EFFECT OF REINFORCEMENT VOLUME FRACTION ON THE MECHANICAL PROPERTIES OF THE AL-SIC COMPOSITE

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ABSTRACT

This thesis mainly focuses on the effect of reinforcement volume fraction on the mechanical properties of Al-SiC composite. Nowadays, there are many approach is used to enhance the mechanical properties of composite. The only argument is which method will deliver the most effective result and exhibited better mechanical properties. The decrease in volume fraction of SiC particle increase its ductility but the hardness is decrease. Therefore, the objectives of this thesis is to investigate the effect of volume fraction on the mechanical properties of Al-SiC and to optimize the mechanical properties of Al-SiC to obtain optimum volume fraction. The experiment was carried out by the powder metallurgy process. The raw materials was mixed and compact in the hydraulic press to make the green compact samples. After that the samples were sintered in the sintering furnace. The samples were prepared with 10 and 15 vol% of the SiC particles. 20 Ton load was used as the compaction load of all the samples. After that the samples were prepared for the mechanical testing and microstructure observation. The microstructure was observe in the optical microscope. The density and hardness of the samples were measured and compared. The hardness was measured by the Vickers micro hardness testing machine as per the ASTM e348. The results showed that the 15 vol% of SiC reinforcement provided better mechanical proper as compared to the other volume fraction of the reinforcement.

ABSTRAK

Tesis ini memberi tumpuan terutamanya kepada kesan jumlah pecahan pada sifat-sifat mekanikal Al-SiC komposit. Pada masa kini, terdapat banyak pendekatan yang digunakan untuk meningkatkan sifat-sifat mekanikal komposit. Salah satu daripada kaedah tersebut akan memberikan hasil yang paling berkesan dan akan menghasilkan sifat-sifat mekanikal yang lebih baik. Penurunan dalam jumlah sebahagian kecil daripada zarah SiC meningkatkan kemuluran tetapi sifat kekerasan akan menurun. Oleh itu, objektif kajian ini adalah untuk mengkaji kesan jumlah pecahan pada sifat-sifat mekanik Al-SiC dan untuk mengoptimumkan sifat-sifat mekanik Al-SiC untuk mendapatkan jumlah pecahan yang memberikan hasil yang optimum. Eksperimen telah dijalankan menggunakan proses metalurgi serbuk. Bahan-bahan mentah dicampurkan dan akan dipadatkan padat dalam mesin tekanan hidraulik untuk menghasilkan sampel asli. Selepas itu sampel telah dipanaskan dalam mesin pemanasan. Sampel disediakan dengan peratus pecahan adalah 10 dan 15 vol% daripada zarah SiC. 20 Ton beban telah digunakan sebagai beban pemadatan bagi semua sampel. Selepas itu sampel telah disediakan untuk menjalani ujian mekanikal dan pemerhatian mikrostruktur. Mikrostruktur telah dilihat di dalam mikroskop optik. Ketumpatan dan kekerasan sampel telah diukur dan dibandingkan. kekerasan yang diukur oleh mikro mesin ujian kekerasan Vickers dengan rujukan nombor e348 ASTM. Hasil kajian menunjukkan bahawa 15% daripada isipadu pecahan SiC menghasilkan ciri-ciri mekanikal yang lebih baik berbanding dengan pecahan isipadu lain.

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CHAPTER 1

1.1 INTRODUCTION

Aluminum metal matrix become favorable due to its ability to offer better mechanical properties for instant higher strength, higher tensile, increase of hardness, durability and more. Due to these advantages, Aluminum metal matrix is widely used in many engineering applications such as aerospace industry, automotive industry, electrical parts and many more. Nowadays, even bicycle and golf stick use aluminum matrix because it offers lighter weight compared to other material such as magnesium or copper.

Metal matrix composite materials increasingly replace traditional materials used in building engineering, aeronautics, mechanical engineering and in many other domains. It is related to a possibility of obtaining practically any combination of beneficial mechanical properties of the material, for example, high tensile strength, yield strength, high corrosion resistance, high vibration damping coefficient, high abrasion resistance, and higher value of the Young's modulus, low specific gravity and low coefficient of thermal expansion.

Powder metallurgy is a scope covering a wide range of ways as the materials or components are made from metal powders. Powder metallurgy refers to the process of making components with particular properties and shape by combining metal and non-metal powders. Although the process has prevailed for about 100 years, over the past century, it has become widely recognized as a better way of producing high-quality parts for a variety of important applications.

1.2 PROBLEM STATEMENT

During the last decades, numerous researches had been conducted on metal matrix composites (MMC). Some technical issues arise during the research. One of the major issues is the particle break as the crack grows because the lower volume fraction of reinforcement reduces the strength of the material. For lower volume fraction, there are many spaces between the particles as they`re only a small amount of composite fit to particular aluminum matrix composite and resulting the reduce of the material`s strength. Thus, the big spaces allow the crack to go through the material faster and break the particle. The lifetime of material reduces as the strength reduces [17]. For higher volume, huge amount of composite particle can fit in; hence make the aluminum matrix composite much more compact, hence the strength also increases. Higher amount of reinforcement inclusion in the composite forbids the cracks go through it and make the crack grow slower and take time before it reach its critical point thus break the particle. Hence the lifetime of the material increase as the strength increase. SiC known as a brittle material, hence the larger amount of SiC in a composite gives higher hardness to the Al-SiC.

The next issue is the uniformity and homogeneity of the particle is not achievable in other conventional techniques. Other conventional techniques such as stir casting, metal infiltration, spraying and in-situ process offers less uniformity of the material, because of that, the finish material does not have same strength contribution to all areas of the material. For example, a pen that its uniformity contribution is not achieved make the top part with the more compact particle distribution has far better strength compare to the middle part of the pen body which consist of less particle distribution. To overcome the problem, powder metallurgy is selected. This is due to its ability to produce material of fine and uniform microstructure [23]. Powder metallurgy offers a uniform and the same distribution of particle toward whole area of the material.

1.3 OBJECTIVES

i) To fabricate Al-SiC composite with different volume fraction of SiC particles using powder metallurgy technique.

ii) To investigate the effects of volume fraction on the mechanical properties of the Al-SiC.

iii) To optimize the mechanical properties of the Al-SiC to obtain the optimum volume fraction

1.4 PROJECT OUTCOME

The following expected outcome was determined based on the objective mentioned earlier.

i) Al-SiC MMC with different volume fraction will be fabricated

ii) Volume fraction effect will be determined

iii) Mechanical properties will be optimized

1.5 RESEARCH SCOPE

This research will focus on Al-SiC composite material of the mechanical properties and specimen standard to carry out the test. Other than that, this research focused on the data analysis of some mechanical properties of Al-SiC composites. For this research, here are the scopes that have been identified to ensure that this project keeps right on track and the objectives shall be achieved.

i. Al-SiC MMC with volume fraction of 90-10 and 85-15 will be fabricated by using powder metallurgy technique.

ii. Mechanical testing process such as hardness and density test will be carried out to determine the mechanical properties of the specimen.

iii. Microstructure will be observed and the data will be optimized for further application.

1.6 RESEARCH ORGANIZATION

The first step of this research is the background of the study. Chapter two discusses literature related to the research while chapter three explains the various steps of the experiment in this research. Chapter four discusses the result of the experiment and discussion. Chapter 5 contains the conclusion of the experiment and some recommendations also presents to improve the research and to indicate the future research goal in the related field of study. The machine and material used are contained within the appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is to provide a review of past research efforts related to metal matrix composite, aluminum matrix composite, SiC reinforcement, composites production and powder metallurgy. A review of other relevant research studies is also provided. Substantial literature has been studied on the mechanical properties effects toward a different particle volume fraction of reinforcement. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope and direction of the present research effort.

2.2 METAL MATRIX COMPOSITE

Metal matrix composite materials increasingly overcome traditional materials used in many engineering applications. It is connected to a probability of gaining practically any combination of the good properties of the material for example, high vibration damping coefficient, high abrasion resistance, high value of the Young’s modulus, low specific gravity and low coefficient of thermal expansion [1].

Table 2.1: Applications of MMC

Industrial Applications	Components
Aerospace	Struts, antennae
Automobile	Piston crowns, engine block
Electrical	Superconductor, electrodes

Source: Sandeep Mahore, 2014

According to Broutman and Krock, the term of composite material refer to the meanings as follows: “A composite material is formed by a close combination of at least two chemically and physically distinct materials which should remain separate and distinct while a good and continuous interface between them is maintained; the reinforcing components in the whole volume of the metal matrix should be as uniform as possible.” This definition explained a perfect composite material of an ideal structure. In realistic composites, an imperfect structure is generally present if the composite materials contain various defects [1], especially if cast composites are considered.

The cause for this is the specific structure of castings, resulting from a course of the manufacturing process. Description of these imperfections allows their unequivocal determination, establishing reasons of their formation and stage of the manufacturing process at which they start to emerge and quick undertaking of preventive measures.

Material involved in making composite can be organics, metal or ceramics. Accordingly, there are many type of composite and several methods of classifying them [1]. One method is based on geometry and consists of three distinct families:

a) Structural (laminar or layered composite)
b) Particulate composites
c) Fiber-reinforced composites

Figure 2.1 shows classification tree of the classification of composite material. It will give better understanding and view regarding the way it’s been classified.

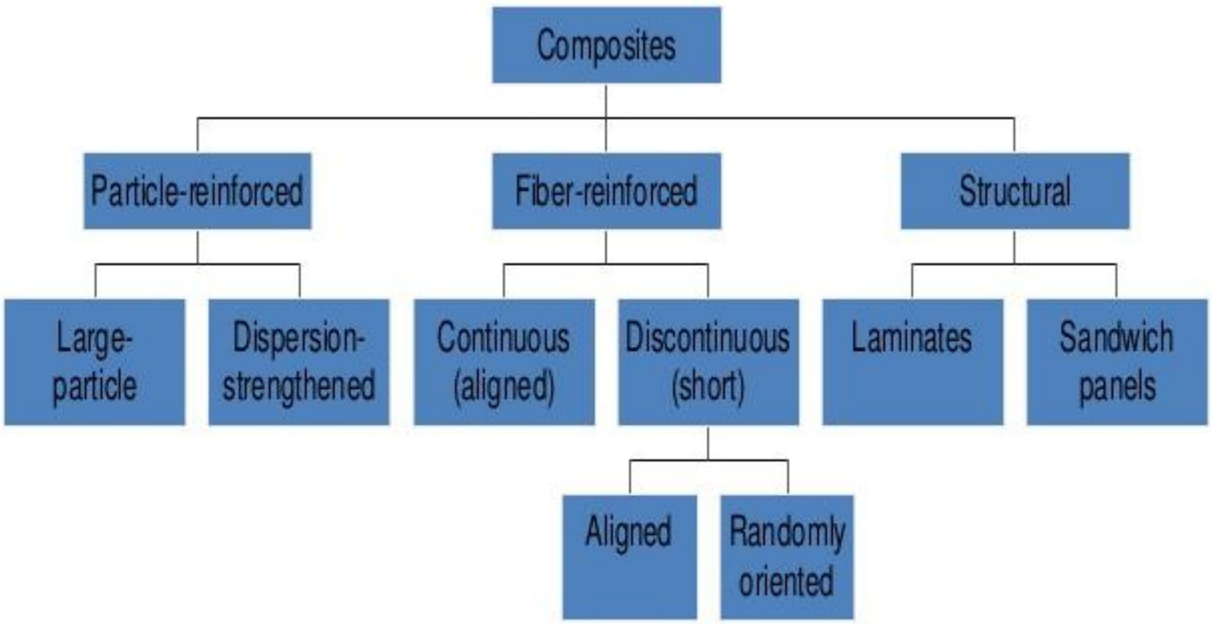


Figure 2.1: Classification of composite based on geometry

Source: www.slideshare.net

Metal matrix composites provide high strength to weight ratio, increase in stiffness, good wear resistance and higher resistance to corrosion. Those factors emerge them as an attractive option in replacing conventional materials for many engineering applications [2]. Nowadays, composite that have more than one reinforcement is referring as hybrid composites. This composite considered favorable to use in an application because of improved mechanical properties and better substitutes for a composite with single reinforcement.

Metal matrix offers better properties, both in term of physical and mechanical properties than other conventional materials in scope of surface characteristic, strength, microstructure and many more. Metal matrix composites are composed of an elemental or alloy matrix in which a second phase is bound and distributed to achieve improvement [3]. The composite property varies based on the particle size, shape of the particle and the amount of the second phase.

There are considerable differences in published property data for MMC`s. This is mostly due to the fact that there are no standard industries for MMC. Reinforcements and composite are particularly made by proprietary processes and as implications; the properties of materials having the same nominal composition can be radically not the same. Many changes may happen due to its manufacturing process, reinforcement and matrix reaction, particle size and volume fraction of the reinforcement [4].

They`re widely used in the field of automotive and also aerospace due to their high strength to weight ratio, light in weight, lower cost spends and excellent behavior. In composites, the higher demands of further structural application lead to the meet of combination of light weight material, high wear resistance and useful mechanical properties. MMC`s are always more expensive than the other conventional material they are replacing. As a result, they are found where much better properties and performance justify the increase in cost. Today they are broadly found in aircraft components, space systems and high end boutique sport equipment.

2.3 ALUMINUM METAL MATRIX

The two commonly used metal matrices are aluminum and titanium based metal. This titanium and aluminum metals have radically low specific gravities and available in a variety of forms. Despite magnesium provides less weight, its huge attraction toward oxygen (H2O) causes corrosion of atmosphere and makes it less effective for multiple applications. Beryllium is considered the lightest compared to other structural metals and has a higher tensile modulus than any other steel material. However, it suffers from the exceptional brittle problem, which is the main cause for its elimination as a candidate of matrix material [5].

Aluminum is the majority metal in the planet earth, and come third as most abundant element after oxygen and silicon. The aluminum matrix composites compose from the mixtures of two or more elements that is one of the main elements must consist of aluminum or aluminum alloy. The element needs to present in a large number of volumes and need to be in the form of matrix material. Aluminum alloys are particularly favored as a matrix due to its advantages such as low in density, excellent isotropic mechanical properties, good corrosion resistance and fair cost. Amongst aluminum, 6061 is an Al–Mg–Si alloy broadly used for important approach because it provides good material strength, weld ability, high resistance to corrosion, exemption to stress corrosion cracking as well as establish precipitates that increase the strength but somewhat reduces its ductility [6]. Figure 2.2 shows the grain structure of Aluminum powder.

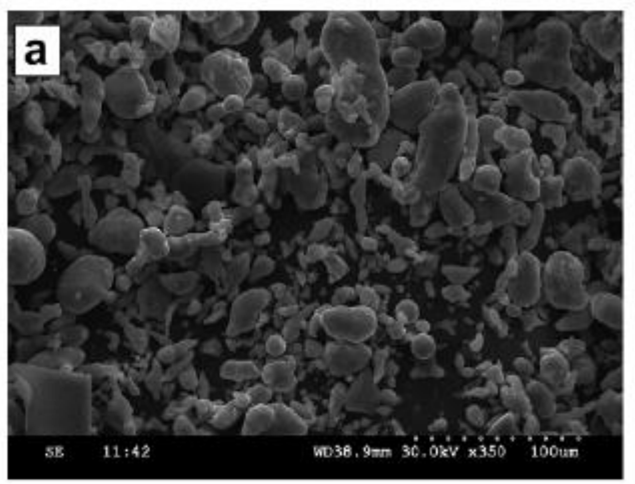


Figure 2.2: Grain structure of Aluminum powder

Source: P.Ravindran, 2012

Some benefits of using AMCs for various structural, non-structural and functional purposes in different engineering application and approach are excellent performance level, fairly economic and environmental friendly. An important virtue in carriage sectors is a lower rate of fuel consumption, less noise and cost competitive as compared to other engineering materials [7]. The aluminum alloy composites are becoming favorable engineering materials and delivering a magnificent fusion of properties for an instant increase in specific strength, specific stiffness become higher and also offer excellent conductivity of electrical and thermal factors.

Moreover, it also provides benefits such as low coefficient of thermal expansion and wear resistance.

In automobile field, aluminum composites are usually used in producing numerous components such as brake drum, engine pistons, functional drive shafts and more. In aerospace industries, composites are widely used essentially in structural approach such as helicopter parts and rotor vanes in compressors.

The main limitation of aluminum is it has low resistance to wear. This problem can be solved and overcome by the presence of ceramic particles in the aluminum matrix. Composites can be constructed with fibers or unrefined materials, which there is a higher possibility to apply hard ceramic particles.

This is due to the factor in which by using such reinforcement, it enables the control of matrix toward the behavior of microstructure and mechanical and physical properties through restraining the factor such as volume fraction, particle size and distribution of constituents.

2.4 SILICON CARBIDE REINFORCEMENT

Silicon Carbide (SiC) usually selected as reinforcement because it offers good properties, for instance increase in strength, high Young’s modulus, high resistance to thermal shock and its ability to configure a powerful bond to aluminum [8]. The matrix–particle strength is important as it controls the efficiency of load transfer; affect the strength behaviors, also the serenity of decohesion, which can lead to the composite’s failure mechanism [9]. Figure 2.3 shows the Aluminum powder used mainly in industry and also for education purpose.

Figure 2.3: Commercially available silicon carbides particles

Source: S.K Mishra, 2012

In aeronautic–aerospace, transport, the automotive industry and many more, SiC reinforced metal–matrix composites are believed to be good candidates to be used as exceptional materials. The main point to their benefits of refinement located in the structure, chemistry factor and the nature of bonding of Al–SiC. An imminent limitation faced in the invention of Al-SiC alloy composites is that Al alloys basically do not wet with the ceramic reinforcements [10]. Aluminum is a material that is economical, sustainable and mobile. The inclusion of ceramic particle into Aluminum structure can enhance certain mechanical properties. Figure 2.4 presents an illustration of Al-SiC composite microstructure.

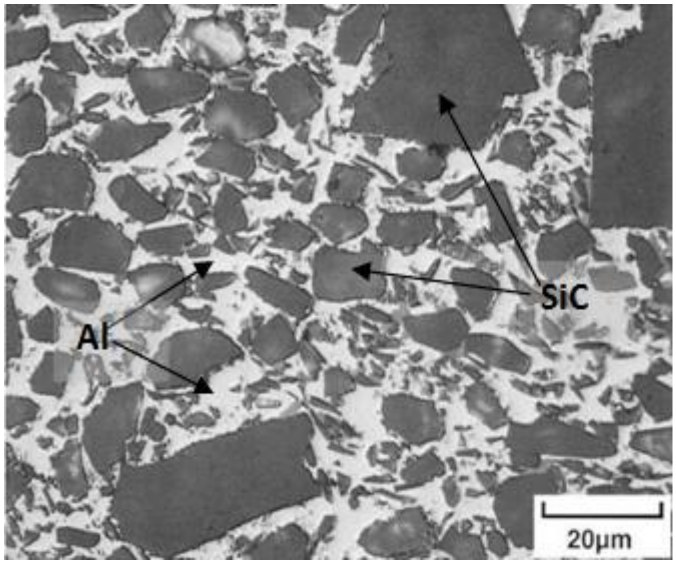


Figure 2.4: Microstructure of Al-SiC Composite

Source: H.R Zafarani, 2013

2.5 COMPOSITE PRODUCTION

There are many ways to produce matrix composites. Those processes are powder metallurgy, metal infiltration, stir casting, spraying and also in-situ processing techniques. Compare to all technique, powder metallurgy is considered favorable in producing matrix composite. Powder metallurgy is the process of constructing components with specific properties and shape by combining two distinct materials which are metal and non-metal powders. Powder metal products are manufactured by the various procedures. Some of the procedures are manufacturing of metal powders, sintering, finishing and compacting [11].

Stir casting happens when the powder form was distributed into magnesium in the form of molten magnesium, via a process called mechanical stirring. The stir casting of metal matrix composites was established way back in 1968, when S. Ray [1969] proposed aluminum particles into melting alumina by stirring the molten aluminum alloys with a ceramic powder in it. This required fusion of ceramic particulate into melting liquid aluminum and the solidifying process occur. Good wetting between the particle reinforcement and the melting liquid aluminum alloy is the crucial thing to create [12].

Compared with ordinary processes of powder metallurgy (PM) and casting in producing metal matrix, pressure-less melt infiltration is considered as a cost-effective way to produce the composites containing high value of volume fraction of reinforcements [13]. The aluminum matrix composite supplement with high value of volume fraction of SiC particles is a representative one synthesized by pressure-less melt infiltration. However, their properties and the influences of high volume fraction reinforcement on them, especially the creep behavior, have yet to be clarified, therefore they present work is dedicated to the research of the compression creep conduct of aluminum composite reinforced with a high volume fraction of SiC particles [13]. Figure 2.5 show the forming of sample after undergoes powder metallurgy process.

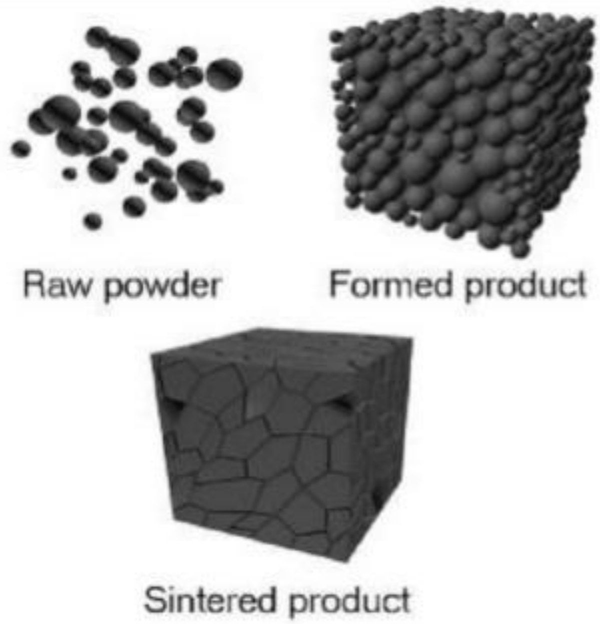


Figure 2.5: Powder metallurgy process sample structure

Source: XU Fu-mina, 2006

Atmospheric plasma spraying is one of the most basic concepts to use in thermal spraying processes because it offers some good capabilities such as flexibility, increase in deposition rates and multifunction. Plasma spraying is engaged to deposit coatings for most materials, including metal alloys and ceramics.

In an in-situ process, the reinforcements are established in between the matrix during the manufacture of the composite by some reaction of chemical. The in-situ reinforced MMCs offer more benefits compare to other traditional existing ex-situ process of MMC reinforcement as follows [15];

a) reinforcements are fairly steady in the matrix
b) strong interfacial bonding resulting in the form of clean, non oxidized particle– matrix interfaces
c) better reinforcing phases are distributed evenly, thus better mechanical properties can be achieved
d) cost effective

For many processes exist in producing matrix material, powder metallurgy technique is considered favorably compare to other technique exist. It can verify as many applications in industry such as aerospace application and automobile industry prefers to use powder metallurgy in producing the mixture of metal matrix composite with composite particle.

There are a number of reasons for making engineering components by powder metallurgy and these lead to the groupings below:

a) High duty material
b) Composite Materials
c) Porous Materials
d) Structural (or Mechanical) Parts

2.6 POWDER METALLURGY

Powder metallurgy is considered the most appropriate method to fabricate MMC because of the ability of the process to come up with near net shapes and less material waste [11]. Powder metallurgy (PM) has much to provide because the mixture and sintering of powder materials produces an extremely fine material with uniform microstructure [15]. Table 2.2 shows the typical work piece materials use for this technique.

Table 2.2: Typical work piece materials

Workpiece material	Density (grams/cc)	Yield strength (psi)	Tensile strength (psi)	Hardness
Iron	5.2 to 7.0	$5.1*10^3$ to $2.3*10^4$	$7.3*10^3$ to $2.9*10^4$	40 to 70
Low alloy steel	6.3 to 7.4	$1.5*10^4$ to $2.9*10^4$	$2.00*10^4$ to $4.4*10^4$	60 to 100
Alloyed steel	6.8 to 7.4	$2.6*10^4$ to $8.4*10^4$	$2.9*10^4$ to $9.4*10^4$	60 and up
Stainless steel	6.3 to 7.6	$3.6*10^4$ to $7.3*10^4$	$4.4*10^4$ to $8.7*10^4$	60 and up
Bronze	5.5 to 7.5	$1.1*10^4$ to $2.9*10^4$	$1.5*10^4$ to $4.4*10^4$	50 to 70
Brass	7.0 to 7.9	$1.1*10^4$ to $2.9*10^4$	$1.6*10^4$ to $3.5*10^4$	60

Source: en/ Wikipedia.org

The used of powder metallurgy method in order to produce aluminum composite reinforced with SiC particulates produce a homogenous and evenly uniform distribution of reinforcements in the matrix, compare to another method of production like casting and thixo-forming. Casting and thixo-forming have the difficulties in reinforcement separation and converging, the interfacial reaction of chemical, localized residual porosity is high and decrease in interfacial bonding strength. Some other production method, for example spray deposition is required higher cost which might lie down its application [15].

The main advantages of powder metallurgy techniques over other methods, such as liquid and vapor state processing, the processing temperature is relatively low, which might evade unnecessary interfacial reactions of both matrix and reinforcements. As some demand of specific desirable mechanical properties based on characterization, condition and needs, powder metallurgy technique variations emerged. Those variations consist of cold compaction, hot pressing and sintering.

2.7 MECHANICAL PROPERTIES

Several research have stated that desired mechanical properties such as hardness, density, yield strength, thermal conductivity and tensile strength could be easily achieved and controlled by varying different processing routes such as compaction pressure or sintering temperature of the powder metallurgy method.[16,17] In powder metallurgy method by increasing sintering temperature above the melting point of matrix metal not only breaks oxidation layer and fill porosity but also increases micro-mechanical properties [17].

In order to shape powders into porous parts, called greens, the cold compaction process is used. Basic processes of compaction of the powder are uniaxial pressing, isostatic pressing, high speed forming, extrusion forming, vibration forming, centrifugal forming, rolling forming, continuous forming, gravity forming, and mixture forming. The cold compaction method is mostly preferred because of its lower cost and satisfactory properties.

The sintering process refers to the process in which heat treatment is applied to the material so the compact powder gains stable cohesion. The sintering temperature needs to be lower than the melting temperature of the main component to prevent the powder melt [18]. The typical properties of some metal used as matrices in composites are shown in Table 2.3.

Table 2.3 Typical properties of some metal used as matrices in composites

Source: Jasmi Hashim, 1999

Metal	Density [gcm^{-3}]	Melting Point [^oC]	CTE [$x10^{-6o}C^{-1}$]	Tensile Strength [MPa]	Modulus [GPa]
Aluminum	2 8	590	23 4	310	70
Beryllium	1 9	1280	11 5	620	290
Copper	8 9	108	17 6	340	120
Lead	11 3	320	28 8	20	10
Nickel	8 9	1140	13 3	760	210
Niobium	8 6	2470	6 8	280	100
Steel	7 8	1460	13 3	2070	210
Tantalum	16 6	2990	6 5	410	190
Tin	7 2	230	23 4	10	40
Titanium	4 4	1650	9 5	1170	110
Zinc	6 6	390	27 4	280	70

In comparison to the cold pressing, higher densities can be obtained by means of the hot pressing method. The densification capability of metal powders is an important factor, which determine the final properties of the materials, for instant hardness, the tensile strength and wear resistance [19]. Hot Pressing is a process of powders densification or cast and parts that have been sintered in a furnace at relatively high pressure in the range of 100 to 200 MPa and at particular high temperatures, with a range in between 900 to 1250°C such as steels and super alloys.

2.8 VOLUME FRACTION FACTOR

In the Al-SiC MMCs materials there are certain factor that will affect the properties of the materials. Based on the journals, volume fraction is one of the factors that will affect the properties of the materials.

With increasing particles' volume fraction the strength is improved due to a greater number of dislocation barriers but the ductility will affected and if too many volume is used the materials can be brittles, as deformation is localized on a smaller volume of the plastic matrix which is then less able to accommodate the deformation[20]. Figure 2.7 shows the microstructure of composites under different value of volume fraction.

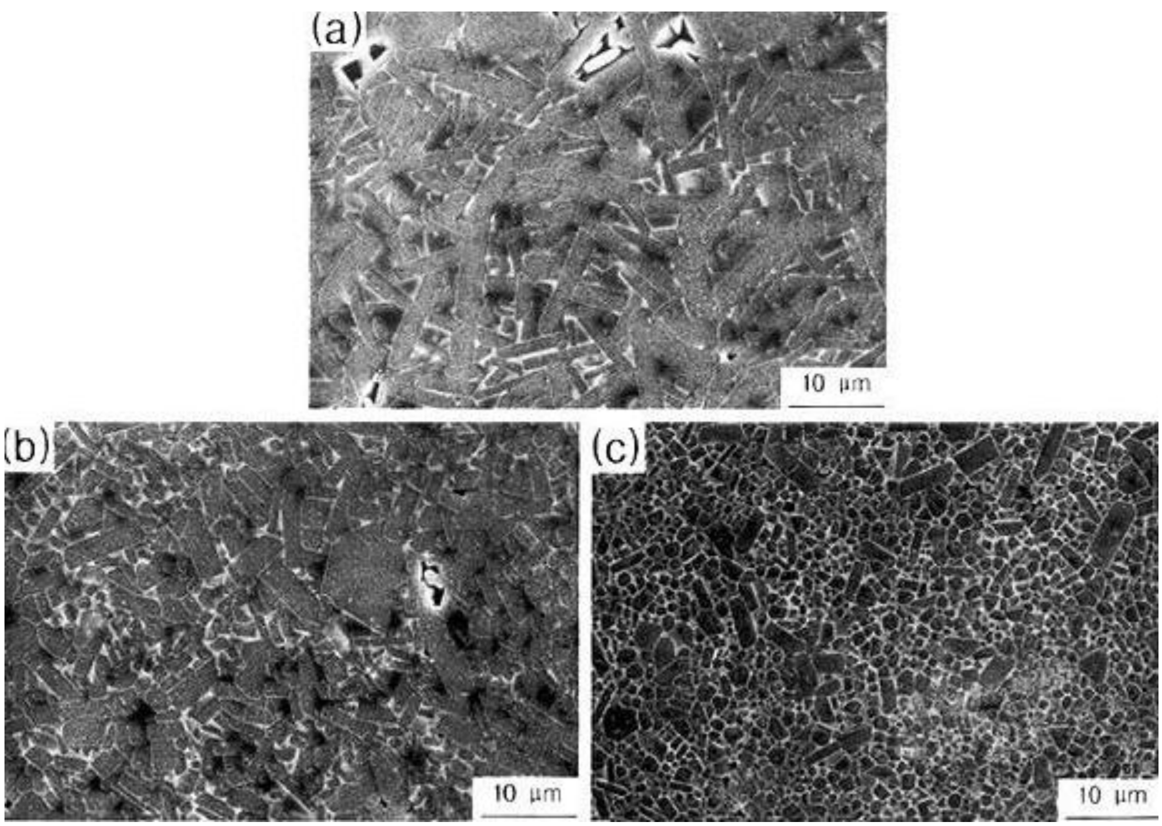


Figure 2.7: Microtructure of composite under different volume fraction: a) 100% Al b) 90% Al-10% SiC c) 100% SiC

Source: V. K. Mai, 2009

Yield strength and tensile strength will growth if the volume fraction of the SiC particles is multiplied, at the same time as the elongation could be decreases if the volume fraction of the SiC particles is extended, indicating that increasing the volume fraction of the SiC particles can enhance the strength, however degrade the plasticity of the composites. Increasing the volume fraction of the particles additionally decreases the ductile fracture characteristic. [21] Table 2.3

Table 2.3: Mechanical properties of composites

Volume fraction of SiC particles/%	Yield strength/MPa	Tensile strength/MPa	Elongation/ %
0	56.6	84	26.2
4	58.3	91	14.1
8	59.7	96	12.5
12	61.4	103	9.5
16	62.9	115	8.4
20	64.6	127	7.2

Source: Min Song, 2010

Lewandowski, 2001, indicated that reinforcement distribution improves and mechanical properties gained better combination when the volume fraction of reinforcement increases from 10% to 20% of SiC. [21] The inclusion of ceramic particle inside the composite can improve the hardness and durability but the ductility is decrease.

2.9 CONCLUSION

Matrix composites with higher volume fraction highlight the strength and hardness, but had lower tensile strength and durability compared to matrix composite containing smaller volume fraction of reinforcement. However, further researches on the effect of volume fraction toward the behavior of a microstructure, density and hardness are still restricted, especially at a certain temperature. Particle-reinforced metal-matrix composites combining with ceramic particle-reinforced aluminum had already become as good prospect for many engineering and industrial application due to their high value of their increase in specific strength and stiffness and also the extra benefits of being easy to machine and workable. There are lots of reinforcement characteristics that affect the mechanical properties of the composites. These mechanical properties converge into three main components which are volume fraction, particle size of reinforcement and reinforcement dispersion.

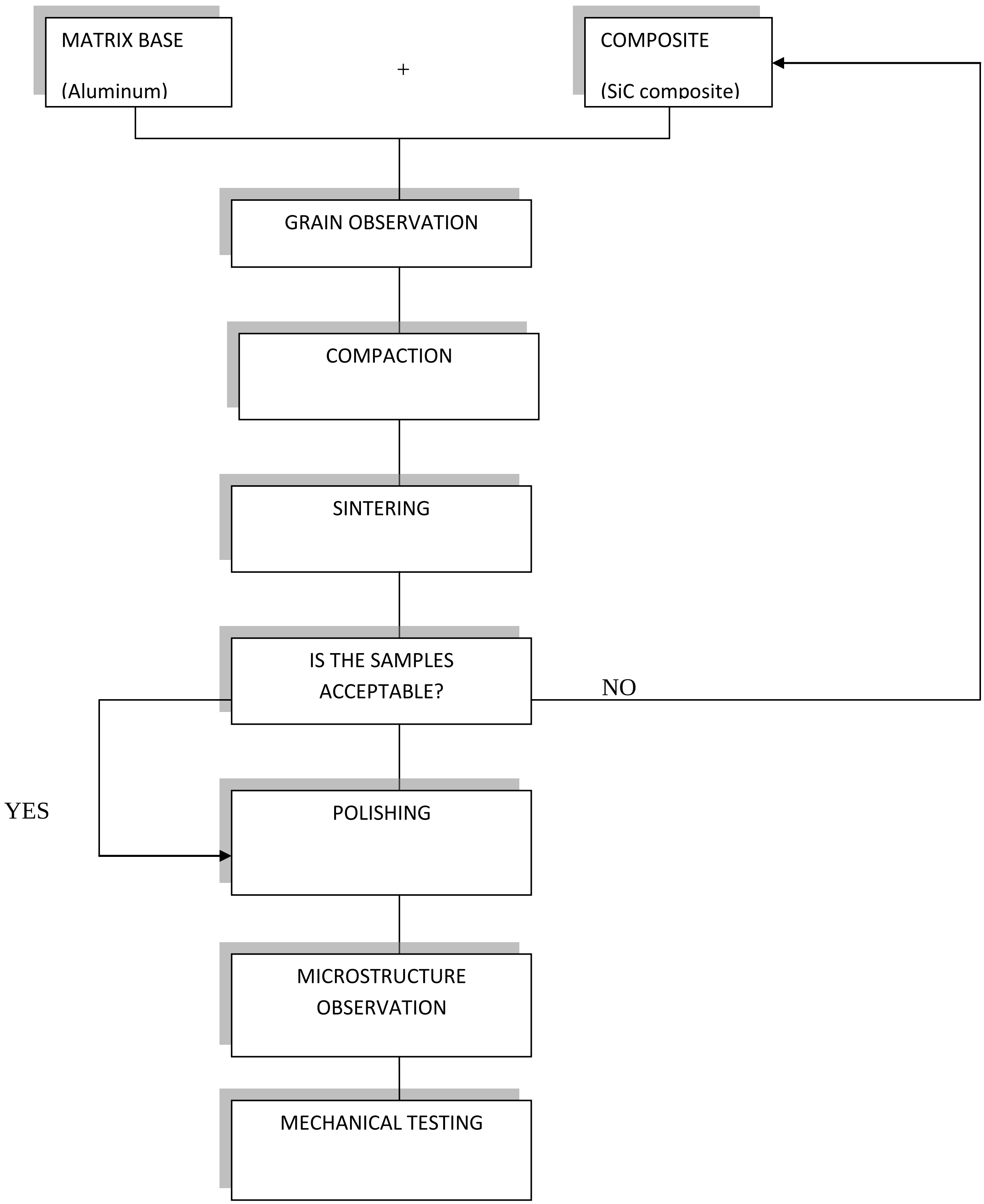
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the methodology that is used in this study. The first section describes the steps involved. It is represented in the form of flow chart to give a better understanding and explanation. The flow chart shows the sequence of steps that is used to produce samples of Al-Sic composite by using powder metallurgy technique. This research study was conducted based on the methodology. This methodology plays an important role in implementing this research study accordingly. The details of the methodology are explained in detail in this chapter.

3.2 FLOW CHART



3.3 RAW MATERIAL

The raw material is very important for this research. It is the main ingredient in producing the composites. The material is present in the form of powder and each material need to be treated properly to prevent any inclusion of unwanted substances. The raw material forms are shown as in figure 3.1.

Aluminum powder Silicon Carbide powder

Figure 3.1: Al and SiC powder

3.4: SAMPLE PREPARATION

First step in producing the sample is calculated the weight fraction of each Aluminum powder and Silicon Carbide powder. Each molecular weight is identified and a ratio of 1:4 is used. The mass of the Al powder and SiC powder are measured by the electronic weighing scale. The mass of the powders is calculated by the molecular mass.

The mass of the Al powder is calculated using the equation as expressed in Eq. (3.1)

$$m_{Al} = \frac{90}{100} \times M_{Al} \tag{3.1}$$

Where, m_{Al} = mass of Aluminium

M_{Al} = molecular mass of Aluminium

The mass of the SiC powder is calculated using the equation as expressed in Eq. (2.2).

$$m_{SiC} = \frac{10}{100} \times M_{SiC} \tag{3.2}$$

Where, m_{SiC} = mass of Silicon Carbide

M_{SiC} = molecular mass of Silicon Carbide

The calculation for specimens is as follows

Same concept is used for 85-15 composition. The percentage need to change for such 82445/100 for Al and 15/100 for SiC. The powder is then being weighed to get the same exact mass of specimen as the calculated weight fraction. Figure 3.1 show the visual of the weighed Al and SiC powder.

Next step is mixing process of both powder by powder metallurgy techniques. The mixture is prepared by mixing the Aluminum powder and Silicon Carbide powder together until it has become a homogenous mixture called Aluminum + Silicon Carbide composite. The mixture process is manually done by using ceramic bowl and pastel mortar. The mixing process took about an hour before it is considered as homogeneous mixture. The visual process of mixing is shown as figure 3.2.

Figure 3.2: Mixing of Al and SiC powder

The process is continued with the compaction phase. The mixture of Al-SiC powder needs to undergo compaction process in order to get a compact, solid form of composites. The mixture is put in designated die before compaction process occurs.

This compaction process involves a machine call hydraulic press. A hydraulic press is a machine that generates a compressive force by applying a hydraulic cylinder to the die. The machine will abrasively press the mixture material using 20 Ton of pressure.

After the sample is press for about 3-4 minute, it will be taken out form the die. A round shape of solid Al-SiC composite will produced. The sample is shown in figure 3.3.

Figure 3.3: Sample of composite after compact (green compact)

After compact powder material exists, sintering process takes over. Sintering is a heat treatment exerted to a compact powder in order to provide strength and binding integrity of the powder compact. A furnace machine is used to sinter the powder material in certain temperature. Usually, the temperature used for sintering is below the melting point of the powder metallurgy material. For this research, a temperature of 540 degrees is used. An exceeding of temperature can cause the melting of Aluminum composite.

The sintering process took about 8 hours of sintering and a day of cooling phase before the sample is considered as finish goods. Figure 3.4 shows the final product of composite experienced cooling phase.

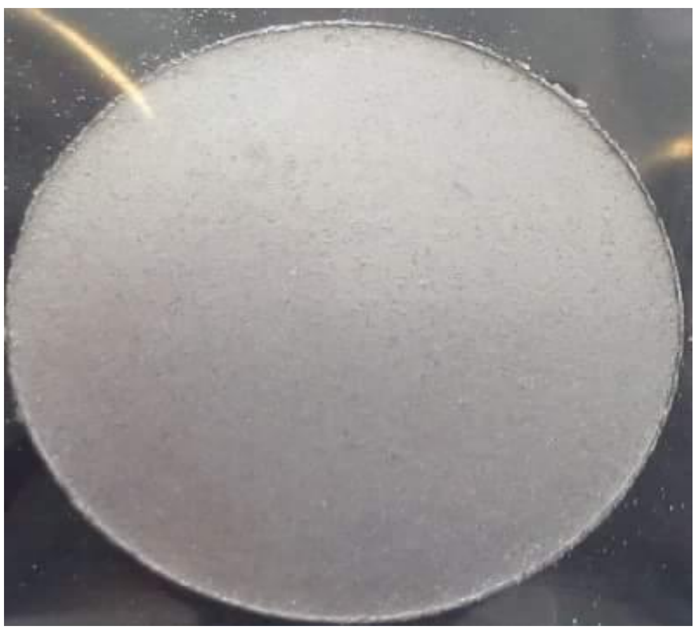


Figure 3.4: Sample after sintering

After sintering, the sample will be mounting. First, the sample will be cut into pieces. A saw is used to cut the sample in few pieces. Figure 3.5 shows the pieces sample that is cut into pieces.

Figure 3.5: Pieces of sample

The pieces were then will undergo mounting process. Acrylic resin powder, Acrylic hardener clear liquid and Silica gel were used as mounting medium. Those materials will blend together and a piece of sample will be put inside a container. Then the sample took about 4-5 minute before it hardened. Figure 3.6 show the final form of sample after being mounted and harden.

Next, the sample will be grind so that a smooth surface can be achieved. Different type of surface of sand paper is used for grinding process, starting from 600p until 1800p before a clear and shiny surface is achieved. Force is applied to the sample as the rotating sand paper grinds the surface of the sample. The grinding machine is used for the grinding process.

Lastly, polishing process of sample is conducted. This process is important so that a good, clear surface of sample for microstructure observation is achieved. Polishing powder and liquid are used to in this polishing process.

3.3 MECHANICAL TESTING OF SAMPLES

3.3.1 MICROSTRUCTURE OBSERVATION

The microstructure of the composite will be observed to identify and observe the actual structure of Aluminum and Silicon Carbide inside the composite. A machine called optical microscope is used for the microstructure observation process. Sample is put on the platform and will be observe by various selection of magnification lens.

3.3.2 DENSITY TEST

Density test is conduct to identify the mass of samples before and after sintering. Weighing machine is used to weigh the mass of the sample before and after sintering. The process is shown as in figure 3.6.

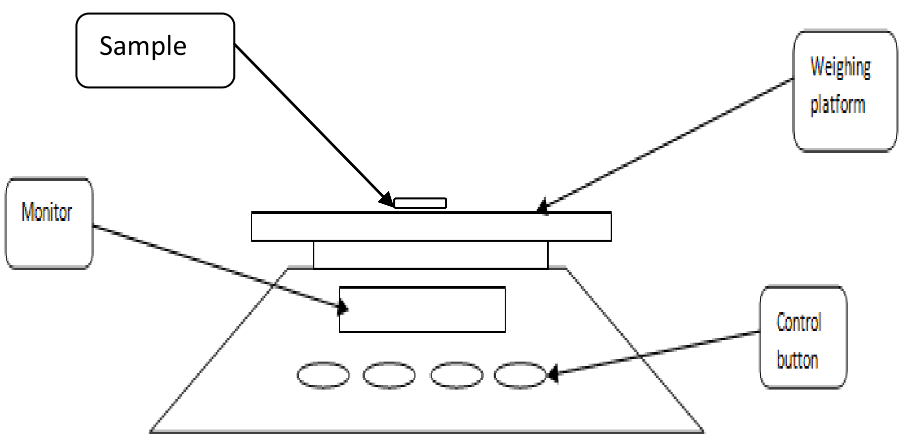


Figure 3.6: Density test

3.3.4 HARDNESS TEST

Hardness test is the most important aspect for this research to evaluate the properties of the composites. Result of hardness test can be used to determined the sustainability of the composites and to identify which composition provide better strength. The hardness is determined by forcing the load tip to specified area and measuring the diameter of Silicon Carbide structure, which appear in the form of diamond shape. The process is shown as in figure 3.7.

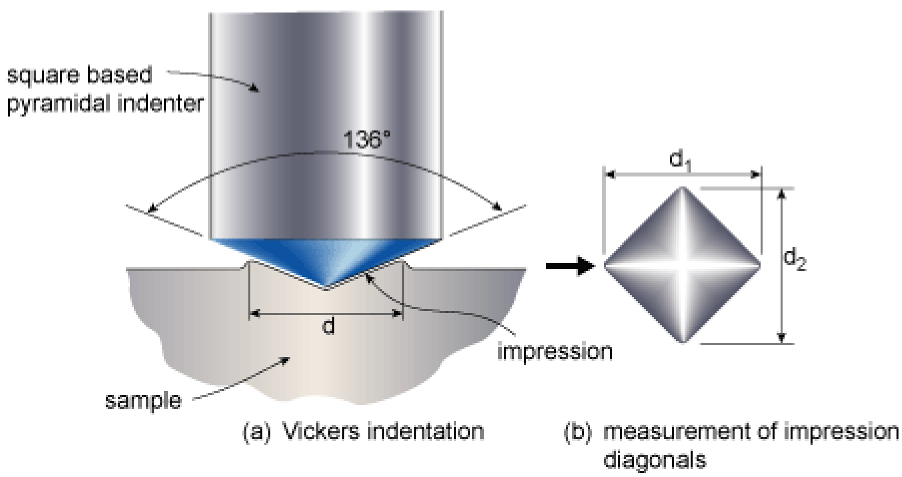


Figure 3.7: Hardness test

This test used Vicker hardness machine to identify the hardness of the composite. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist deformation from a standard source. The unit of hardness given by the test is known as the vickers pyramid number (hv) or diamond pyramid hardness (dph).

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results of magnified image of the microstructure, density of composite before and after sintering and the hardness test result of the composites. The result of mechanical properties obtained were then compared in order to verify the effect of volume fraction toward the composite`s mechanical properties.

4.2 WEIGHT FRACTION AND MATERIAL COMPOSITION

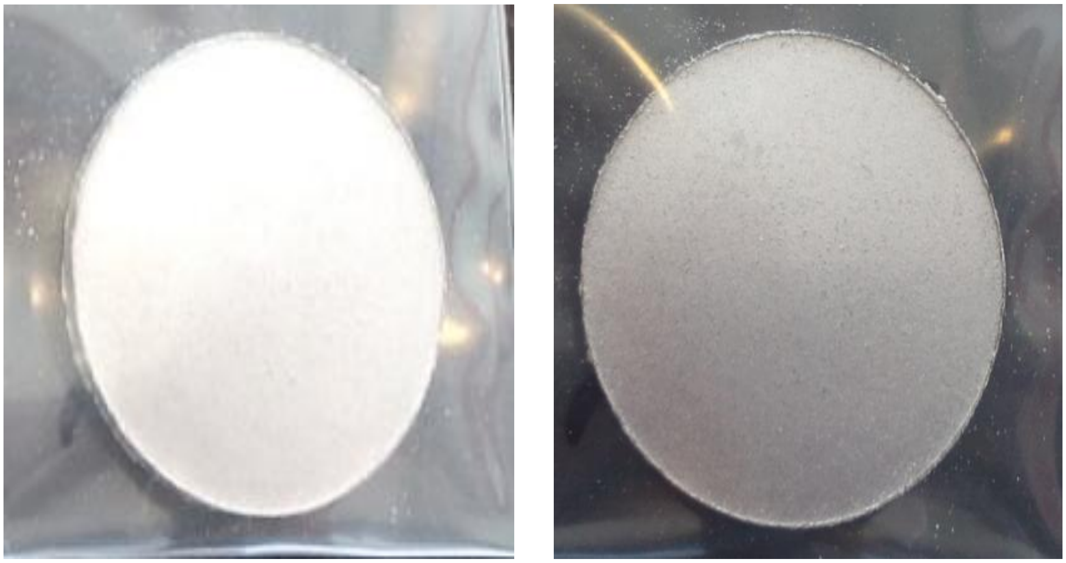
The material's weight fraction and material composition of the specimen was determined by the percentage of 90-10 and 85-15 from the mixture of both Aluminum powder and Silicon Carbide powder. After the molecular mass of Aluminum and Silicon Carbide is identified, a calculation to set up the weight fraction of the composite mixture is conducted. A ratio of 1:4 of the actual mass is used. Table 4.1 shows the result of final weight fraction used in this experiment.

Table 4.1: Weight fraction of Al-SiC mixture

	Al	SiC
Molecular weight	26.98 g/mol	40.0692 g/mol
Composition of Al-SiC (90% Al + 10% SiC)	24.282 g	4.009 g
Composition of Al-SiC (85% Al + 15% SiC)	21.584 g	6.0104 g
Ratio of 1:4 90-10	6.0705 g	1.0025 g
85-15	5.396 g	1.5026 g

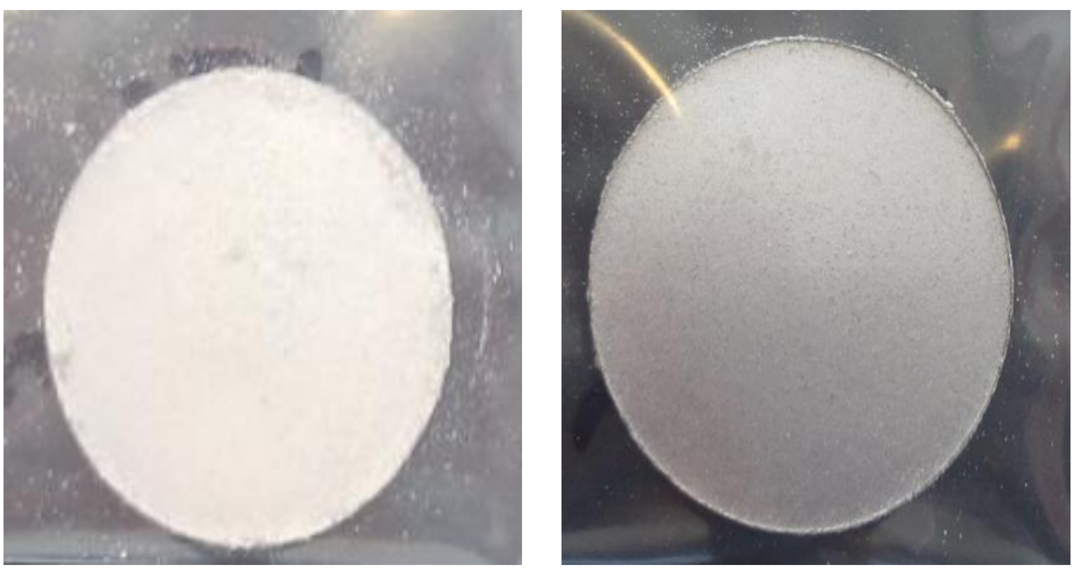
4.3 SAMPLE BEFORE AND AFTER SINTERING

The sintering process was done to get a solid form of Al-SiC composites. Two samples of Al-Sic with 90-10 and 85-15 composition undergo sintering process. Both samples show distinct differences especially toward its surface finish and physical structure. Figure 4.1 and 4.2 show the sample of both samples before and after undergo sintering process.



Green compaction Sintering

Figure 4.1: Sample of 90-10 before and after sintering

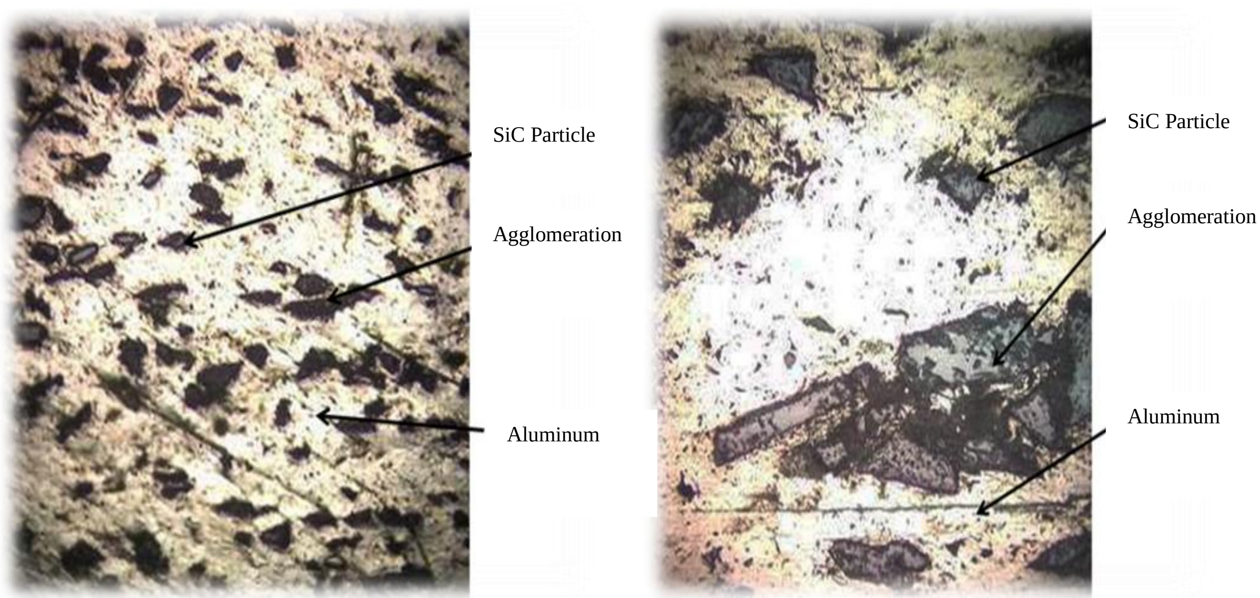


Green compaction Sintering

Figure 4.2: Sample of 85-15 before and after sintering

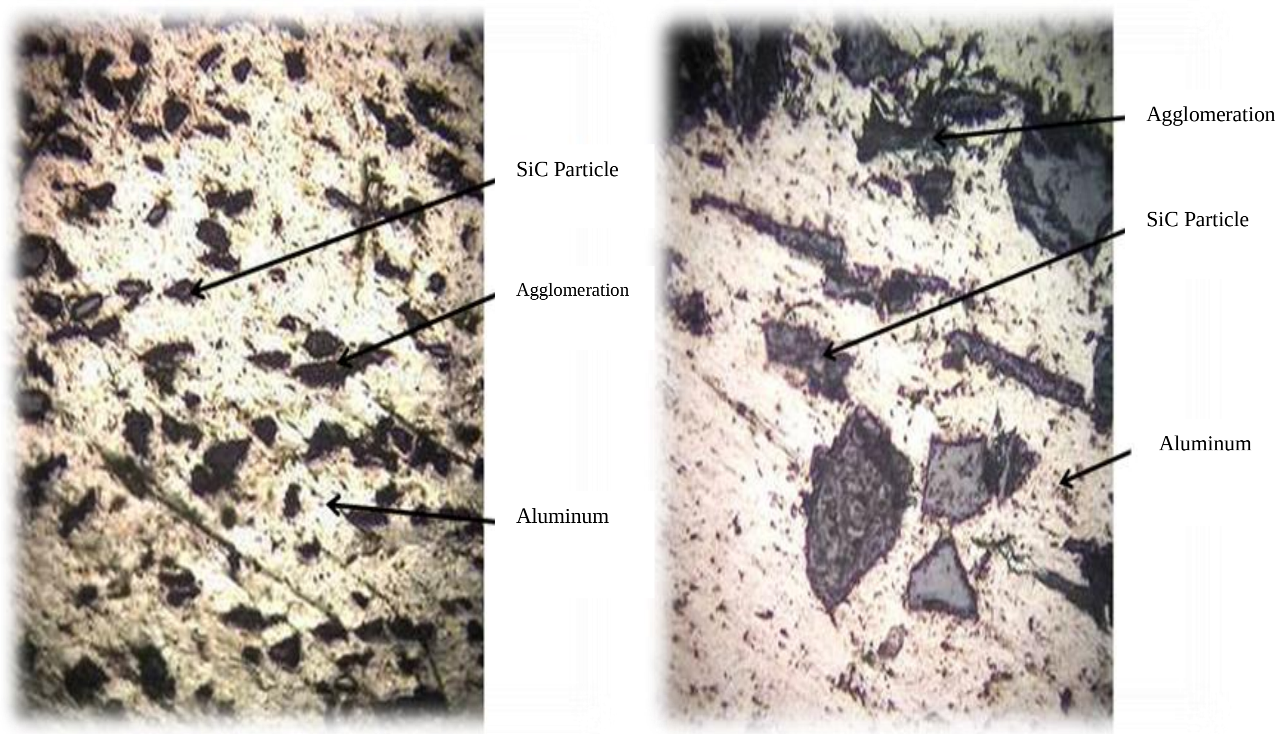
4.4 AL-SIC MICROSTRUCTURE

Both samples of 90-10 and 85-15 of Al-SiC were then undergoes microstructure observation by using optical microscope. This process is important in order to identify the microstructure forming and to observe the structure of Aluminum, Silicon Carbide and also the forming of agglomeration inside the composite microstructure. Magnification of x5 and x20 is used in the microstructure observation process. Figure 4.3and 4.4 show the microstructure of the Al-Sic composites for both compositions.



5 X magnification 20 X magnification

Figure 4.3: Microstructure of 90-10 Al-SiC



5 X magnification 20 X magnification

Figure 4.4: Microstructure of 85-15 Al-SiC

4.4: DENSITY OF SAMPLE BEFORE AND AFTER SINTERING

The samples of both Al-SiC composition carry out different density whether before and after sintering process. Both samples experienced in the loss of density after undergo sintering process. The difference in density is shown in table 4.2.

Table 4.2: Density of Al-SiC before and after sintering

Composition	90-10	85-15
Weight before	0.0253 g	0.0264 g
Weight After	0.0151 g	0.0159 g

Figure 4.5 shows a graph of comparison between 90-10 and 85-15 composite in term of density before and after sintering process.

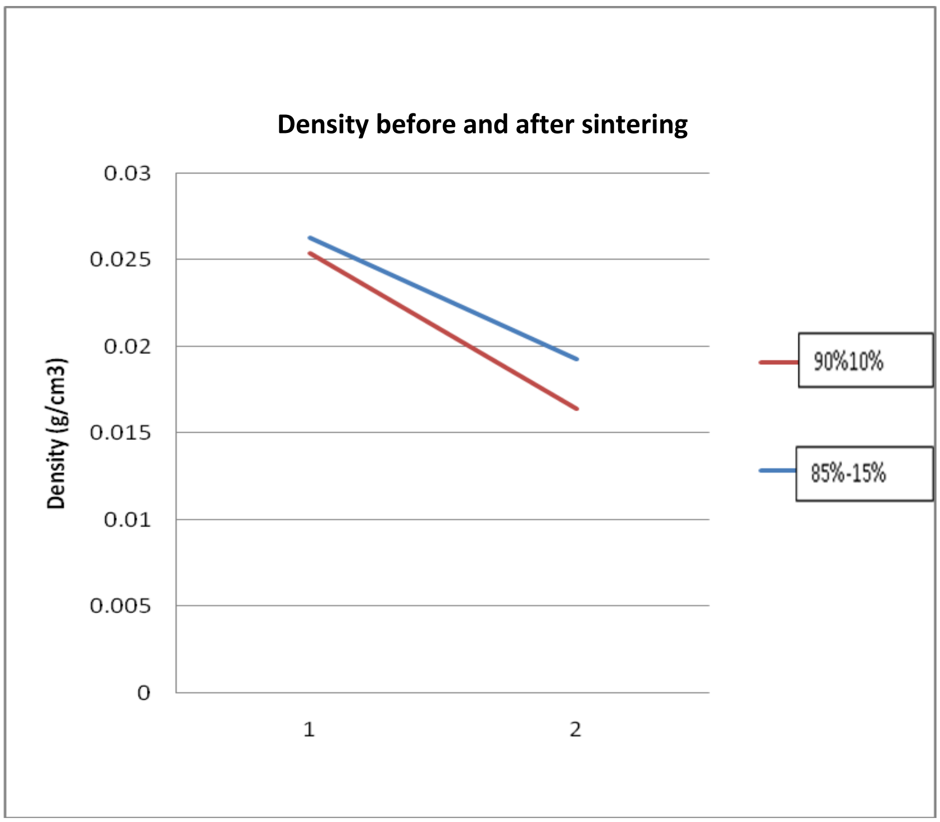


Figure 4.5: Density between composition before and after sintering

4.5 HARDNESS TEST RESULT

Hardness test is the most important aspect for this research to evaluate the properties of the composites. Result of hardness test can be used to determined the sustainability of the composites and to identify which composition provide better strength. 10 reading is taken to get the accurate average value. Table 4.3 show the tabulation data of the values and its average reading.

Table 4.3: Hardness test result

Composition (%)	90-10	85-15
Hardness test reading (Hv)	23.4	42.3
	27.3	46.9
	25.6	44.4
	32.3	54.7
	24.9	53.7
	27.5	49.3
	33.7	48.6
	22.8	55.5
	27.8	47.9
	29.9	51.2
Average	27.52	49.45

Figure 4.6 shows a graph of comparison between 90-10 and 85-15 composition in term of the value of the hardness test taken by 10 reading.

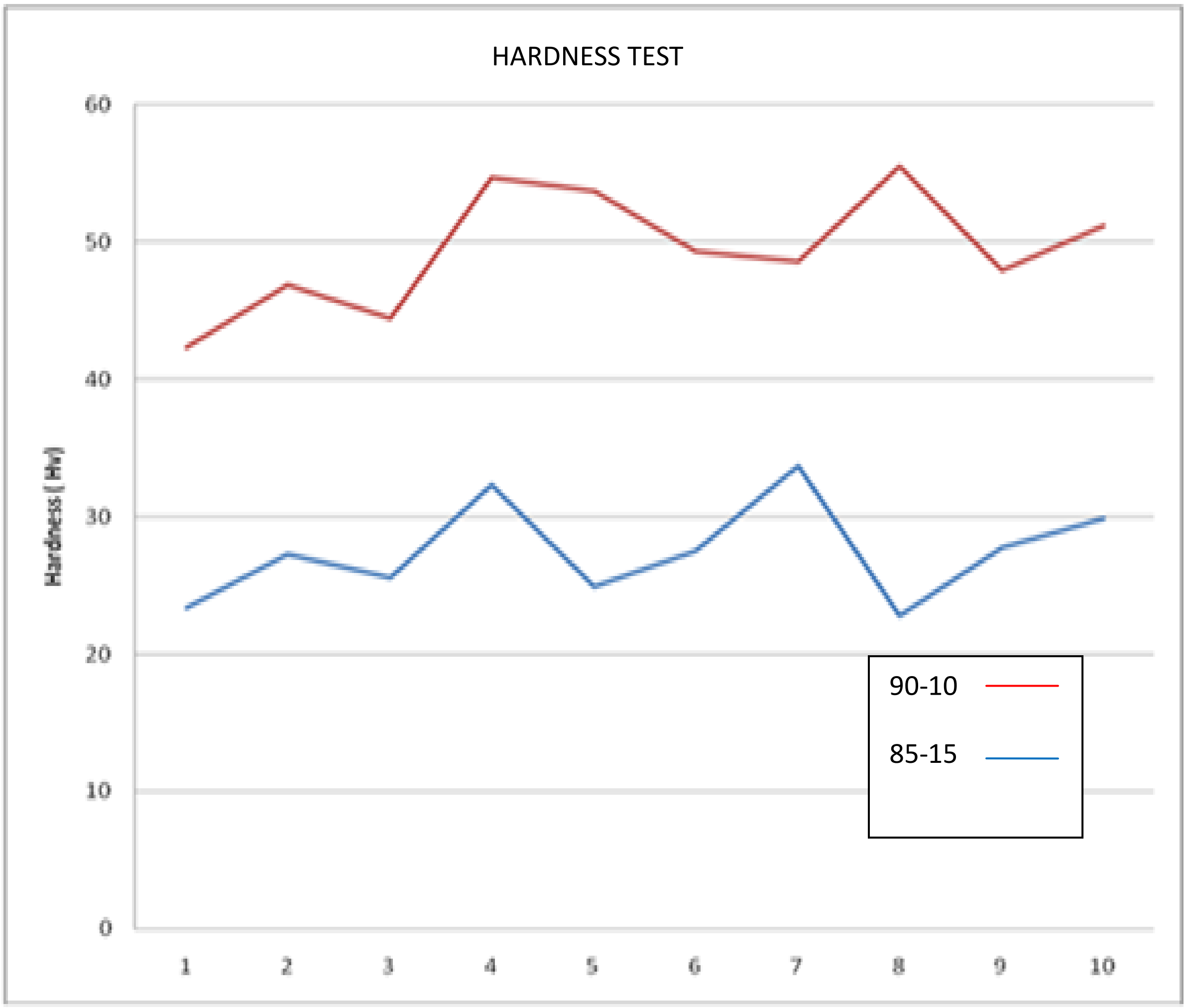


Figure 4.6: Hardness test

4.6 DISCUSSION

The result from the experiment had shown that the density of both 90-10 and 85-15 sample of Al-SiC composite decrease from its original density after undergo sintering process. Temperature is related to the average kinetic energy of the atoms within the sample. By applying high temperature to the samples, it causes the molecules to speed up and spread lightly further apart. Thus the molecules will occupy larger volumes that subsequently result in a decrease in density. The present of porosity inside the sample might be other cause of the drop in density after sintering. As the compaction load of 20 Ton is not enough to make the sample compact and bind together, it will leave an air space inside the sample. This air will then expand when heat, thus resulting in the present of pocket in the sample. This pocket affects the overall density of the sample to drop from its original density.

From the experiment, sample with 85-15 composition exhibited greater hardness compare to the sample with 90-10 composition. This is due to the higher inclusion of ceramic particle (SiC) in the composite. Aluminum is known to have high versatility and corrosion but in term of hardness, it can be considered as moderate material. The present of SiC inside the composite increase its overall hardness. Silicon carbide is a brittle material that has high hardness, durability and heat resistance. Silicon carbide has quite similar structure as diamond, which explains why it has exceptional hardness. Hence, the higher amount of SiC in the composite, the higher the hardness.

The microstructure showed the present of agglomeration inside the composite. Agglomeration is a cluster of different material that binds together. Agglomeration occurs during the cooling process as the substances shrink together and bind. The composite showed agglomeration due to the mixture is not homogenously distributed as the process of mixing is done manually. The inability to require the service of the ball mill machine gives a limitation toward the research progress. A ball mill is a type of grinder used to blend material homogenously and work by the principle of impact and attrition.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

The purpose of this chapter is to conclude the overall experiment based on the result. This chapter determines whether the objectives were achieved or not. Some recommendation also presents to improve the research and to indicate the future research goal in the related field of study.

5.2 CONCLUSIONS

Sample with 85-15 composition exhibited higher hardness compare to 90-10 composition. After taking 10 readings, average reading is taken to compare which composition contributed greater hardness. The average reading of hardness of 85-15 composition is 49.45, while the average reading of 90-10 composition is 27.52. This show that the higher the amount of SiC addition in the composite, the higher the hardness of the composite.

The microstructure of 90-10 composition samples showed less agglomeration than the 85-15. From figure 4.4 and 4.3, a comparison on the amount of agglomeration in the composite can be done. The smaller inclusion of ceramic particle (SiC) in the composite of 90-10 composition reduce the chances for agglomeration to appear. Meanwhile, for 85-15 composition, the higher inclusion of SiC in the composite contributed higher chances for the agglomeration to appear.

Sample with 15% volume fraction showed better mechanical properties. The high amount of SiC in the composite enhanced some mechanical properties of the composites in term of hardness, microstructure and density. Sample with 10% volume fraction exhibited less effect into the mechanical properties enhancement compare to 15% volume fraction.

In conclusion, the project outcome has achieved the project objective. Al-SiC composite with different volume fraction is fabricated. The volume fraction does give effect to the mechanical properties of the Al-SiC. The mechanical properties of Al-SiC composite are optimized and the optimum volume fraction is obtained. The 85-15 composition of Al-SiC is better than the 90-10 composition of Al-SiC.

5.3 RECOMMENDATIONS

The following recommendations are made for future study related to this research.

1. The use of ball mill is can provide better result. It is important so that the mixing of Al powder and SiC powder could be more uniform and homogenously distributed which can prevent the forming of agglomeration. Mixing of powder manually does not give a good particle distribution.

2. The value of pressure needs to be increased more than 20 Ton so that the mixture is perfectly compact without leaving an air space inside the sample. Air space can cause the forming of pocket in the sample after furnace. It will affect the density and microstructure forming of Al-SiC.

3. The volume fraction of SiC particle need to be increase to optimize the mechanical properties of the composite. Higher amount of SiC inclusion inside the composite enhanced the composite`s mechanical properties.

4. More analysis in SEM and XRD could give better result. The use of SEM machine can give better and precise microstructure view while XRD analysis can give provide information on unit cell dimensions

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APPENDICES

A) CALCULATION OF WEIGHT FRACTION

Molecular weight: -

Al= 26.98 g/mol SiC=40.0962 g/mol

Composition of Al-SiC

For 90-10 composition

(90/100) X 26.98 g/mol = 24,282g

(10/100) X 40.0962 g/mol= 4.009g

Make ratio 1:4

24.282/4= 6.0705g of Al

4.009/4= 1.0025g of SiC

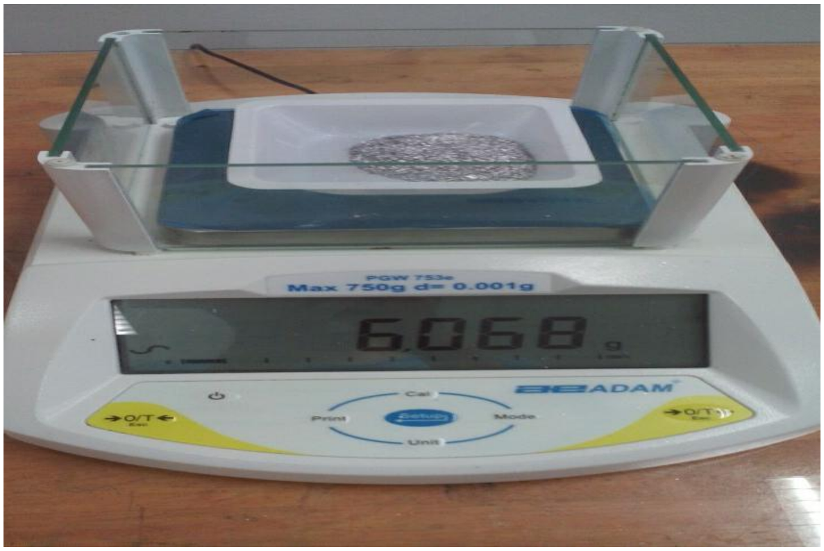
For 85-15 composition

(85/100) X 26.98 g/mol= 22.933g

(15/100) X 40.0962 g/mol= 6.0144g

B) MACHINES AND MATERIAL USED IN SAMPLE PREPARATION

a) Weighing machine

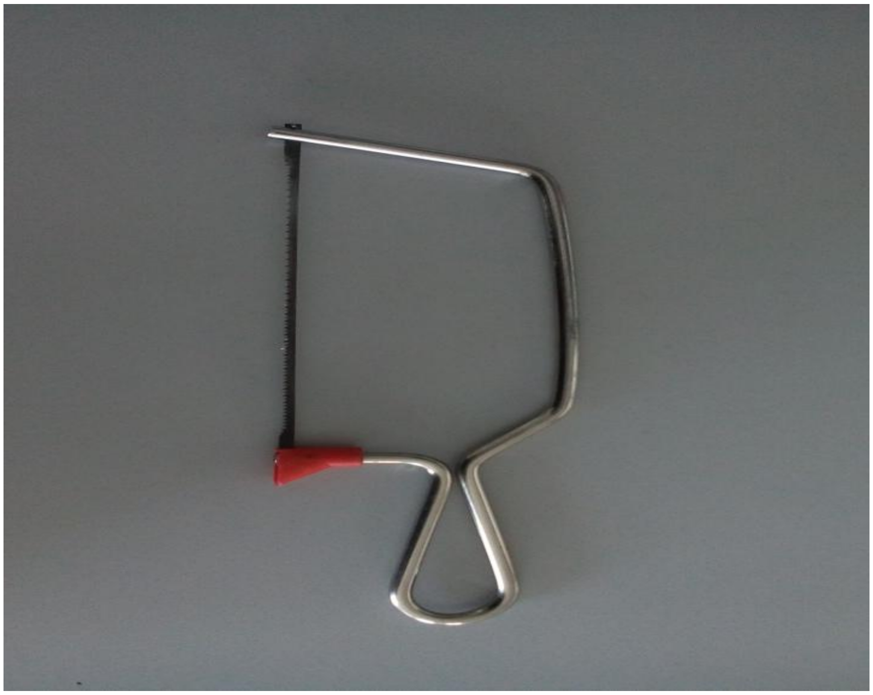


b) Die

c) Hydraulic press

d) Furnace machine

e) Saw



f) Mounting material

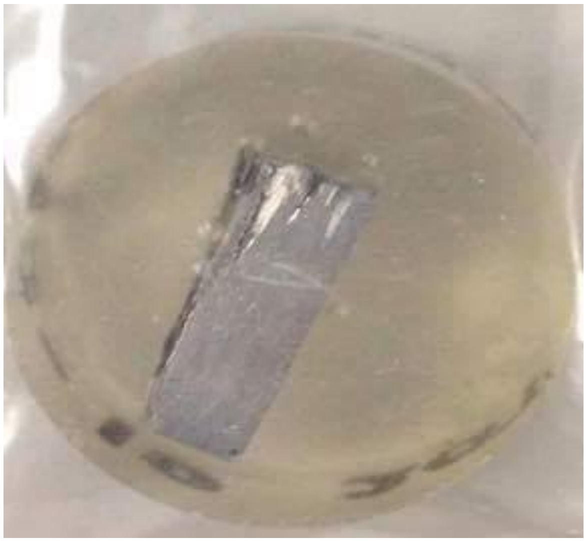
g) Mounting container

h) Sand paper

i) Grinding machine

j) Polishing material

k) Final sample



C) MACHINE USED IN MECHANICAL TESTING

a) Optical microscope

b) Weighing machine

c) Vickers micro hardness testing machine

D) GANTT CHART

FYP 1

Week Progress		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title Confirmation	**Plan**														
	Actual														
Objective and Scope	**Plan**														
	Actual														
Hypothesis	**Plan**														
	Actual														
Charts	**Plan**														
	Actual														
Literature Review	**Plan**														
	Actual														
Methodology	**Plan**														
	Actual														
Presentation	**Plan**														
	Actual														

FYP 2

Week Progress		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Experiments	**Plan**														
	Actual														
Analysis	**Plan**														
	Actual														
Thesis Writing	**Plan**														
	Actual														
Draft Submission	**Plan**														
	Actual														
Final Presentation	**Plan**														
	Actual														
Thesis submission	**Plan**														
	Actual														