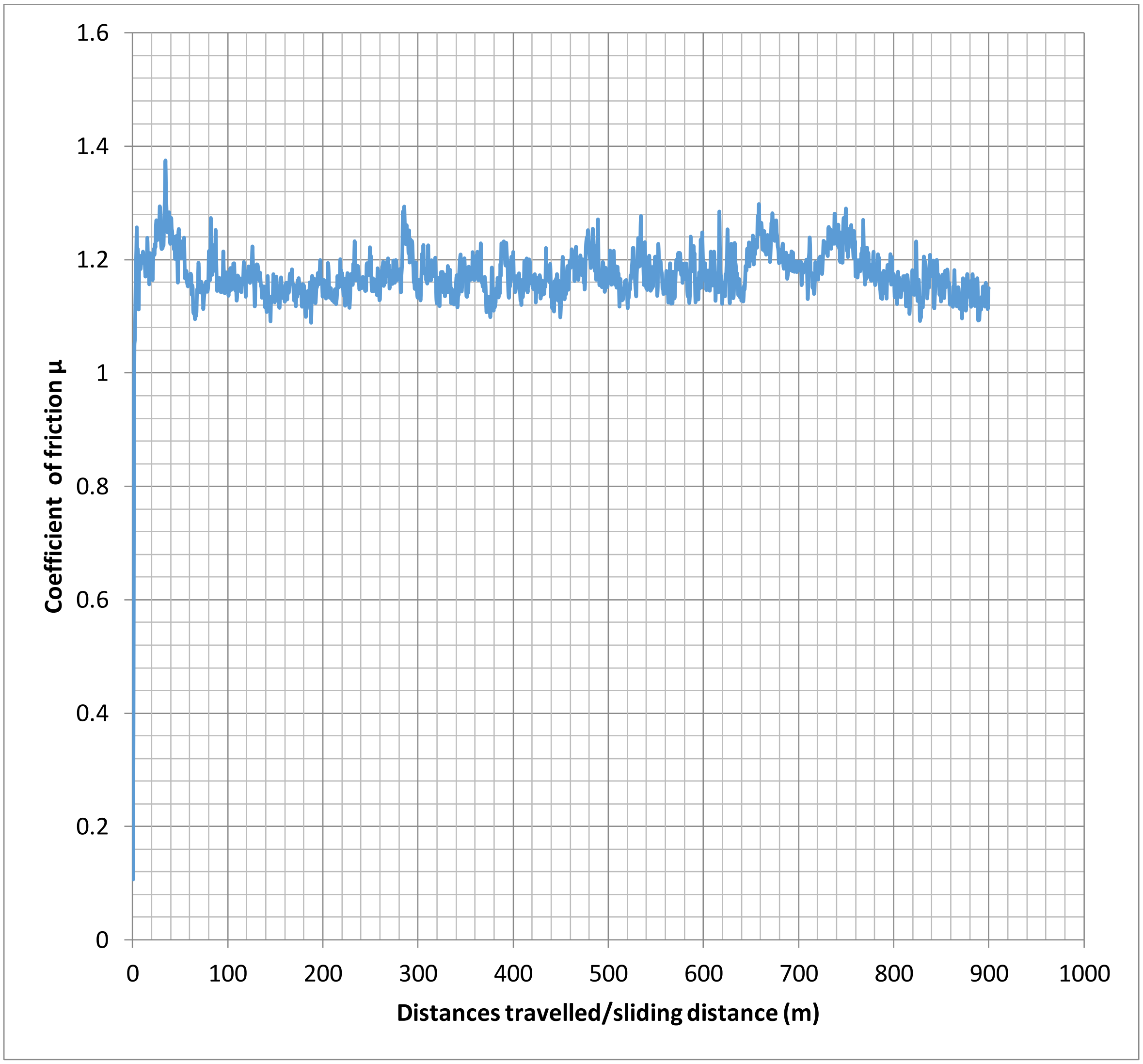


Figure 4.15: Coefficient of friction µ for AL MMC
(POFA – 5vol. % and the size d<75µm for the best hardness result)

Figure 4.13, 4.14 and 4.15 show the correlation of the mechanical and the tribological properties of the AL MMC reinforced by 5% POFA with the size of 75µm. The mean of COF (coefficient of friction) for the three different sizes of 5% POFA of the new AL-

MMC is shown in the Figure 4.16. Clearly shows the average of the COF for the sizes of POFA less than 75µm is the highest among three sizes of 5% POFA of the ALMMC samples. The correlation between them was the most optimum of the best hardness, at lowest weight loss and the highest average of COF.

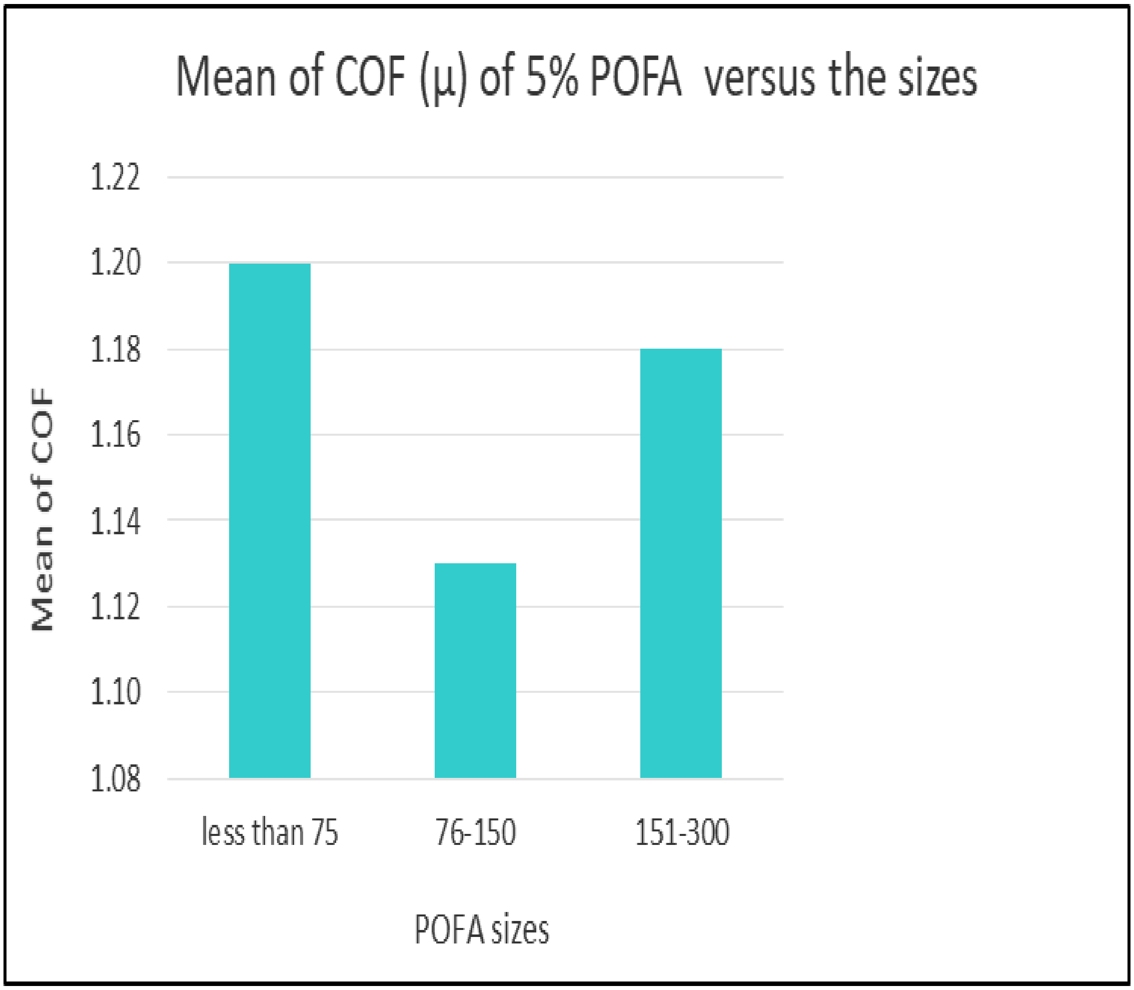


Figure 4.16: The average of COF is shown for new MMC

The fractured surface of the sample ALMMC from impact test in Figure 4.17 of microscopic revealed a smooth and lumpy texture of the Al 6061. Whereas the silicon in Figure 4.17 showed minor existence. The fracture happened to be at the surface of grains which covered by the Silica which proved in Figure 4.17. The chemical component analysis showed clearly that Silica with turquoise colour covered the matrix that is AL 6061. It is clearly indicated that the joining of a different matrix involving Silicon from POFA and Silicon from Al 6061 could be possible employing this matrix and fabrication. No physical surface defects like arc strike, crack and undercut have been observed in the above sample of the wear track.

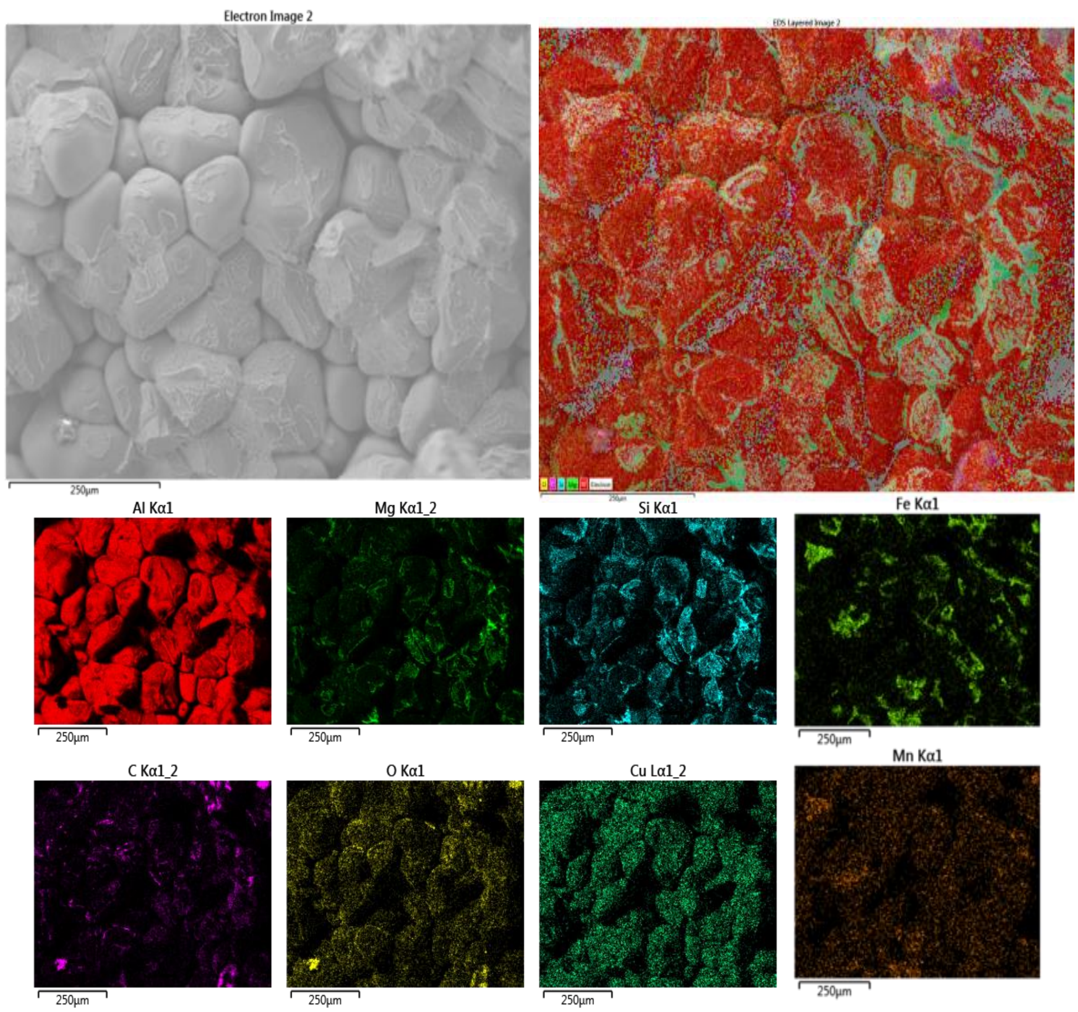


Figure 4. 17: The distribution of the Silica on the surface of the best sample of AL MMC (reinforced by 5vol. % of POFA sizes less than 75µm -the best hardness and best weight loss).

As compared to the results of the research on RHA and Alumina(Al_2O_3) done by Kenneth and Peter shows the COF, and consequently, the wear rate of composites was observed to increase by the increase in RHA wt.% (Alaneme and Olubambi 2013). The same goes for a research done on MMC consisting of Al alloy (A332) reinforced by Al_2O_3/SiC, the coefficient of friction of a fine hybrid particle size MMC's tested was lower than that of a coarse particle size MMC tested at room temperature (Altinkok, Özert, and Findik. 2013). The correlation on stainless steel showed that the Coefficient of friction, as well as surface roughness during dry sliding wear, increased with an increase in temperature (Parthasarathi, Borah, and Albert 2013).

All the selected mechanical and physical properties showed that the result of the ALMMCs was better than AL 6061 alone. Refer to chapter 2, the mechanical and physical properties of the composites depend on the bonding between matrix and reinforcement materials, and the role of the matrix is to transmit the fibres (reinforcement) the external mechanical load and to protect the fibers' external attack. Therefore, the nature of the fibers' reinforcement factor such as length, orientation, shape and material will lead to the fabrication proses of the composites as well as the mechanical and physical properties of the composites. The chemical, mechanical and reaction bonding between fibre and matrix may form the interface and the SEM analysis also help to assess the structure – properties correlations.

In the present study on a new product of the metal matrix composites (MMC) that was fabricate the AL 6061 as matrix by utilized POFA (agro Industrial waste) as reinforcement materials. This clearly showed that the result of particular mechanical and physical properties were better than an AL 6061 without reinforcement material. The investigation of new ALMMC is to get the effect of the particle reinforcement that is POFA size, percentage of volume fraction to the AL 6061 as the matrix is investigated on the impact, hardness and tensile strength as mechanical properties of new ALMMC. Wear (weight loss), friction behaviour (Coefficient of frictions (µ) as well as microstructure on new AL MMCs as physical properties were done to reveal the optimum mix that produces the best result.

The summary of the findings:

1. Fabrication of ALMMC by using stir casting method with AL6061 as matrix and reinforced by POFA successively a potential to be a new finding.

2. The chemical content in the POFA is depend on the location of the plantation, sizes of selected POFA, duration and condition of burning process and part of palm oil tree waste.

3. None from the nine samples of POFA with different conditions had Alumina (Al_2O_3). The bigger the size of POFA, more percentage of SiO_2 content, same finding to the percentage of Ferric trioxide (Fe_2O_3) content in the selected POFA.

4. The density of the POFA and density of ALMMC increased by increasing the mass percentage of the SO_3 content in the POFA.

5. The tensile strength of the ALMMC increased to a certain limit depending on the size of the POFA. The best result was shown for the sample with 5vol. % of POFA as reinforcement for the size 76 to 150 µm.

6. The Izod impact of ALMMC increased by decrease of POFA sizes up to 5.0vol. % of POFA and the smallest size shows the best result.

7. The best hardness gain for the sample of ALMMCs is 5vol. % of POFA with the smallest size that is 75µm. The correlation between the hardness and the dry sliding wear was clearly shown that the best hardness point of the new ALMMCs reinforcement was by 5vol. % of POFA at the lowest or minimum of weight loss during moving 150m distance with load 10N.

8. The average of the COF for the sizes of POFA less than 75µm was the highest among three sizes of 5vol. % POFA of the ALMMC samples. The correlation of

the mechanical (hardness) and tribological properties of the AL MMC reinforced by 5vol. % POFA with the size of 75µm, was the most optimum of the best hardness, at lowest weight loss and the highest average of COF.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions

This research report is dedicated to synthesising POFA based Al-MMC by utilising locally available Agro-Industrial waste materials (POFA). The research had examined the mechanical, and tribological properties of the fabricated POFA based AL metal matrix composite (AL MMC) material. The ALMMC was fabricated using stir casting method with POFA volume ratio between 2.5vol. % to 10vol. %. When the percentage of POFA is above 5 vol. %, the POFA cannot mix well in the stir casting machine, and the microstructure indicated that all the specimens are non-uniformly distributed.

The summary of the findings of this study were as follows:

- Fabrication of ALMMC by using stir casting method with AL6061 as matrix and reinforced by POFA successively a potential to be a new finding.

- The chemical content in the POFA is depend on the location of the plantation, sizes of selected POFA, burning process, duration of burning and part of POFA waste. None from the nine samples of POFA with different conditions had Alumina (Al_2O_3). The bigger the size of POFA, more percentage of SiO_2 content, same finding to the percentage of Ferric trioxide (Fe_2O_3) content in the selected POFA.

- The result shows the correlations between density of the ALMMCs with density POFA, the mass percentage of the SO_3 content in the POFA and tensile strength of the product. The best result was shown for the sample with 5vol. % of POFA as reinforcement for the size 76µm to 150µm.

- There is also correlation between Izod impact and hardness result of ALMMC. The best gain for the sample of ALMMCs is the 5vol.% of POFA with the smallest size that is 75µm.

- The microstructure of the POFA revealed that the more magnesium in the POFA, with size less than 75µm and between 76µm to 150µm resulting higher the high hardness and the impact energy at the fractured surface.

- The correlation of the mechanical properties (hardness) and tribological properties of the AL MMC reinforced by 5vol.% POFA with the size of 75µm, was the most optimum of the best hardness, at lowest weight loss and the highest average of COF.

5.1 Recommendations for Further Investigation

Further investigation of the new MMC consisting of mixture Aluminium 6061 and POFA are as follows:

- Overall, the result of the mechanical and tribological properties of new ALMMC are influenced by the size and volume percentage of POFA. By reducing the sizes of POFA, the bonding will be better. As this finding did not consider the agent of wettability for bonding proses, further investigation is needed to identify the wettability agent so that the new product can increase the bonding for better physical properties results.

- The sizes of reinforcement will result on the impact on the bonding process between the matrix, which is Al 6061 and its reinforcement material; references show that magnesium oxide 1% was used for wettability of the Fly ash.

- Furthermore, the conditions of the wear and friction behaviour can be more specific, such as dry (abrasive) wear to the wet (slurry) wear test, as well as different loads, sliding velocity, sliding distances and various temperatures.

- A better result in all mechanical and physical properties can be improved using Nano particles as a reinforcement material to the Aluminium alloy by reducing the porosity, so the product of MMCs can increase in its density. As a result, the more diffused the reinforcement material in the matrix, then the MMC's strength will be increased. Increase in strength of the MMC will reduce the weight loss, therefore it will be increased the wear properties.

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