EFFECT OF WEIGHT PERCENTAGE OF SILICON CARBIDE (SiC) REINFORCEMENT PARTICLES ON MECHANICAL BEHAVIOR OF ALUMINUM METAL MATRIX COMPOSITE (Al MMC)

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JUDUL: **EFFECT OF WEIGHT PERCENTAGE OF SILICON CARBIDE (SiC) REINFORCEMENT PARTICLES ON MECHANICAL BEHAVIOR OF ALUMINIUM METAL MATRIX COMPOSITE (Al MMC)**

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ENGKU AMALINA SYAZANA BINTI KU MOHD NAZRI

A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Signature : …………………………..
Name of Supervisor :
Position :
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ABSTRACT

Silicon carbide particle reinforced aluminum matrix composites have been developed over past few decades, owing to their excellent properties like light weight, high elastic modulus and wear resistance. Thus, the silicon carbide particle reinforced aluminum matrix composites are expected to have many applications in aerospace, aircraft, automobile and electronic industries. In this study, aluminum metal matrix composites containing several weight percentages of reinforcement particles were prepared by using powder metallurgy method. The main steps in powder metallurgy are blending, compacting and sintering. The experiments were performed on different composition of silicon carbide powder in the composite. The study presents the results of experimental investigation on mechanical behavior of silicon carbide particle reinforced aluminum matrix. The influence of reinforced ratio of 0, 5, 10 and 15 weight percentage of silicon carbide particles on mechanical behavior was examined. The effect of different weight percentage of silicon carbide in composite on hardness and microstructure was studied. Digital image analyzer was used to characterize the composites. The effect of weight percentage of silicon carbide on hardness of composites was investigated by using Vickers hardness Test. It was observed that the distribution of silicon carbide particles was uniform. The hardness of the composites increased with increasing reinforcement element addition in it. In addition, and for the purpose of verification of the present theory, other published work was also compared and found to be in very good correlation with the predicted result.

ABSTRAK

Komposit matrik aluminium yang diperkuat oleh silikon karbida telah berkembang beberapa dekad yang lalu berdasarkan sifat-sifatnya yang istimewa seperti ringan, modulus kekenyalan yang tinggi dan tahan haus. Oleh itu, komposit matrik aluminium yang diperkuat dengan silikon karbida dijangka mempunyai banyak aplikasi kepada industri aeroangkasa, pesawat udara, otomobil dan industri-industri elektronik. Dalam kajian ini, komposit matrik aluminium yang mengandungi beberapa peratusan berat zarah penguatan telah disediakan menggunakan kaedah serbuk metalurgi. Langkah-langkah utama dalam serbuk metalurgi adalah pengisaran, pemampatan dan pensinteran. Eksperimen telah dijalankan ke atas serbuk silicon karbida yang berlainan komposisi dalam komposit yang dihasilkan. Kajian ini memberikan hasil keputusan eksperimen terhadap sifat mekanikal komposit matrik aluminium yang diperkuat dengan silikon karbida. Pengaruh nisbah penguat iaitu pada kadar 0, 5, 10 dan 15 peratus berat silicon karbida ke atas sifat mekanikal telah diselidiki. Kesan daripada perbezaan peratusan berat silikon karbida dalam komposit ke atas ketahanan dan struktur mikro telah dikenalpasti. Analisis imej digital telah digunakan untuk mempercirikan komposit-komposit tersebut. Kesan daripada peratusan berat silikon karbida ke atas ketahanan komposit telah dikaji menggunakan Ujian ketahanan Vickers. Ia telah diperhatikan bahawa taburan partikel silikon karbida adalah seragam. Ketahanan komposit meningkat dengan peningkatan peratusan elemen penguatan di dalamnya. Tambahan lagi, kajian lain yang telah diterbitkan turut dibandingkan dengan hasil ujikaji yang dijalankan dan didapati terdapat hubungkait di antara kedua-duanya.

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LIST OF SYMBOLS

%	Percent
$Ø_{in}$	Inner diameter

LIST OF ABBREVIATIONS

A	Area
Al	Aluminum
Al MMC	Aluminum Metal Matrix Composite
Al-B	Boron reinforcing Aluminum alloy
Al-Li	Lithium reinforcing Aluminum alloy
B	Boron
Co	Cobalt
CMC	Ceramic Matrix Composite
DMD	Disintegrated Melt Deposition
F	Force
FCC	Face centered cubic
HIP	Hot Isostatic Pressing
HV	Vickers pyramid number
IM	Ingot Metallurgy
M	Magnification
Mg	Magnesium
MMC	Metal Matrix Composite
Pb	Plumbum
PM	Powder Metallurgy
PMC	Polymer Matrix Composite

PTE	Polarization Transformation Efficiency
Sn	Stanum
Ti	Titanium
TR	Theta radiation
UV	Ultraviolet
Vol%	Volume percentage
Wt%	Weight percentage

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Composite materials are important engineering materials due to their outstanding mechanical properties. Composites are materials in which the desirable properties of separate materials are combined by mechanically or metallurgically binding them together. Each of the components retains its structure and characteristic, but the composite generally possesses better properties. Composite materials offer superior properties to conventional alloys for various applications as they have high stiffness, strength and wear resistance. The development of these materials started with the production of continuous-fiber-reinforced composites. The high cost and difficulty of processing these composites restricted their application and led to the development of discontinuously reinforced composites (Ozdemir et. al.1999).

Aluminum (Al) is a silvery white and ductile member of the poor metal group of chemical elements. Al is an abundant, light and strong metal which has found many uses. Like all composites, aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, and thermal and electrical properties can be tailored. The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties. Regardless of the variations, however, Al composites offer excellent thermal conductivity, high shear strength, excellent abrasion resistance, high temperature operation, nonflammability, minimal attack by fuels and solvents, and the ability to be formed and treated on conventional equipment.

Silicon carbide (SiC) is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. SiC is not attacked by any acids or alkalis or molten salts up to 800^oC. In air, SiC forms a protective silicon oxide coating at 1200^oC and is able to be used up to 1600^oC. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. SiC ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600^oC with no strength loss. Chemical purity, resistance to chemical attack at temperatures, and strength retention at high temperatures has made this material very popular as wafer tray supports and paddles in semiconductor furnaces. Properties of silicon carbide are low density, high strength, low thermal expansion, high hardness, and high elastic modulus.

Particle reinforced composites have relatively isotropic properties compared to short fiber or whisker reinforced composites. The properties of the composites can be tailored by manipulating parameters such as reinforcement particle distribution, size, volume fraction, orientation, and matrix microstructure (Ayyar et. al, 2006). Metal matrix composites (MMCs), such as SiC particle reinforced Al, are one of the widely known composites because of their superior properties such as high strength, hardness, stiffness, wear and corrosion resistance. SiC particle reinforced Al based MMCs are among the most common MMC and available ones due to their economical production. They can be widely used in the aerospace, automobiles industry such as electronic heat sinks, automotive drive shafts, or explosion engine components. The physical and chemical compatibility between SiC particles and Al matrix is the main concern in the preparation of SiC/Al composites.

Therefore, the particle reinforced metal matrix composites can be synthesized by such methods as powder metallurgy (PM), standard ingot metallurgy (IM), disintegrated melt deposition (DMD) technique, spray atomization, and co-deposition approach. Different method results in different properties. In this study, the PM method is carried out to prepare SiC particle reinforced Al MMC. The effect of weight percentage of the reinforced particles on mechanical behavior such as hardness and microstructure of the composites can be investigated. The PM processing route is generally preferred since its shows a number of product advantages. The uniform distribution of ceramic particle reinforcements is readily realized. On the other hand, the solid state process minimizes the reactions between the metal matrix and the ceramic reinforcement, and thus enhances the bonding between reinforcement and the matrix (Wang et. al, 2007).

Powder metallurgy is a net shape forming process consisting of producing metal powder, blending them, compacting them in dies, and sintering them to impart strength, hardness and toughness. Although the size and the weight of its products are limited, the PM process is capable of producing relatively complex parts economically, in net shape form and wide variety of metal and alloy powders. Basically, in the conventional PM production, after the metallic powders have been produced, the sequence consists of three steps. Firstly, blending and mixing the powder, and then compaction, in which the powders are pressed into the desired part shape. The last step of PM method is sintering, which involves heating to a temperature below the melting point to cause solid state bonding of the particles and strengthening the part. Blending refers to when powders of the same chemical composition but possibly different chemistries being combine. After that, in compaction (pressing), high pressure is applied to the powders to form them into the required shape. The pressure required for pressing metal powders ranges from 70MPa (for Al) to 800MPa (for high density iron parts). After pressing, the green compact lacks strength and hardness. Sintering is a heat treatment operation performed on the compact to bond its metallic particles. Sintering is a high temperature process used to develop the final properties of the component.

1.2 PROBLEM STATEMENT

Aluminum metal matrix composites (Al MMCs) are attractive for a wide variety of aerospace and defense applications. But it has lower resistance, ductile, low strength and hardness. To overcome this problem, silicon carbide is added as a reinforcement particle to enhance the mechanical behavior of Al MMC. The experiment was performed on different composition of SiC, the reinforcement particles which are consist of 0, 5, 10 and 15 of weight percentage. The composite was prepared by powder metallurgy method and the specimens were examined using the standardized test which are Image Analyzer (ProGres C3 Model) and Vickers Hardness test (MMT-X7 Model).

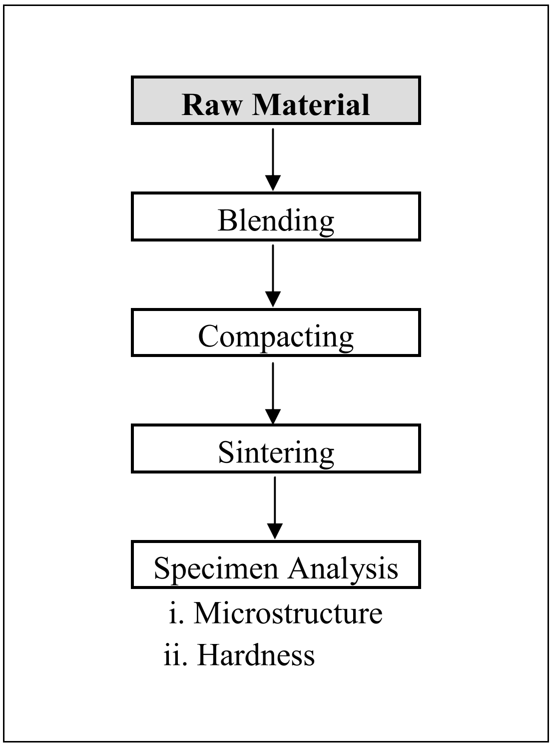


Figure 1.1: A flow chart of powder metallurgy method and specimen analysis

Figure 1.1 shows the powder metallurgy method to produce four composite specimens with different weight percentage of SiC, the reinforcement particles in the composites. In this study, four specimen of the composite are produced with different weight percentage of SiC which are 0, 5, 10 and 15 % to investigate the effect on mechanical behavior on the composites. From the specimens that have been produced by the PM method, then they will be analyzed on microstructure and the hardness using the standardized testing method.

1.3 OBJECTIVES

The main purposes in accomplishing of this project are:

i. To synthesis silicon carbide particle reinforced aluminum metal matrix composite using powder metallurgy process.
ii. To study the effect of weight percentage of silicon carbide on mechanical behavior of aluminum metal matrix composite.
iii. To characterize the properties of aluminum metal matrix composite on hardness and microstructure.

1.4 SCOPE OF THE STUDY

SiC particle reinforced Al MMC can be synthesized by powder metallurgy method which the steps are blending, compacting and sintering. The blending time used is one hour while the pressure used in this study is 30kg/cm^2 and lastly the sintering temperature used is 550^{o}C for 10 minutes. All this parameters is constantly used for every specimen. The effect of different weight percentage of the reinforcement particles which are 0,5,10 and 15% of SiC on mechanical behavior of Al MMC such as hardness and microstructure of the composites can be investigated. To determine the mechanical properties of the materials, various standardized testing methods have been developed to determine the hardness and microstructure of the SiC particle reinforced Al MMC. The hardness of the composite was determined by using Vickers Hardness Tester (MMT-X7 Model) while its microstructure was observed by using Image Analyzer (ProGres C3 Model).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to composites, the reinforcement particle, the matrix element and the process used in this study. A review of other relevant research studies is also provided. Substantial literature has been studied on metal matrix composite, silicon carbide, aluminum and powder metallurgy methods. The review is organized chronologically to offer sight 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 tailored to the present body of literature as well as to justly the scope and direction of the present research effort.

2.2 COMPOSITE

There have been tremendous strides in engineering materials since 1950s. Several superalloys and heat resistance materials have been developed for various industrial applications, especially aerospace/aircraft and defense. Automotive, medical and sport equipment industries pushed advances in materials particularly having low density and very light weight with high strength, hardness and stiffness. One of these important advanced material is composites (Ozben,T. 2007).

A composite material is a nonuniform solid consisting of two or more different materials that are mechanically or metallurgically bonded together. Each of the various composites retains its identity in the composite and maintains its characteristic properties such as stiffness, strength, weight, high temperature, corrosion resistance, hardness, and conductivity, which are not possible with the individual components by themselves (Black, 2007). Example of the traditional composite is brick which consists of clay that mix up with grass and concrete that have mixture of cement and sand. In this example, clay and cement are matrix component while grass and sand are the reinforcement (Hashim,J. 2003).

Generally, one component acts as a matrix in which the reinforcing phase is distributed. The matrix component is, thus the continuous phase. When the matrix component is metal, we call such a composite a metal matrix composite (MMC). The reinforcement can be in the form of particles, whiskers, short fibers, or continuous fiber. There are three entities that determine the characteristics of a composite which are reinforcement, matrix and interface. The role of matrix was considered to be that of a medium or binder to hold the strong and stiff fibers or other types of reinforcement. Over the years, however, it has been realized that the matrix microstructure and consequently its mechanical properties have a considerable influence on the overall performance of a composite. This is particularly true of the MMCs because the very act of incorporating a reinforcement can result in change(s) in the microstructure of the metallic matrix and, consequently in their structure-sensitive properties such as a strength and toughness (Cahn, et.al. 2005).

2.2.1 Metal Matrix Composites (MMCs)

Metal matrix composite materials have been so intensely researched over the past years that many new high-strength-to-weight materials have been produced. Most of these materials have been developed for the aerospace industries, but some are being used in other applications such as automobile engines. In, general, according to reinforcement, the three main types of MMCs are continuous-fiber, discontinuous-fiber, and particulate reinforced.

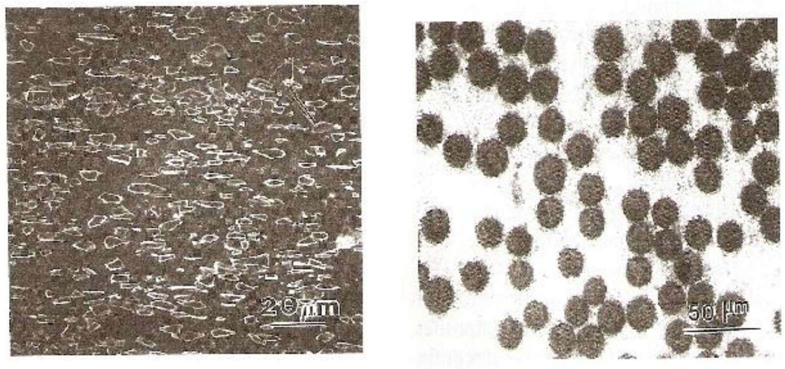


Figure 2.1: Typical microstructure of some metal matrix composites: (a) Particle (SiC particle/Al) and (b) continuous fiber reinforced (Al2O3/Al-Li) composites.

Source: Cahn, et. al. 2005

i. Continuous-Fiber Reinforced MMCs

Continuous filaments provide the greatest improvement in stiffness (tensile modulus) and strength for MMCs. One of the first developed continuous-fiber MMCs was aluminum alloy matrix boron fiber reinforced system. The boron fiber for this composite is made by chemically vapor depositing boron on tungsten-wire substrate. The Al-B composite is made by hot pressing layers of B fibers between aluminum foils so that the foils deform around the fibers and bond to each other. Table 2.1lists some mechanical properties for some B fiber reinforced-aluminum alloy composites. With the addition of 51% volume of B, the axial tensile strength of Al alloy 6061 was increased from 310 to 1417MPa, while its tensile modulus was increased 69 to 231 GPa. Other continuous-fiber reinforcements that have been used in MMCs are silicon carbide, graphite, alumina, and tungsten fibers. A composite of Al 6061 reinforced with SiC continuous fibers is being evaluated for the vertical tails section for an advanced fighter aircraft. Of special interest is the projected use of SiC continuous-fiber reinforcement in a titanium aluminide matrix for hypersonic aircraft such as National Aerospace plane (Smith, 2004).

Table 2.1: Mechanical Properties of Metal Matrix Composite Materials

	Tensile Strength		**Elastic Modulus**		**Strain to failure**
	MPa	**ksi**	**Gpa**	**Msi**	**%**
Continuous-fiber MMCs:					
Al 2024-T6 (45% B) (axial)	1458	211	220	32	0.81
Al 6061-T6 (51% B) (axial)	1417	205	231	33.6	0.735
Al 6061-T6 (47% SiC) (axial)	1462	212	204	29.6	0.89
Discontinuous-fiber MMCs:					
Al 2124-T6 (20% SiC)	650	94	127	18.4	2.4
Al 6061-T6 (20% SiC)	480	70	115	17.7	5
Particulate MMCs:					
Al 2124 (20% SiC)	552	80	103	15	7
Al 6061 (20% SiC)	496	72	103	15	5.5
No reinforcement:					
Al 2124-F	455	66	71	10.3	9
Al 6061-F	310	45	68.9	10	12

Source: Smith, 2004

ii. Discontinuous-Fiber Reinforced MMCs and Particulate Reinforced MMCs

Many different kinds of discontinuous and particulate reinforced MMCs have been produced. These materials have the engineering advantage of higher strength, greater stiffness, and better dimensional stability than the reinforced metal alloys. In this brief treatment of MMCs we will focus on aluminum alloy MMCs.

Particulate reinforced MMCs are low cost Al alloy MMCs made by using irregular shaped particles of alumina and SiC in the range of about 3 to 200μm in diameter. The particulate, which is sometimes given a proprietary coating, can be mixed with the molten Al alloy and cast into re-melt ingots or extrusion billets for further fabrication. Table 2.1 indicated that the ultimate tensile strength of Al alloy 6061 can be increased from 310 to 103GPa. Applications for this material include sporting equipment and automobile engine parts.

Discontinuous-fiber reinforced MMCs are produced mainly by powder metallurgy and melt infiltration processes. In the powder metallurgy process, needle-like silicon carbide whiskers about 1 to 3μm in diameter and 50 too 200μm long are mixed with metal powders, consolidated by hot pressing, and then extruded or forged into the desired shape. Table 2.1 shows that the ultimate tensile strength of Al alloy 6061 can be increased from 310 to 480MPa with a 20% SiC whiskers addition, while the tensile modulus can be raised fro 69 to 115GPa. Although greater increases in strength and stiffness can be achieved with the whiskers additions than with the particulate material, the powder metallurgy and melt infiltration processes are most costly. Applications for discontinuous-fiber reinforced Al alloy MMCs include missile guidance parts and high-performance automobile piston (Smith, 2004).

2.2.2 Ceramic Matrix Composites (CMCs)

Ceramic matrix composites have been developed recently with improved mechanical properties such as strength and toughness over the unreinforced ceramic matrix. Again, the three main type according to reinforcement are continuous-fiber, discontinuous (whisker) fiber, and particulate reinforced.

i. Continuous-Fiber Reinforced CMCs

Two kinds of continuous fibers that have been used for CMCs are silicon carbide and aluminum oxide. In one process to make a ceramic matrix composite, SiC fibers are woven into a mat and then chemical vapor deposition is used to impregnate SiC into the fibrous mat. In another process, SiC fibes are encapsulated by a glass-ceramic material. Applications for these materials include heat-exchanger tubes, thermal protection systems, and materials for corrosion-erosion environment.

ii. Whisker and Particulate Reinforced CMCs

Ceramic whiskers can significantly increase the fracture toughness of monolithic ceramics (Table 2.2). a 20 vol% SiC whisker addition to alumina can increase the fracture toughness of the alumina ceramic from about 4.5 to 8.5 MPa$\sqrt{m}$. Short fiber and particulate reinforced ceramic-matrix materials have the advantage of being able to fabricate by common ceramic processes such as hot isostatic pressing (HIP).

Ceramic matrix composites are believed to be toughened by three main mechanisms, all of which result from the reinforcing fibers interfering with crack propagation in the ceramic. These mechanisms are:

i. *Crack defection*. Upon encountering the reinforcement, the crack is deflected, making its propagating path more meandering. Thus, higher stresses are required to propagate the crack.
ii. *Crack bridging*. Fibers or whiskers can bridge the crack and help keep the material together, thus increasing the stress level needed to cause further cracking. (Figure 2.3).

iii. *Fiber pullout*. The friction causes by fibers or whiskers being pulled out of the cracking matrix absorbs energy, and thus higher stresses must be applied to produce further cracking. Therefore, a good interfacial bond is required between the fibers and the matrix for higher strengths. There also should be a good match of coefficient of expansion between the matrix and fibers if the material is to be used at high temperatures.

Table 2.2: Mechanical Properties of SiC Whisker Reinforced Ceramic Matrix Composites at room temperature

Matrix	**SiC whisker content (vol%)**	**Flexural strength (MPa)**	**Fracture toughness (MPa $\sqrt{m}$)**
Si_3N_4	0	400-650	5.0-7.0
	10	400-500	6.5-9.5
	30	350-450	7.5-10
Al_2O_3	0	…	4.5
	10	400-510	7.1
	20	520-790	7.5-9.0

Source: Smith, 2004

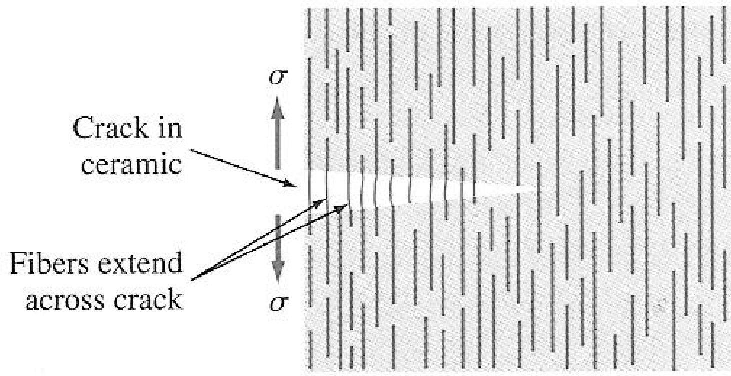


Figure 2.2: Schematic diagram showing how reinforcing fibers can inhibit crack propagation in ceramic matrix materials by crack bridging and fiber pullout energy absorption.

Source: Smith, 2004

2.2.3 Polymer Matrix Composites (PMCs)

Polymer-matrix composites (PMCs) consist of a polymer resin (high-molecular-weight reinforcing plastic) as the matrix, with fibers as the reinforcement medium. The materials are used in the greatest diversity of composite applications, as well as in the largest quantities, in light of their room-temperature properties, ease of fabrication, and cost.

i. Glass-Fiber Reinforced Polymer (GFRP) Composites

Fiberglass is simply a composite consisting of glass fibers, either continuous or discontinuous, contained within a polymer matrix; this type of composite is produced in the largest quantities. Glass is popular as a fiber reinforcement material for several reasons which is easily drawn into high-strength fibers from the molten state. Besides that, it is readily available and may be fabricated into a glass-reinforced plastic economically using a wide variety of composite-manufacturing techniques. As a fiber, it is relatively strong, and when embedded in a plastic matrix, it produces a composite having a very high specific strength. When coupled with the various plastics, it possesses a chemical inertness that renders the composite useful in a variety of corrosive environments. Many fiberglass applications are familiar: automotive and marine bodies, plastic pipes, storage containers, and industrial floorings. (Callister, 2005).

ii. Carbon-Fiber Reinforced Polymer (CFRP) Composites

Carbon is a high performance fiber material that is the most commonly used reinforcement in advanced PMCs. The reasons for this are as follows where fibers have the highest specific modulus and specific strength of all reinforcing fiber materials. They retain their high-tensile modulus and high strength at elevated temperatures. At room temperature carbon fiber are not affected by moisture or a wide variety of solvents, acids and bases. These fibers exhibit a diversity of physical and mechanical characteristics, allowing composites incorporating these fibers to have specific engineered properties. Fiber and composite manufacturing processes have been developed that are relatively inexpensive and cost effective.

2.3 POWDER METALLURGY (PM)

Powder Metallurgy (PM) is a manufacturing method that has gained interest over the last decades as an economic and fast method to produce different mechanical parts as for instance structural components, self-lubricating bearings and cutting tools. The PM manufacturing process has become a great industrial potential for companies to gain market advantages over other companies using conventional manufacturing methods. One main reason for this is that the details are pressed into near-net shape with little or no machining. This lead to cost savings and rapid method that is also suitable for mass production.

The PM route for manufacturing metal matrix composites (MMCs) offers some advantages compared with ingot metallurgy and diffusion welding, the main of which is the low manufacturing temperature that avoid strong interfacial reaction minimizing the undesired reactions between the matrix and reinforcement. In other cases, PM allows materials to be obtained which cannot be obtained by any other alternative route (i.e. SiC reinforcing Ti alloy). Composites that use particles or whiskers as reinforcement can be obtained easily by PM than by other alternative route. Another advantages of PM is the uniformity in the reinforcement distribution. This uniformity not only improves the structural properties but also reproducibility level in the properties (Torralba,J.M., 2003).

In the manufacturing processes, the raw materials used are either in a molten state or in solid form. Powder metallurgy (PM) is a net shape forming process consisting of producing metal powders, blending them, compacting them in dies, sintering them to impart strength, hardness, and toughness. Classically, it involves the mixing of elemental powders, their compaction in a closed die followed by sintering under controlled atmosphere. Some parts are then ready for immediate service, although many parts undergo some secondary processing such as sizing, grinding or heat treatment. Because complicated geometries can be produced with a minimal number of processing steps, powder metallurgy is the quintessential net shape manufacturing technology. Although the size and the weight of its products are limited, the powder metallurgy process is capable of producing relatively complex parts economically, in the net-shape form and wide variety of metal and alloy powders (Kalpakjian,S. et.al. 2007).

2.3.1 Powder

There are several reasons to use powder and of course powder compaction. Some materials can not be used in other manufacturing methods, and of course, because the powder compaction method is proven to be more economically favorable method than other manufacturing method.

One type of material that is used in powder compaction are materials with a very high melting point, so called refractory metals, where casting would not be economic because of the high melting point. Materials in this category are for example tungsten, molybdenum, and tantalum. Another category of materials used in powder compaction are composite materials that can not easily be mixed in other manufacturing methods or handled in post operation due to its constituents. Examples of such categories are copper/tungsten, silver/cadmium and different types of cemented carbides. Structural parts with porous structure, like filters and bearings, are easy to manufacture with powder compaction. The material powders mentioned above are manufactured in different ways depending on the mechanical behavior. The methods to manufacture powder are solid state reduction, electrolysis, atomization, mechanical comminution and chemical processes (Kalpakjian,S. et.al. 2007).

2.3.2 Blending

It is rare that a single powder will possess all of the characteristics desired in a given process and product. Most likely, the starting material will be a mixture of various grades or sizes of powder, or powders of different compositions, along with additions of lubricants or binders.

In powder products, the final chemistry is often obtained by combining pure metal or nonmetal powder, rather than starting with prealloyed material. To produce a uniform chemistry and structure in the final product, therefore, sufficient diffusion must occur during the sintering operation.

2.3.3 Compacting

Compaction is a process whereby powders that are already blended are pressed into the required shape. The purpose of compaction is to obtain uniform shape and size among particles and to provide enough strength for the powder to withstand further processing. Powder metal is commonly compressed in a die cavity by one or more punches to create the shape of the part. Compaction can be performed in cold and hot condition. Compacting pressures generally range between 40 to 1650 MPa depending on material and application. Compaction also can be done by using isostatic pressing. This method applies uniform pressure in every direction that given to the components using compacting medium especially water or gas. There are two types of isostatic pressing which are in cold and hot condition.

i. Hot Isostatic Pressing

The HIP process, which subjects a component to elevated temperatures and pressures to eliminate internal micro shrinkage, helped engineers respond to the aerospace industry's increasingly stringent regulations. HIP enabled engineers to design components so they could meet specifications for use in critical, highly stressed applications. The HIP process provides a method for producing components from diverse powdered materials, including metals and ceramics (Bruce,R.G., et. al. 2004).

During the manufacturing process, a powder mixture of several elements is placed in a container, typically steel can. The container is subjected to elevated temperature and a very high vacuum to remove air and moisture from the powder. The container is then sealed and hot isostatic pressed. he application of high inert gas pressures and elevated temperatures results in the removal of internal voids and creates a strong metallurgical bond throughout the material. The result is a clean homogeneous material with a uniformly fine grain size and a near 100% density.

The reduced porosity of hot isostatic pressed materials enables improved mechanical properties and increased workability. The HIP process eliminates internal voids and creates clean, firm bonds and fine, uniform microstructures. These characteristics are not possible with welding or casting. The virtual elimination of internal voids enhances part performance and improves fatigue strength. The process also results in significantly improved non-destructive examination ratings.

ii. Cold Isostatic Pressing

Metal powders are contained in an enclosure e.g. a rubber membrane or a metallic can that is subjected to isostatic that is uniform in all directions, external pressure. As the pressure is isostatic the as-pressed component is of uniform density. Irregularly shaped powder particles must be used to provide adequate green strength in the as-pressed component. This will then be sintered in a suitable atmosphere to yield the required product (Smith, 2004).

Normally this technique is only used for semi-fabricated products such as bars, billets, sheet, and roughly shaped components, all of which require considerable secondary operations to produce the final, accurately dimensioned component. Again, at economical working pressures, products are not fully dense and usually need additional working such as hot extrusion, hot rolling or forging to fully density the material.

2.3.4 Sintering

Sintering is the method involving consolidation of powder grains by heating the "green compact" part to a high temperature below the melting point, when the material of the separate particles diffuse to the neighboring powder particles. The green compact is sintered in an atmosphere chosen to provide a nanoxiding, reducing, or for steel, sometimes also a carburizing environment. With proper allowance for shrinkage, tolerances can be held to a 0.1 to 0.2mm range on a 25mm dimension.

The surface finish will be rougher than that of the compacting die because porosity is still significant: 4 until 10% depending on powder characteristics, compacting pressure, and sintering temperature and time. Particularly, for bearing applications, density is often kept even lower so as to allow infiltration with lubricating oil, a lubricating polymer (such as PTE), or a metal (such as Pb or Sn). The infiltrate is drawn into the sintered skeleton by capillary forces after it is heated above the melting point of the infiltrant. Copper infiltrated into iron increases strength and improves machinability.

Cold restricting (coining or sizing) of the sintered compact increases its density and improves dimensional tolerance to 0.025mm. further densification and strength improvement can be achieved by re-sintering the re-pressed compact or by increasing sintering time.

The sintering process is carried out at temperatures of about 60-80% of the melting temperature of the basic matrix material and takes mostly 15 to 60 minutes. One constituent melts, as in the case of tungsten carbide tools, where the WC grains amount to 90 to 98% of weight and the rest is Co binder. Sintering is done in two steps. After pressing the compact at room temperature into the green state comes the pre-sintering step. At about 700 to 800^{o}C the binder grains soften, and the compact is pressed again to higher density than the green state. Then it goes again into oven where it is sintered at 1250 to 1350^{o}C for about 30 minutes (Kalpakjian,S. et.al.2007).

Most PM products, however, are sintered at temperature below melting of all the constituents, and the consolidation of the compact is fully derived by solid-state diffusion. In any case the distributions of the particles, their sizes, and their shapes do not change much. Consequently, the composition and the structure of the material can be rather accurately controlled.

Instead of the traditional pressing, sintering, re-pressing, and re-sintering sequence, the green compact ay be preheated to the forging temperature and directly hot forged to close tolerance at full theoretical density. Such parts can posses the same properties (including toughness) as conventionally forged pieces and can be forged to finish dimensions requiring only minimum surface finishing (Tlusty,1999).

2.4 ALUMINUM MMC

For a long period time, aluminum alloys were some of the most widely used materials as the marix MMCs, both in research and development and in industrial applications. This is mainly due to the low density of Al alloys (the first requirement in most applications). Moreover, they are cheap if compared with other low density alloy (such as Mg or Ti). Finally, Al alloys are very well known alloys due to their high use in several industries, from automotive and aeronautics to leisure. Their excellent behavior, from different points of view (strength, ductility, and corrosion), is very well known and can modified in rer to satisfy different applications (Torralba,J.M. 2003).

Aluminium is a silvery white and ductile member of the poor metal group of chemical elements. Al is an abundant, light, and strong metal which has found many uses. Like all composites, Al MMCs are not single material but a family of materials whose stiffness, strength, density, and thermal and electrical properties can be tailored. The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieved required properties. Regardless the variations, however Al composites offer the advantage of low cost over most other MMCs. In addition, they offer excellent thermal conductivity, high shear strength, excellent abrasion resistance, high temperature operation, flammability, minimal attack by fuels and solvents, and the ability to be formed and treated on conventional equipment.

Aluminum is a soft, light weight, malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. Al is nontoxic, nonmagnetic, and no sparking. It is also insoluble in alcohol, tough it can be soluble in water in certain forms. The yield strength of pure Al is 7 to 11 MPa, while Al alloys have yield strength ranging from 200MPa to 600MPa. Al has about one-third of the density and stiffness of steel. It is ductile, and easily machined, cast, and extruded. Corrosion resistance is excellent due to a thin surface layer of aluminum oxide that forms when the metal is exposed to air, effectively preventing further oxidation. The strongest Al alloys are less corrosion resistant due to galvanic reactions with alloyed copper. Al atoms are arranged in an face centered cubic (FCC) structure. Al has a high stacking-fault energy of approximately 200mJ/m^2.

Aluminum is one of the few metals that retain full silvery reflectance in finely powdered form, making it important component of silver paints. Al mirror finish has the highest reflectance of any metal in the 200-499nm (UV) and the 3000-10000nm (far TR) regions, while in the 400-700nm visible range it is slightly outdone by tin and silver and in the 700-3000 (near IR) by silver, gold, and copper.

Aluminum is a good thermal and electrical conductor, by weight better than copper. Al is capable of being a superconductor, with a superconducting critical temperature of 1.2 Kelvins and a critical magnetic field about 100 gauss.

Aluminum is the most widely used non-ferrous metal. Global production of Al in 2005 was 31.9 million tones. It exceeded that of any other metal except iron (837.5 million tones. Relatively pure Al is encountered only when corrosion resistance and/or workability is more important than strength or hardness. A thin layer of Al can be deposited onto a flat surface by physical vapor deposition or (very infrequently) chemical vapor deposition or other chemical means to form optical coatings and mirrors. When so deposited, a fresh, pure Al film serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared.

Pure Al has a low tensile strength, but when combined with thermomechanical processing, Al alloys display a marked improvement in mechanical properties, especially when tempered. Al alloys form vital components of aircraft and rockets as a result of their high strength-to-weight ratio. Al readily forms alloys with many elements such as copper, zinc, magnesium, manganese and silicon (e.g. duralumin). Today, almost all bulk metal materials that are referred to loosely as "aluminum" are actually alloys. For example, the common Al foils are alloys of 92% to 99% Al. Some of the many uses for Al metal are in transportation (automobiles, aircraft, trucks, railway cars, marine vessels, bicycles), packaging (cans, foils), construction (windows, doors, siding, building wire), in the blades of prop swords and knives used in stage combat and Al is widely used in watch production as it provides durability and resists tarnishing and corrosion (Kalpakjian, S. et.al. 2007).

2.5 SILICON CARBIDE

Silicon carbide is composed of tetrahedral of carbon and silicon atom with strong bonds in crystal lattice. This produces a very hard and strong material. Silicon carbide is not attached by any acids or alkalis or molten salts up 800^oC. In air, SiC forms a protective silicon oxide coating at 1200^oC and is able to be used up to 1600^oC. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no gain boundary impurities maintain their strength to very high temperatures, approaching 1600^oC with no strength loss. Chemical purity, resistance to chemical attack at temperature, and strength retention at high temperatures has made this material very popular as wafer tray supports and paddles in semiconductor furnaces. Properties of silicon carbide are low density, high strength, low thermal expansion, high hardness, and high elastic modulus.

Silicon carbide exists in at least 70 crystalline forms. Alpha silicon carbide (α-SiC) is the most commonly encountered polymorph; it is formed at temperatures greater than 2000^oC and has a hexagonal crystal structure (similar to Wurtzite). The beta modification (β-SiC), with a face-centered cubic crystal structure (similar to diamond and shalerite) is formed at temperature below 2000^oC. Silicon carbide has a specific gravity of 3.2, and its high sublimation temperature (approximately 2700^oC) makes it useful for bearings and furnace parts. Silicon carbide does not melt at ant known pressure. It is also highly inert chemically. There is currently much interest in its use as a semiconductor material in electronics, where its high thermal conductivity, high electric field breakdown strength and high maximum current density make it more promising than silicon for high-powered devices.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents a details discussion about the methodology structures of this study. The chapter begins with a general overview of the methodology adopted, followed by a rational for a specific method used. This is followed by a discussion of procedures used step by step from raw material until performing experiment, collect and manage data, as well as the procedures followed in conducting the data analysis.

Powder metallurgy process is one of the most widely used methods for producing Al MMC due to its low processing costs added to its high versatility. On the other hand, some types of composites cannot be made by other alternative route (Torralba, J.M. 2003).

In this study, the Al reinforced SiC composites are produces by using powder metallurgy method. Then, the hardness and microstructure of 0,5,10 and 15% of SiC particle reinforcing Al MMC will be investigated by using standardized testing method. The hardness is measured by Vickers Hardness Tester while the microstructure is observed by using Image Analyzer.

This chapter also introduces the machines and lab equipments that are used in this project to produce four specimens of Al composites with different weight percentage of SiC.

3.2 FLOW CHART

In fulfillment of the project objective, the following flow chart is followed to ensure the experiment will perform successfully and without any error would occur.

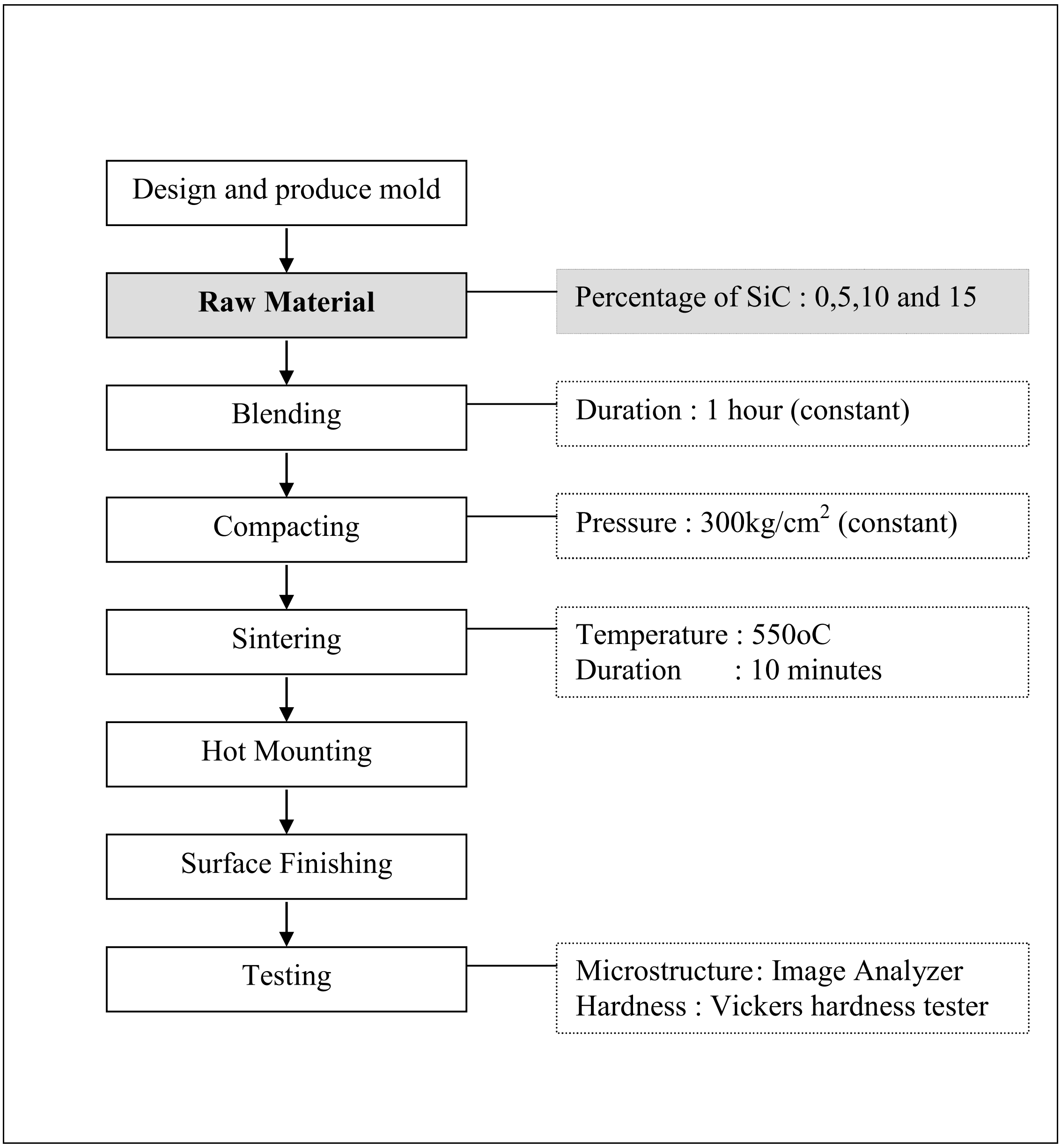


Figure 3.1: Flow chart of the process

3.3 MOLD

The process of methodology is started by design and produce mold. The mold was produce by using lathe machine. The conventional compaction tooling consisted of a strong cylindrical container with a central hole, which represented the diameter of the compact part. The typical dimensions of the compacted product are 2.0cm in diameter.

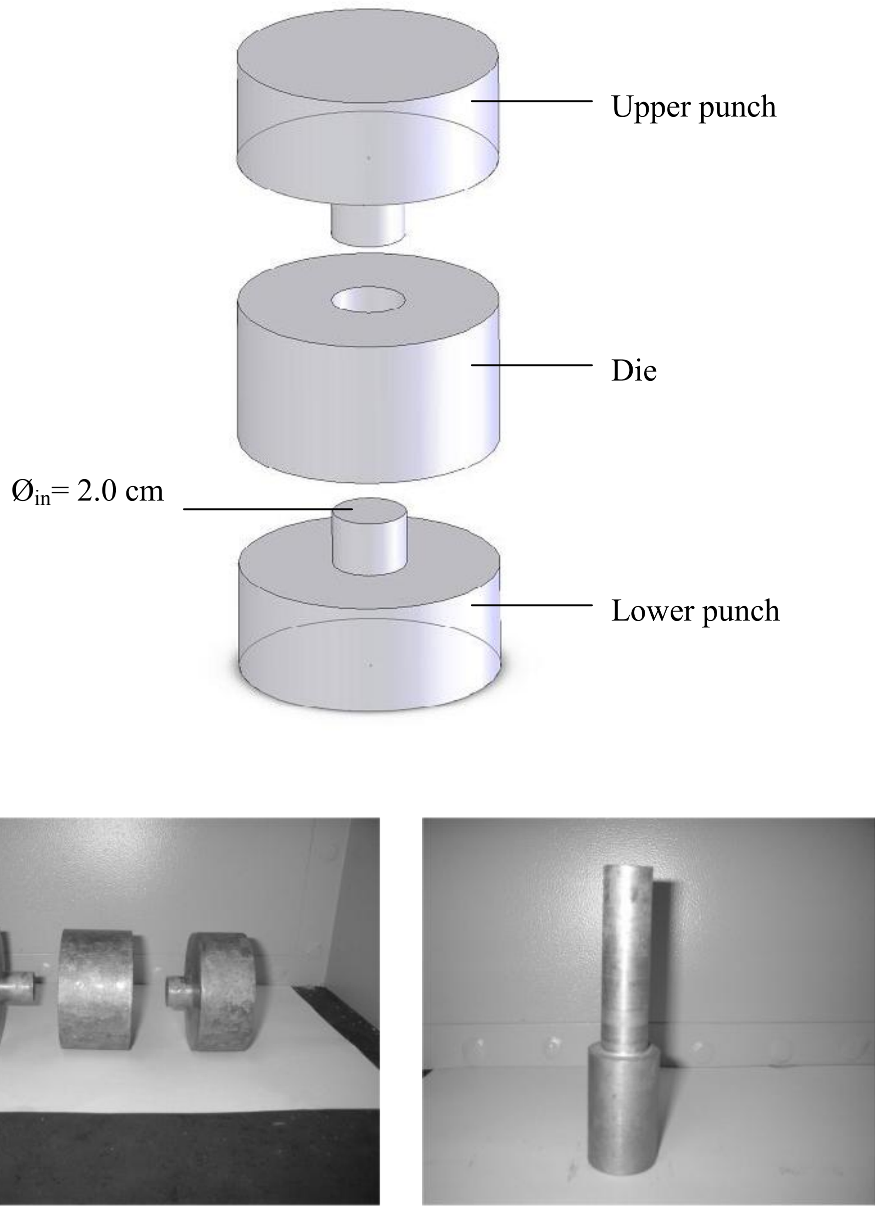
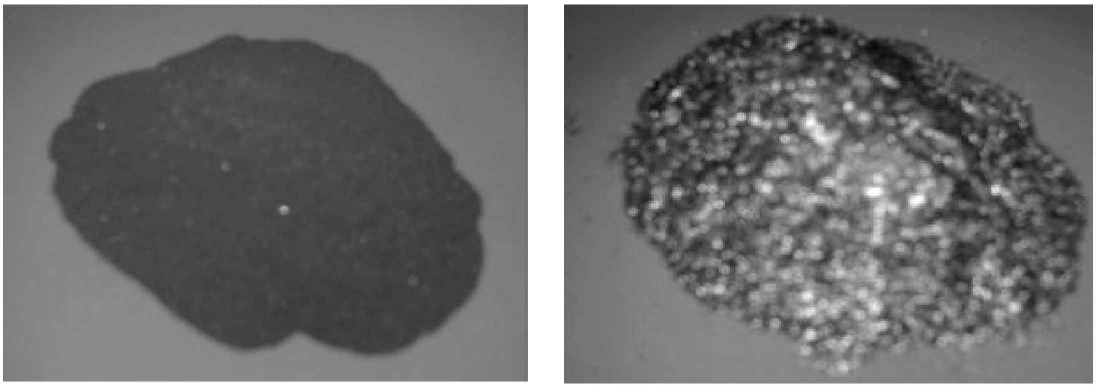


Figure 3.2: Experiment tools for powder compaction

3.4 RAW MATERIAL

In this study, raw materials that used are aluminum powder and SiC powder. Al was used as the matrix while SiC powder with different weight percentage which are 0,5,10 and 15 was used as the reinforcement particle. The composition of Al and SiC powders used in this study is presented in Table 3.1.



(a) (b)

Figure 3.3: Raw material that used to produce composite. (a) Silicon carbide powder and (b) Aluminum powder

Table 3.1: Composition of aluminum and silicon carbide powder

Powder	Composition (wt%)			
	1	2	3	4
SiC	0	5	10	15
Al	100	95	90	85

The composite powders were produced by ball mill with weight ball to powder ratio 10:1. Firstly, the ball mill was weighted by using digital analytical balance followed the composition needed. Then, 10% of weight ball mill are considered as the weight of the powder.

3.5 BLENDING

After the Al and SiC powders were mixed and was put into jar, the jar was then put into the fall mill machine together with the weighed ball mill. Then, the jar was hold tightly in its place. Then, the cover of the machine is closed. After that, the blending time was set to one hour. To run the machine, the yellow button was pressed. The composite was blended in the fast mill machine. Ball mill was rotate around a horizontal axis, partially filled with the material to be ground plus the grinding medium.

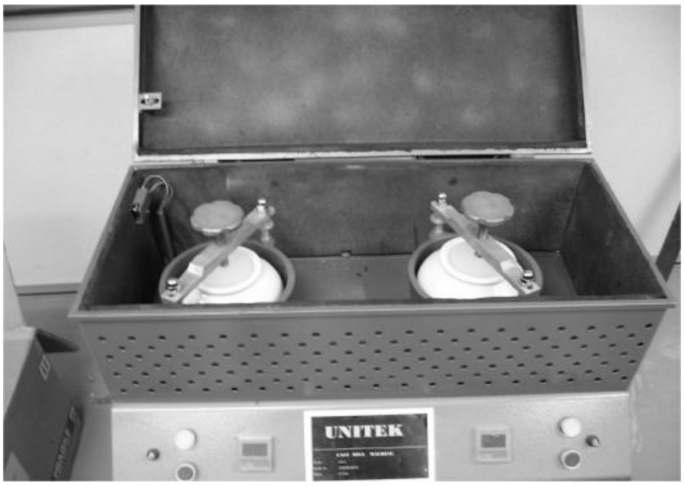


Figure 3.4: Fast Mill Machine that used to blend the composite

3.6 COMPACTING

Die compacting is the powder compaction method involving uniaxial pressure applied to the powder placed in a die between to rigid punches. The scheme of the die compacting method is presented in the Figure 3.6.

In this experiment, a strong cylindrical container with a central was housed in a special cavity in a floating die attached to the fixed platen of the hydraulic power pressure testing machine. Whereas, the upper punch was attached to the movable platen of the press, the lower punch rested on the fixed platen. The compaction process was simply performed by filling the cylindrical space in the container with the pre-prepared powder. Both the upper and the lower punches were brought into contact with tapped powder in the cylinder. This was followed by applying axial load, 30MPa which caused the powder to be compressed from both ends simultaneously, and subjected to high compressive stresses. At the end of the compaction stroke, the upper punch was removed and the lower punch used to eject the compact cylindrical product.

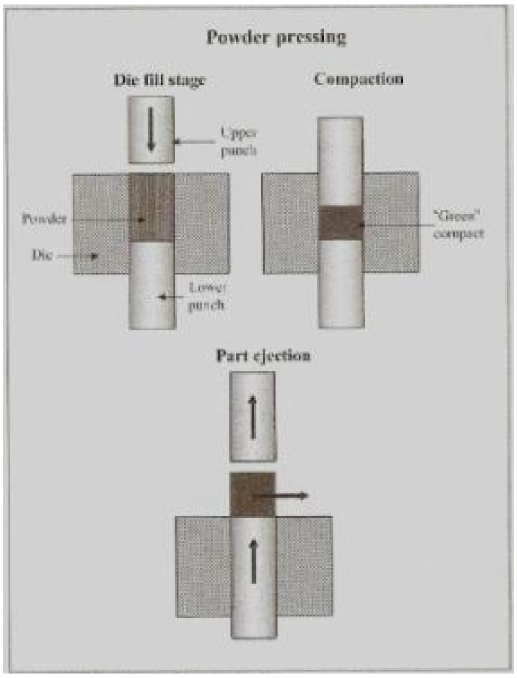


Figure 3.5: Powder compacting process

Source: Smith, 2004

The compacting process consists of the following stages:

i. *Die filling.* At this stage a controlled amount of blended powder is fed into the die filling.
ii. *Compaction.* The upper punch is moved down and pressed the powder with a predetermined pressure. In this study, the pressure used was 300kg/cm^2 = 29.42MPa.
iii. *'Green' compact part ejection and removal.* After the pressing was done, the unsintered powder that had finished compacted was removed from the die by using ejector.

3.7 SINTERING

After the green compact was removed from the die, then the green compact was put into the heat treatment furnace. For the setting procedure, firstly, the time T1 was set. Then, the time T2 was set to 10 minutes and after that set the temperature 550°C. Then, let the temperature become 550°C and let the green compact sintered for 10 minutes.

Figure 3.6: Heat Treatment Furnace that used in the sintering process

3.8 HOT MOUNTING

The sample is placed in the mounting press, the resin is added, and the sample is processed under heat and high pressure. The purpose of hot mounting is to support the brittle composite in the supported medium before doing test on it.

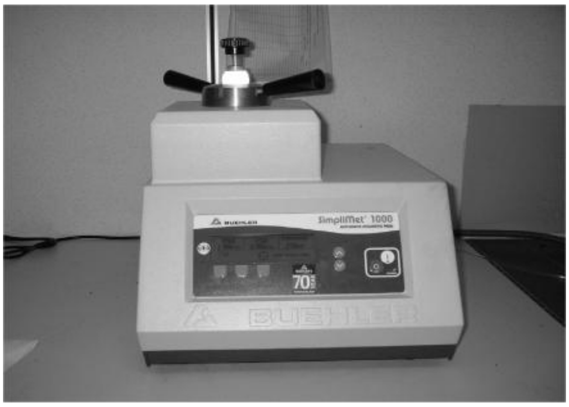


Figure 3.7: Hot Mounting Machine

Figure 3.8: The resin used in hot mounting

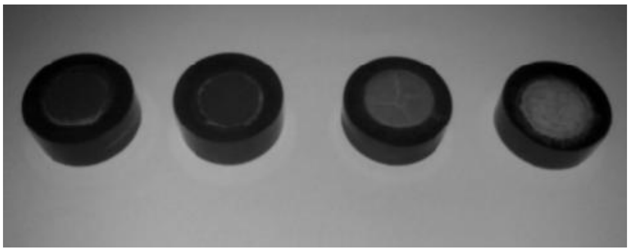


Figure 3.9: The mounted specimen

3.9 SURFACE FINISHING

Surface finishing is used to describe a number of industrial processes that can be applied to improve the surface of manufactured item. The major reason to apply this process is to improve appearance, improve adhesion or ink wettability, corrosion protection, wear resistance and friction control also are areas where performance can be enhanced by these treatments.

The specimens were prepared by grinding with 800 grit papers followed by polishing with diamond paste using surface finishing machine. All specimens that have been mounted was put on the surface finishing machine. All specimens were hold tightly. After that, the machine was "ON" to grind all the specimens until the surface of the specimens smooth.

Figure 3.10: Surface finishing Machine

3.10 PERFORMING EXPRIMENTS

Produced SiC particle reinforced Al MMC, the mechanical properties of the samples were examined by Vickers Hardness Tester for hardness and Image Analyzer for microstructure.

3.10.1 Vickers hardness test

The Vickers hardness test was developed in the early 1920s as an alternative method to measure the hardness of the materials. The Vickers test is often easier to use than other hardness test since the required calculations are depend on the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The basic principle, as with all common measures of hardness, is to observe the questioned materials' ability to resist plastic deformation from a standard source. The Vickers hardness test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test as the Vickers pyramid Number (HV). HV is then determined by the ratio F/A where F is the force applied to the diamond and A is the surface area of the resulting indentation. A can be determined by the

$$A = \frac{d^2}{2\sin(136^o/2)} \quad (3.1)$$

Which can be approximated by evaluating the sine term to give

$$A \approx \frac{d^2}{1.854} \quad (3.2)$$

Where d is the average length of the diagonal left by the indenter. Hence,

$$Hv = \frac{F}{A} \approx \frac{1.854F}{d^2} \quad (3.3)$$

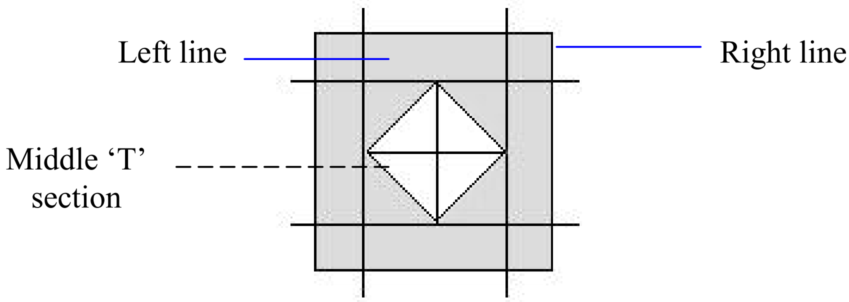


Figure 3.11: Digital micro hardness tester MMT-X7 Model

There are several steps in measuring the hardness of the specimen by using digital micro hardness tester. Firstly, the specimen was clipped tightly by adjusting the universal inclining until the specimen cannot be move anymore. Secondly, the left line was adjusted to the sharpest edge of diamond shape. After that, the right line was adjusted to overlap the line by using the left knob. The next step, the button

ZERO was pressed. Then, the right line was moved back to the sharpest edge of the diamond shape by using the left knob. Lastly, the button READ was pressed to get the reading of the hardness.

3.10.2 Microstructure

The microstructure of SiC and Al powder measured using a standardized test. The microstructure of the composite was observed by using Image analyzer. The Image Analyzer was used to study the microstructure of the composites that containing different weight percentage of SiC that have been produced using powder metallurgy method.

In this study, four samples were observed on purpose to compare the distribution of the different weight percentage of SiC in the Al composite. In addition, the image analysis and computerized scanning composite were employed to quantitatively the SiC distribution.

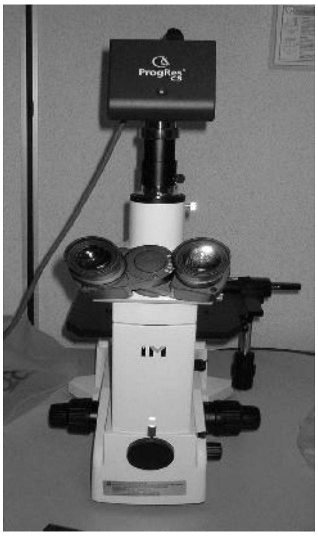


Figure 3.13: Image Analyzer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results of the experiments that were conducted through the hardness test and microstructure. The chapter shows the value of the data and followed with data analysis via showing the graphs and figures. This is followed by a discussion about the findings and the results in order to achieve the objective of the study.

The result in analysis the effect of weight percentage of SiC on mechanical behavior of Al MMC could be divided into several aspects. All these aspects is important to study the effect of weight percentage of SiC on hardness and microstructure of Al MMC.

To determine the result, the aspects that can be considered were divided into three, which are:

i. Hardness
ii. Microstructure
iii. Summary of the result

All these aspect can help to find the best composite due to their mechanical behavior.

4.2 HARDNESS

Testing for hardness is a quick non-distractive test that provides useful information about the strength of materials. Hardness is the characteristic of a solid material expressing its resistance to permanent deformation. It is the property of a metal, which gives it the ability to resist being permanently, deformed such as bent, broken, or have its shape changed, when a load is applied.

Hardness can be measure on the Mohs scale or various other scales. Some of the other scales used for indentation hardness in engineering such as Rockwell, Vickers and Brinell. In this study, the hardness of the composites was studied using Vickers hardness test.

Table 4.1 shows the values of Vickers hardness of the composite with different weight percentage of silicon carbide. Specimen A is referring to pure Al and specimen B for 5 wt% of SiC. Then, specimen C and specimen D are 10 wt% and 15 wt% of SiC, respectively.

For each specimen, the hardness value was taken five times to get the average reading value of hardness. Then, the average value was taken as the value of the hardness of the composite. The formula below shows how to get the average of the hardness.

$$HVave = \frac{\mathrm{Re}\,ading1 + \mathrm{Re}\,ading2 + \mathrm{Re}\,ading3 + \mathrm{Re}\,ading4 + \mathrm{Re}\,ading5}{5} \tag{4.1}$$

Sample calculation for the Vickers hardness of specimen A which are pure aluminum is shown below:

$$HVave,1 = \frac{43.9 + 43.5 + 60.5 + 49.8 + 46.5}{5} = 48.84HV$$

Table 4.1: Values of the hardness of the SiC reinforced Al composites

SPECIMEN	wt% SiC	wt% Al	Reading (HV)					
			1	2	3	4	5	Average
A	0	100	43.9	43.5	60.5	49.8	46.5	48.84
B	5	77.9	82.5	87.3	77	72	70.8	77.92
C	10	90	97.4	94.9	97.9	101.9	97	97.82
D	15	85	110.2	115.6	120.4	119.7	124.8	118.14

The average value of hardness for specimen A is 48.84HV. Then, for the specimen B, the value is increased to 77.92HV while for the specimen C is 97.82HV. The average reading to the D specimen is 118.14HV. From the observation, the highest value of hardness is specimen D. The weight percentage of SiC for specimen D is 15%.

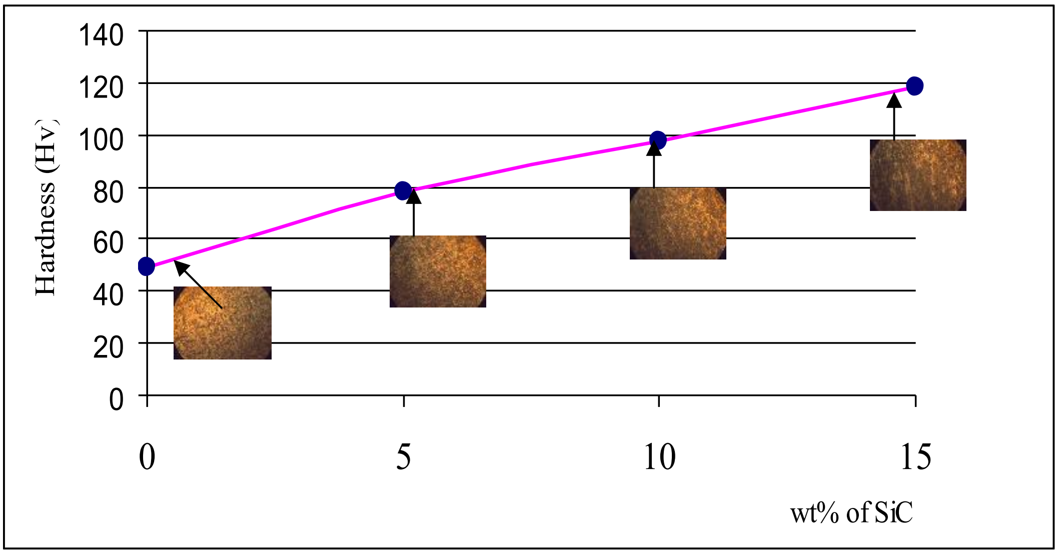


Figure 4.1: Graph of Vickers hardness against weight percentage of SiC

The variation of hardness of the composites with weight percentage of silicon carbide reinforcement particle is shown in the Graph 4.1. The hardness of the SiC reinforced Al MMC increases with the increasing of value of weight percentage of silicon carbide. In composites, hardness increase proportionally by increasing reinforcement amount. As the hardness increases, the specimen becomes stronger while the hardness lower, the specimen become brittle. The introducing SiC particles into the Al matrix resulted in mechanical properties such as hardness and strength.

The variation of hardness of MMCs increased more or less linearly with the weight percentage of SiC particles in the Al matrix due to the increase of the ceramic phase. A higher hardness was also associated with the lower porosity. The porosity of the composite decreased with the increasing weight percentage of SiC is related to the flowing behavior of the composite.

A high hardness is usually associated with good abrasive wear resistance. It has been established that increasing the hardness of the contact surface causes the mild to severe wear transition to move to higher load values. There is also considerable evidence that the addition of hard, nonmetallic reinforcement particles in a metal matrix composite improves the wear resistance and reduces the coefficient of friction.

Table 4.2: The comparison of hardness values of the composite between the result and the previous research

wt%		Reading (HV)	Difference (%)
SiC	Al	Experiment (Previous Research)	
0	100	48.84 (58.75)	16.87
5	95	77.92 (68.80)	13.25
10	90	97.82 (80.00)	22.28
15	85	118.14 (92.50)	27.72

Source: Sahin,Y. et.al., 2003

Table 4.2 shows the comparison of hardness values of the composite between the result and the previous research. For pure aluminum, the difference percentage of hardness is 16.87% while for 5 wt% of SiC is 13.25%. The difference value between the result and the previous research of 10% and 15% of SiC are 22.28% and 27.72% different.

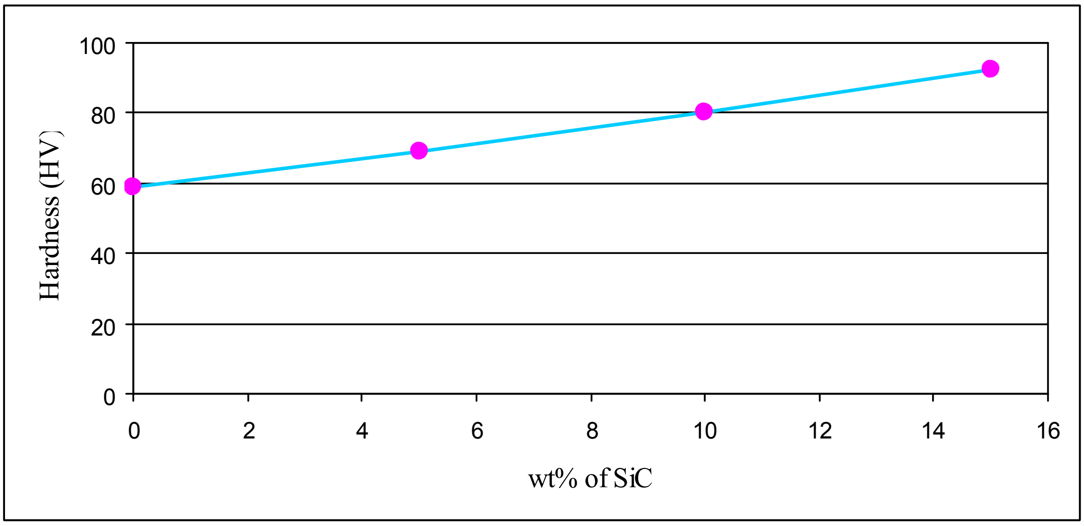


Figure 4.2: Graph of Vickers hardness against weight percentage of SiC based on the data from previous research

From the graph above, it shows that when wt% of SiC increase, the hardness also increases. This means that, when the reinforcement particle exist in the composite, the hardness of the composite material increased.

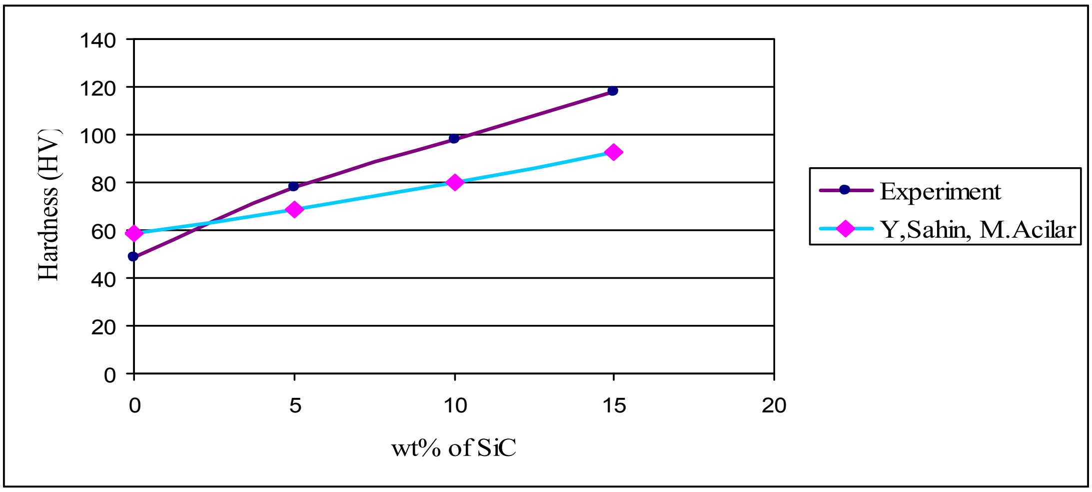


Figure 4.3: Comparison of Vickers hardness values between experimental values and previous research value

The Graph 4.3 shows the comparison graph of hardness values versus weight percentage of silicon carbide between experimental and previous research. Both of the graphs show the same pattern of hardness variation. The hardness of the composite is improved since the weight percentage is increased.

4.3 MICROSTRUCTURE

Microstructure refers to microscopic description of the individual constituents of a material. The microstructure of a material of which we can broadly classify into metallic, polymeric, ceramic and composite is a study of the crystal structure of a material, their size, composition and ultimately their effect on the macroscopic behavior in terms of physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high or low temperature behavior, wear resistance, and so on, which in turn govern the application of these materials in industry and manufacture.

When a polished flat sample traces of its microstructure, it is normal to capture the image using macrophotography. More sophisticated microstructures examination involves higher powered instruments such as optical microscopy, electron microscopy, X-ray diffraction and so on, some involving pre-preparation of the material sample. The methods are known collectively as metallography as applied to metals and alloys, and can be used in modified form for any other material, such as ceramics, glasses, composites and polymers.

When microstructure of composite specimens obtained by powder metallurgy method is examined, it is observed that the distribution within the structure is uniform. But, as the amount of silicon carbide particles increase, distribution of SiC in Al become more closely to each other..

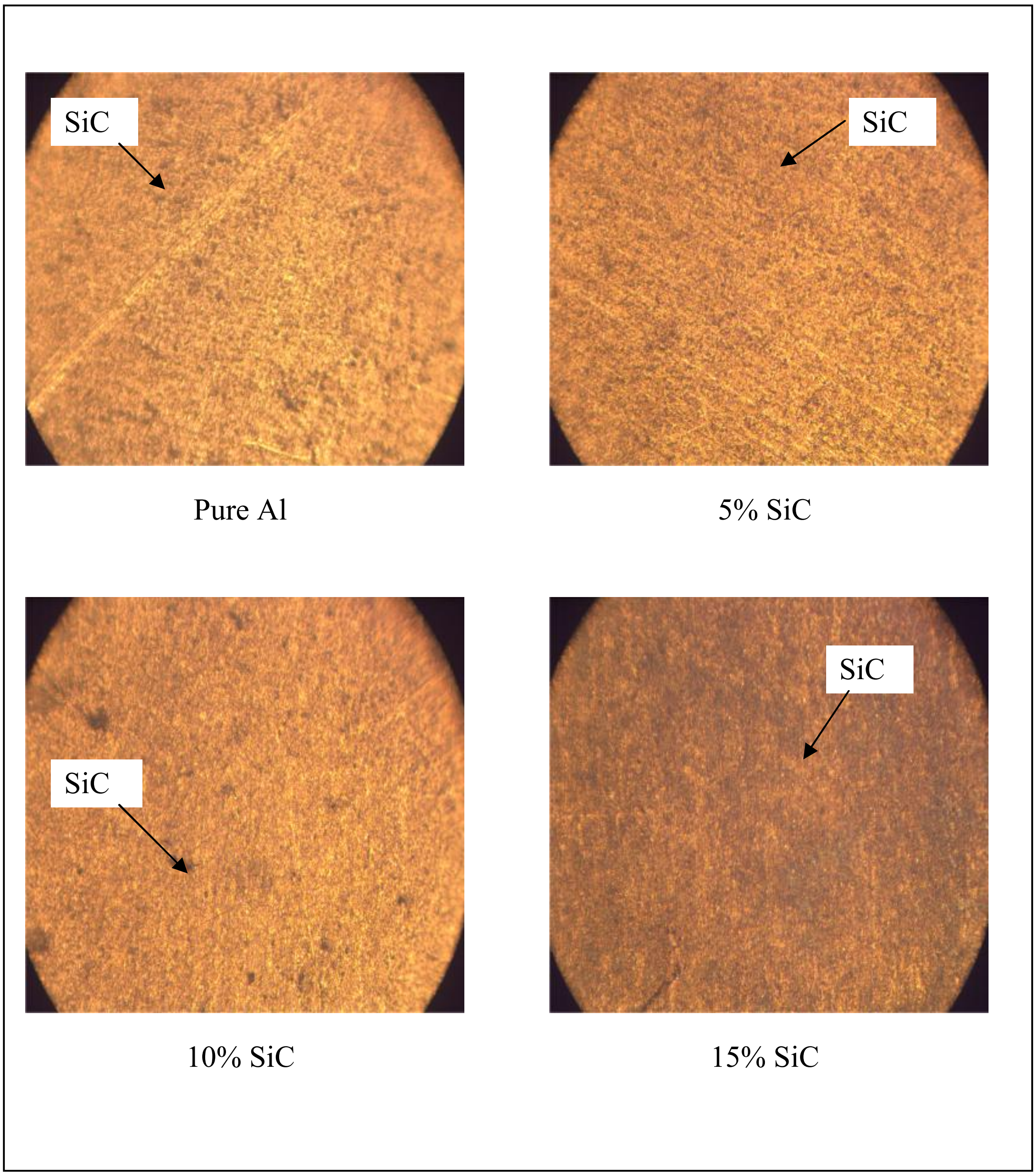


Figure 4.4: Microstructure for variation of wt% of SiC for magnification of 10X

Figure 4.4 shows the microstructures of each specimen under the lowest magnification, M = 10X. From the observation, it shows that the distribution of the composite increased with the increasing of wt% of SiC. As the amount of SiC increased, the black dot in the image is increased.

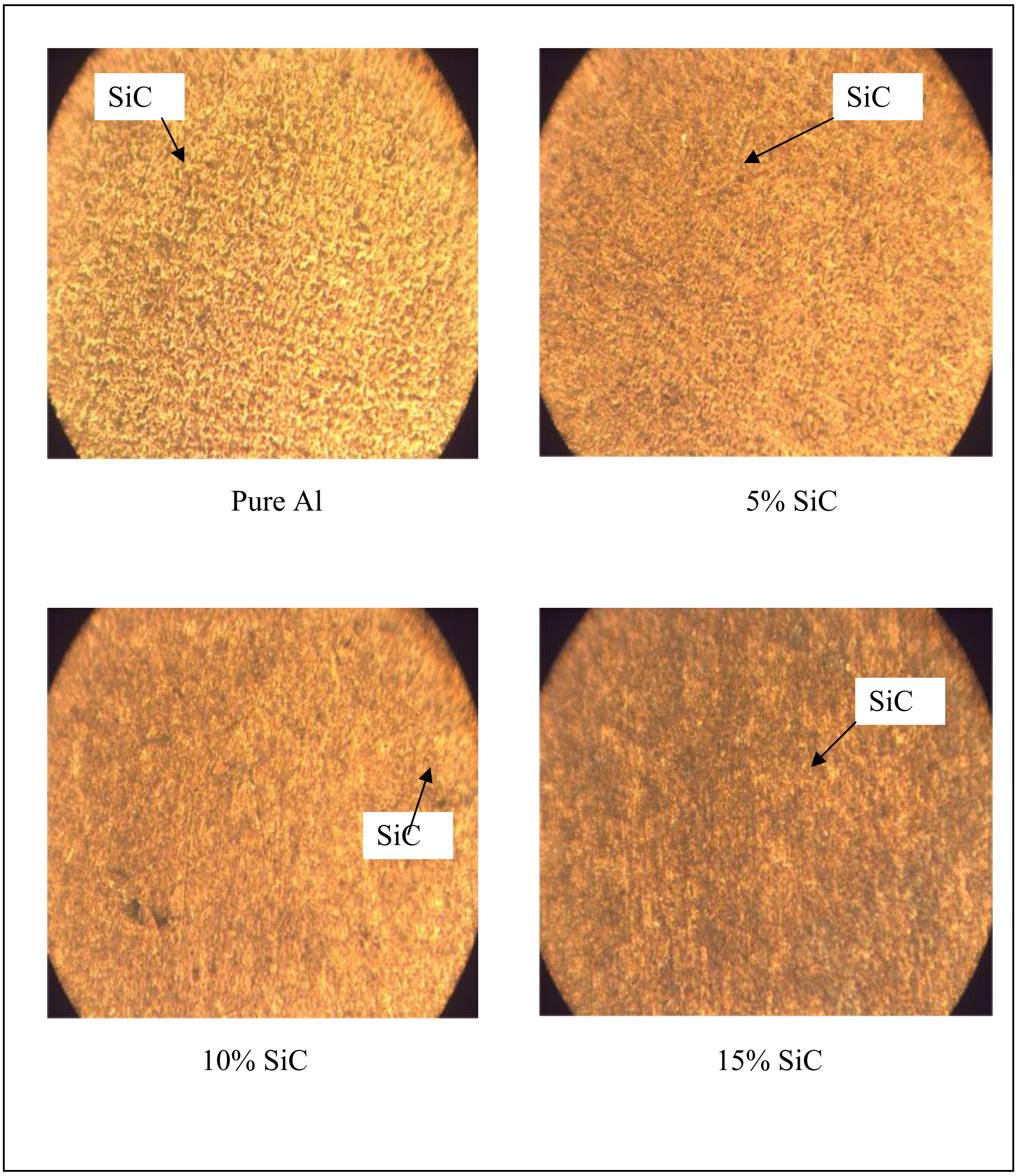


Figure 4.5: Microstructure for variation of wt% of SiC for magnification of 20X

Figure above shows the microstructures for composite with four different weight percentage of SiC. The magnification used was M = 20X. Compared to the microstructures in Figure 4.4, the microstructures in figure 4.5 was clearer. The distribution of SiC shown can be seen. The dark spot's position was found out. As the weight percentage of SiC increased, the dark spot also increased.

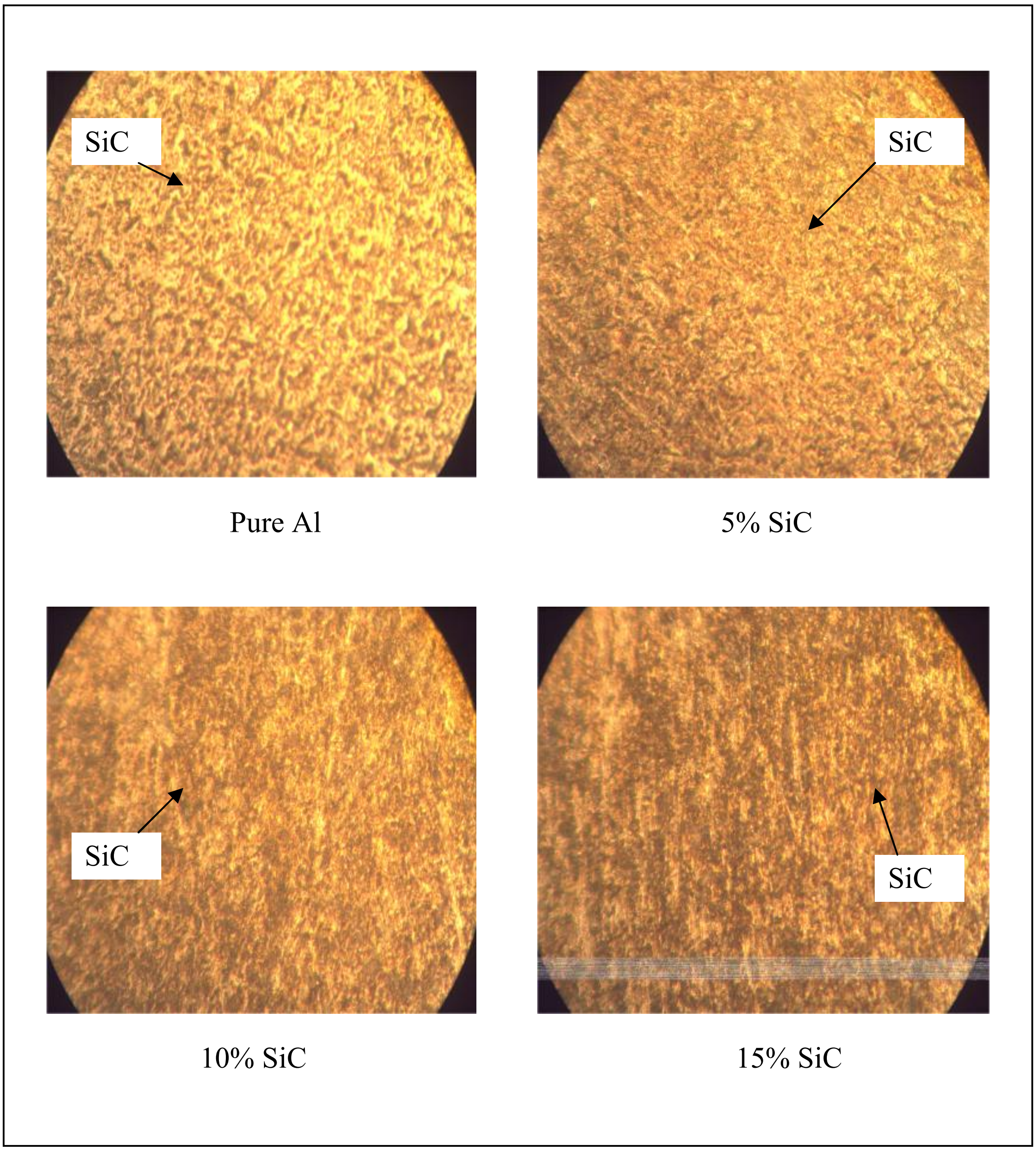


Figure 4.6: Microstructure for variation of wt% of SiC for magnification of 50X

From the figure 4.6, the microstructure become clearer rather than the using magnification 10X and 20X. The microstructure was become clearer using the magnification of 50X. From the observation, the distribution of the reinforcement particle in the Al MMC become more uniform as the weight percentage of SiC increased. With the increasing of the reinforcement particle, the composite become better due to its mechanical behavior.

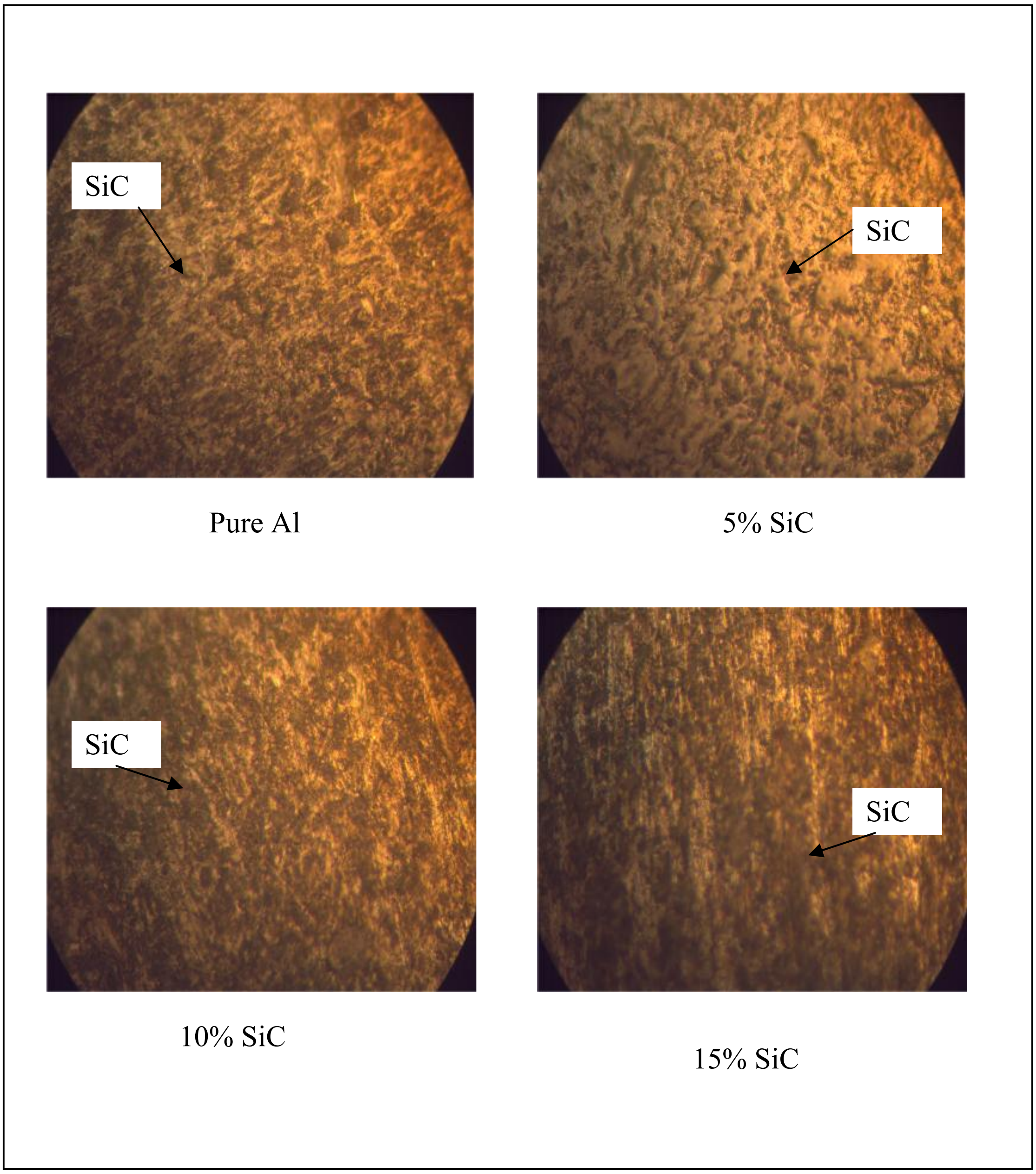


Figure 4.7: Microstructure for variation of wt% of SiC for magnification of 100X

The microstructure of the composite produced was observed using Image analyzer. The highest magnification used to observe the microstructure was magnification lens with M = 100X. As the presence reinforcement increased, the distribution between SiC particle become more uniform and closely to each other.

In the current work, the SiC reinforced Al composites were manufactured by a powder metallurgy route, and their microstructures and hardness were studied. The reinforcement of SiC particles were distributed homogeneously in the Al matrix. In general, the particle size distribution was nearly identical in all the composites.

The properties of MMCs depend not only on the matrix, particle, and the volume fraction, but also distribution of reinforcing particles and interface bonding between the particle and matrix. In practical way, it is difficult to achieve a homogeneous distribution. From the Figure 4.3 - 4.7, the distribution of SiC particles in the composite is uniform.

When microstructure of the composite specimens obtained by powder metallurgy method is examined, it was observed that as the amount of SiC particles increase, distribution within structure worsens. The image of related microstructures are given in Figure 4.1 - 4.4.

From the figure 4.1-4.4, show that a higher magnification used when observing the specimens, it clearly revealed that ceramic particles were covered and were wetted by the matrix alloy. As the weight percentage increase, the dark spot seen in the composite also increase. This proved that, when the amount of SiC increase, the distribution within structure become close to each other. In the figures shown, some of the specimen shows that there were porosities in the specimen. This is because when the compacting process is done, the green compact is not been sintered immediately after the specimen was removed from the die. So that, the air spreads widely into the specimens.

Figures 4.1-4.4 display the optical micrographs taken from low magnification to high magnification from pure Al, 5,10 and 15% of SiC composites. It is seen that the grain size of Al with 0% SiC is quite large. With the introduction of SiC particles, the grain size decreases. At the same time, pores seen as the dark spot increases in number as more SiC particles are introduced in the composites.

4.4 SUMMARY OF THE RESULT

The objective of this experiment is to get the hardness value and microstructure for different specimens that have been produced using powder metallurgy method. The value of hardness and the microstructure then be compared to each other to find which one is the better composite due to their mechanical behavior.

For the Vickers hardness test, the values of hardness for each specimen are:

i. Specimen A, which is pure aluminum, the value is 48.84HV.
ii. Specimen B is contains with 5 wt% of SiC and the value is 77.92 HV.
iii. Specimen C is contains with 10 wt% of SiC and the value is 97.82 HV.
iv. Specimen D is contains with 15 wt% of SiC and the value is 118.14 HV.

For the microstructure, the observation was using Image Analyzer. The magnifications of lens that was used in this experiment were 10X, 20X, 50X and 100X. Microstructure examination showed that the SiC particle distributions were homogeneous and uniform. The microstructure of the composites is strongly depends on the matrix properties and the presence of reinforcement.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This experiment addressed the mechanical behavior of aluminum metal matrix composite such as hardness and microstructure.

In this study, hardness and microstructure of different weight percentage of SiC particle was examined. Four specimens with different weight percentage of SiC which are 0% SiC pure aluminum, 5% SiC, 10% SiC and 15% SiC were successfully done using powder metallurgy method.

The hardness of the composite increase with the increasing of reinforcement ratio. The highest value of the hardness of the composite is 118.14 HV which is specimen D with composition of SiC is 15%.

The microstructure of the composite is examined using Image analyzer. From this, we can conclude that the magnification of lens when examine the microstructure we can see the distribution of SiC and aluminum on it. Microstructural examination showed that the SiC particle distributions were homogeneous.

After the data was collected and analyzed, one specimen was chosed as the best composite compared to others. It was the Al composite that contains with 15% of SiC. Its hardness value is 118.14HV. While its microstructure was seen clearly using lens magnification of 100x.

5.2 RECOMMENDATIONS

This project recommended some additions or adjustments in order to make the experiment run effectively.

From the experiment, there was found that, the specimens contain porosity. After the observation, its found that the porosity exists because the composite was not sintered immediately after compaction. So, it recommend that after the compaction process, the green compact should be sintered instantly in order to reduce porosity.

Besides that, in this project the aspects that have been examined are only the hardness and the microstructure of the composites. Therefore, for further analysis, it should focus on other parameters such as density, porosity, tensile strength, impact, toughness and surface roughness.

Other than that, the hardness value can be shown by using different type of hardness test which are Vickers hardness Test, Brinell hardness test and Rockwell hardness test.

Lastly, for the microstructure was obtained using Image Analyzer. The result was not very clear. So that, for the future research, the microstructure should be observe using Scanning Electron Microscopy (SEM) because it have many advantages compared to Image Analyzer. The SEM has a large depth of field which allows more of a specimen to be in focus in one time. The SEM also has much higher resolution, so closely spaced specimen can be magnified at much higher levels.

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APPENDIX A

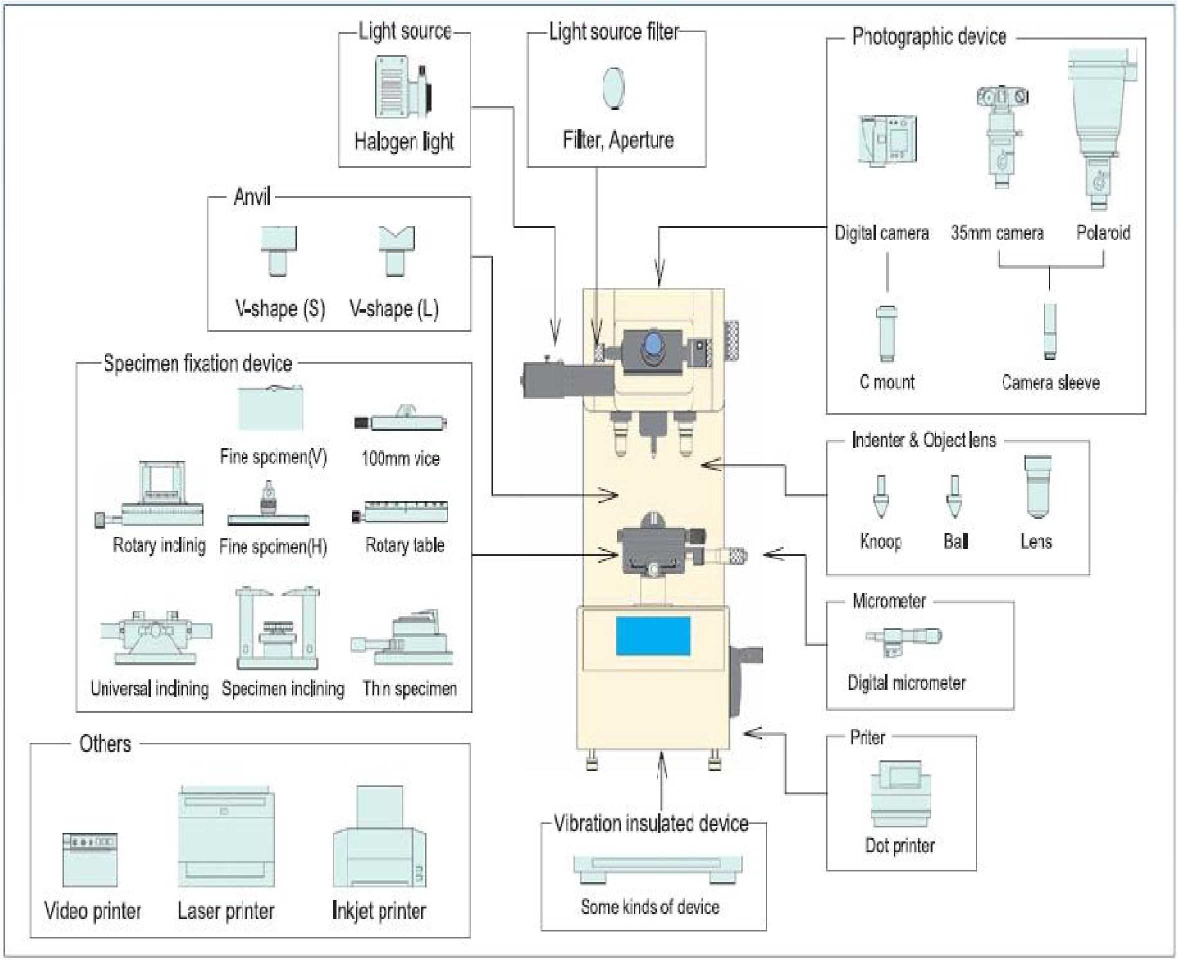

Figure 6.1: Vickers hardness tester

APPENDIX B

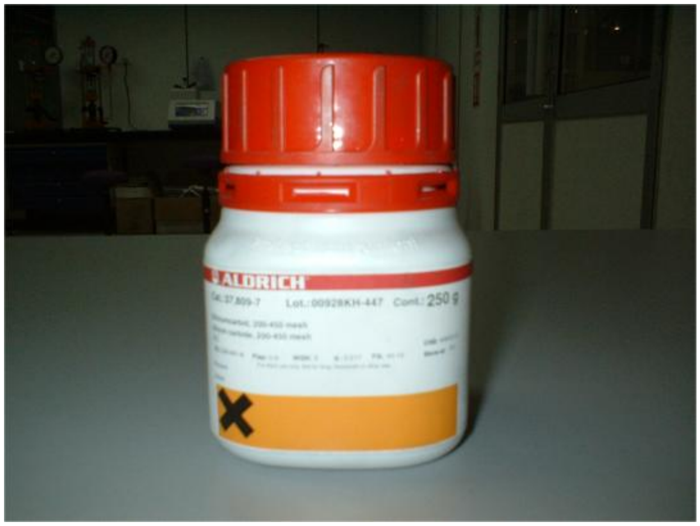

Figure 6.2: Powder used

APPENDIX C1

Figure 6.3: Lathe Machine

APPENDIX C2

Figure 6.4: Digital Analytical balance

APPENDIX C3

Figure 6.5: Hydraulic Power Pressure