EFFECT OF MILLING TIME ON MECHANICAL AND PHYSICAL BEHAVIOR OF AL MMC REINFORCED WITH AL_2O_3

SUHAIMI BIN MD YUSOFF

UNIVERSITI MALAYSIA PAHANG

EFFECT OF MILLING TIME ON MECHANICAL AND PHYSICAL BEHAVIOR OF ALMMC REINFORCED WITH AL_2O_3

SUHAIMI BIN MD YUSOFF

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

SUPERVISOR’S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

Signature: ....
Name of Supervisor: Mr. Wan Azmi Bin Wan Hamzah
Position: Lecturer
Date: 12 November 2008

Signature: ....
Name of Panel: Nur Azhani Binti Abd Razak
Position: Lecturer
Date: 13 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 concurently submitted for award of other degree.

Signature: ....

Name: Suhaimi B. Md Yusoff

ID Number: MA05096

Date: 12 November 2008

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Mr. Wan Azmi Bin Wan Hamzah and Mrs. Pn Julie Juliewaty Binti Mohamed for germinal ideas, invaluable guidance, continueous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a Degree program is only a start of a life-long learning experience. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I also would like to express very special thanks for their suggestions and co-operation throughout the study. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my labmates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to members powder metallurgy research group for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This thesis is to investigate the effect of milling time to the mechanical and physical properties Aluminum metal matrix composite reinforced with alumina. The objective of this thesis is to study the effect of milling time on mechanical and physical properties of powder materials. This thesis also to characterize the hardness and microstructure of Aluminum MMC produced by reinforced aluminum with alumina using powder metallurgy process. The thesis describes the powder metallurgy process to produce Al MMC reinforce with Al_2O_3. The powder metallurgy process consist of three main process which is milling process, compaction process and sintering. The milling process has big influence on the characteristic of powder materials, due to particle deformation followed by welding and fracturing particles. Mechanical milling is a process involving repeated deformation, welding and fracture. The mechanically milled show finer and better distribution of reinforcement particle what lead to better mechanical properties of obtained product. The results are increasing the milling time significant to improve the mechanical and physical properties of the Aluminum metal matrix composite produced.

ABSTRAK

Tesis ini adalah untuk menyelidik kesan masa kisaran terhadap ciri-ciri mekanikal dan fizikal aluminium besi campuran. Tujuan tesis ini adalah untuk memahami kesan masa kisaran terhadap ciri-ciri mekanikal dan fizikal kepada bahan serbuk. Tesis ini juga bertujuan untuk mengelaskan kekerasan dan struktur bahan aluminium besi campuran yang diperkuat menggunakan alumina. Tesis ini menyentuh tentang penghasilan aluminium besi campuran yang diperkuat dengan menggunakan alumina melalui kaedah serbuk metalurgi. Serbuk metalurgi terdiri daripada tiga proses utama iaitu proses kisaran, proses tekanan dan proses pensinteran. Proses pensinteran memberikan kesan besar terhadap cirri-ciri besi campuran melalui perubahan bentuk bahan campuran diikuti oleh penyambungan dan pemecahan biji-biji serbuk. Process kisaran menunjukkan kehalusan dan menyerataan serbuk penguat akan menghasilkan cirri-ciri fizik yang lebih baik bagi sesuatu bahan. Hasil yang diperolehi adalah dengan peningkatan masa kisaran, maka ciri-ciri mekanikal dan fizikal aluminium besi campuran akan bertambah baik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

HV	Hardness Number
wt%	Weight Percentage

LIST OF ABBREVIATIONS

Al	Aluminum
Al_2O_3	Alumina
CFRP	Finate Element Method
CMC	Ceramic Metal Composite
FRP	Fiber Reinforced Particle
FEM	Finate Element Method
GRP	Glass Reinforced Particle
MMC	Metal Matrix Composite
PMC	Polymer Metal Composite
PRM	Particle Reinforced Material

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This project basically concentrates on how to produce the Aluminum metal matrix composite using the powder metallurgy process. The term “composite” broadly refers to a material system which composed of a reinforcement distributed in a matrix phase. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composite. In Al MMCs one of the constituent is aluminum, which forms percolating network and is term as matrix phase. The other constituent is embedded in this aluminum matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Powder metallurgy contains three major steps which are mixing the matrix powders and reinforcement powders. It is carried out to obtain a desired powder distribution. After that, mixed powder will be compacted at certain pressure to produced green compaction material. After compaction, material produced will be sintered to transform compacted bond to much stronger metallic bonding. At the mixing process, time taken to mix the aluminum powder and alumina powder will be varied to get different properties of Al MMC produced. Then Al MMC will be test through several experiments to investigate its mechanical and physical properties.

1.2 PROBLEM STATEMENT

The demand for the light weight components have increased and to reduce the cost of the fabrication. These have led to increase use of the aluminum with the low cost of the fabrication that is the aluminum fabricated using powder metallurgy process. Aluminum powder metallurgy offers components with low density, excellent machinability and good response to a variety of finishing process. In addition, aluminum powder metallurgy parts can be further processed to eliminate porosity and improve bonding properties that compare to those conventional wrought aluminum products.

1.3 THE OBJECTIVES OF THE RESEARCH

The objective of the thesis is:

i) To study the effect of milling time on mechanical and physical properties of powder materials.

ii) To characterize the hardness and microstructure of Aluminum Metal Matrix Composite produced by reinforced Aluminum (Al) with Alumina (Al_2O_3) using powder metallurgy process.

1.4 OVERVIEW OF THE THESIS

Powder Metallurgy is a method of manufacturing reliable net shaped components by blending element powders together, compacting this blend into a die and sintere the pressed part in a controlled atmosphere furnace to bond the particle metallurgucally. The powder metallurgy process fabrication method is highly cost effective in producing parts at, or closed to final dimensions. Powder metallurgy provides advantages such as production of complex shapes to very closed dimensional tolerance and physical and mechanical properties of components can be controlled through the process parameters.

Mechanical milling or mixing, as a method of introducing the reinforcement particles, assures better distribution of the particles in the consolidated material (Lee et al, 1995). This process consists of repeated welding–fracturing–welding of a mixture of powder particles in a high-energy ball mill (Suryanarayana, 2001). The central event is that the powder particles are trapped between the colliding balls during milling and undergo deformation and/or fracture processes, depending upon the mechanical behavior of the powder components. Proper mixing is essential to ensure the uniformity of mechanical properties throughout the part. Even when a single metal is used, the powders may carry significantly in size and shape, hence they must be blended to obtain uniformity from part to part. The ideal mix is one in which all particle of each material are distributed uniformly. The correct determination of the milling time will ensure that the characteristics of the powder will be such as to enhance the final properties of the composite material (Fogagnolo et. al., 2002).

The powder metallurgy components can be produced by cold die compaction of the powder. Normally, die compaction of metal powder undergoes a number of stages, namely, initial compaction, which involves particle rearrangements. The physical properties such as particle size and shape greatly influence this initial stage. This is followed by the deformation, and here the mechanical properties and the quality of the particles are important factors, which control the compressibility behavior of the powder. The final stage of compaction is almost totally an upsetting of the bulk material. As a result, the powder compacted component is produced with inhomogeneous distributions of density and porosity.

Sintering is the process powder compacts are heated so that adjacent particles is bonded together by forming necking, thus resulting in a solid particle with improved mechanical strength compared to the powder compacted. This typically has two heating zones, the first removes the lubricant, and the second higher temperature zone allows diffusion and bonding between powder particles. The density of the component will change during sintering process, depending on the materials and the sintering temperature. These dimensional changes can be controlled by an understanding of the sintering parameters such as temperature and sintering time.

Aluminum possesses a combination of properties that make it extremely useful engineering material. Aluminum has a low density, making it particularly useful for transportation manufactured products. Aluminum also has good corrosion resistance in most natural environment due to tenacious oxide film that forms on its surface, effectively preventing further oxidation. Although pure aluminum has low strength, it can be reinforced to strength of about 690Mpa (W. F. Smith, 2004). Aluminum is nontoxic and is used extensively for food containers and packaging. The good electrical properties of aluminum make it suitable for many applications in the electrical industry. The relatively low prices of aluminum along with its many useful properties make this metal very important industrially.

Aluminum oxide is an amphoteric oxide of aluminum with the chemical formula Al_2O_3. It is also commonly referred to as ceramic materials that can be produced by the Bayer process from bauxite. Alumina most significant use is in the production of aluminum metal because of very hard and high melting point it is used as an abrasive on the alloys.

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure. There are several groups of the composites according to matrix, for example Polymer Matrix Composites, PMC (epoxy/C-fiber, epoxy/SiC-particle), Metal Matrix Composites, MMC (TiAl6V4/SiC-fiber, Al/Al2O3-particle), Ceramic Matrix Composites, CMC (C/SiC-particle, C/C-fiber) and others such as wood and concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to powder metallurgy process. The main process included milling the raw material (powder) which is Aluminum powder and Alumina powder (Al_2O_3), compacting milled powder and sintering process. A review of other relevant research studies is also provided. However, little information can be found on integrated durability evaluation methods. 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.

2.2 POWDER METALLURGY

Powder metallurgy is a method of manufacturing reliable net shaped components by blending element powders together, compact this blend in a die and sintering the pressed part in a controlled atmosphere furnace to bond the particle metallurgucally. The powder metallurgy process fabrication method is highly cost effective in producing parts at, or closed to final dimensions. Powder metallurgy provides advantages such as production of complex shapes to very closed dimensional tolerance and physical and mechanical properties of components can be controlled through the process parameters.

The industry is comprised of companies that make conventional powder metallurgy parts and products from iron and copper-base-powders; and companies that make specialty powder metallurgy products such as superalloys, porous products, friction materials, strip for electronic applications, high strength permanent magnets, magnetic powder cores and ferrites, tungsten carbide cutting tools and wear parts, metal injection molded parts and tool steels. There are international powder metallurgy industries in all of the major industrialized countries.

It has become one of the most common, most efficient processing techniques. Powder metallurgy components are being used in ever increasing quantities in a wide variety of industries as the technology combines unique technical features with cost effectiveness. Powder metal components are used in the aerospace industry for gears and engine parts. However, they are also found in automobiles, sporting goods, and everyday household items. It is important, then, to understand the process, as it is becoming even more common as time goes by.

Powder Metallurgy is a highly developed method of manufacturing reliable ferrous and nonferrous parts. Such metals used are brass, bronze, stainless steel, and iron. There are three basic steps in making a part: mixing elemental or alloy powders, compact the mixture in a die, and sintering the part in a controlled atmosphere furnace to bond the particles metallurgically. This process can be seen in Figure 1.1.

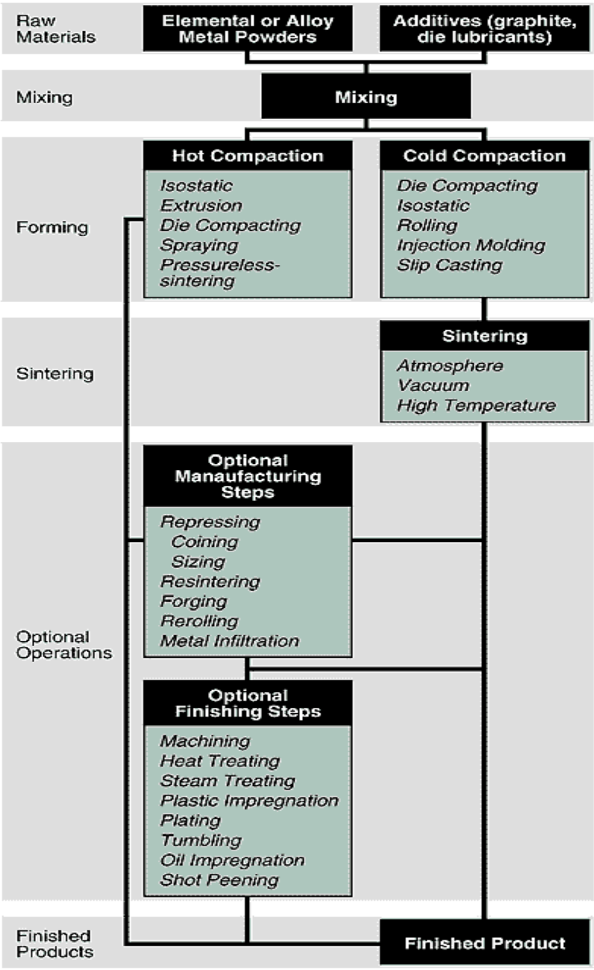


Figure 2.1: Powder Metallurgy Process

Source: Verlinden et al. (1994)

As with any manufacturing process, there are advantages and disadvantages that must be taken into consideration when designing parts. Some of the benefits and limitations of powder metallurgy are discussed in this section. The advantage of powder metallurgy is the powder metallurgy process typically uses more than 97% of the starting raw material in the finished part. This means that powder metallurgy conserves energy and materials. By conserving materials it is cost effective. And because parts can be produced at, or very close to, final dimensions, machining is very limited. Productions rates can be very high as well. Beside that another advantages is minimizes machining, minimizes scrap losses, maintain close dimensional tolerances, produces good surface finishes, provides materials which may be heat-treated for increased strength or increased wear resistance, provides controlled porosity for self-lubrication or filtration, facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metalworking processes and suited to moderate to high volume components production requirements.

There are limitations to the powder metallurgy process. Some of these disadvantages can be costs of powder production, limitations on the shapes and features which can be generated, e.g. process cannot produce reentrant angles by fixed die pressing or radial holes in vertically pressed cylinders and the size will always change on sintering. However, there are some design choices that can be made to make the powder metallurgy process more suitable for a part. For example, sharp corners should be avoided. Instead small radiuses to make the powder metallurgy process more applicable should replace corners. Also, the size change during sintering can be predicted, as it depends on a number of controlled factors including as-pressed density.

Because of its versatility, the powder metallurgy process is being used to produce many thousands of different parts in most product and equipment-manufacturing industries. The applications of powder metallurgy parts in these industries fall into two main groups. The first includes applications in which the part is impossible to make by any other method. Powder metallurgy is the only way of forming vital metals such as tungsten carbide, dispersion-strengthened materials, superalloys and self-lubricating bearings. Porous bearings and many types of magnetic cores are exclusively powder metallurgy products. The second group of uses consists of mechanical and structural parts that compete with other types of metal forms, such as machined parts, castings, and forgings. Examples of such powder metallurgy products include lock hardware, garden tractors, snowmobiles, automobile engines and transmissions, auto brake and steering systems, washing machines, power tools and hardware, sporting arms, copiers and postage meters, off-road equipment, hunting knives, hydraulic assemblies, x-ray shielding, oil and gas drilling wellhead components, fishing rods, surgical instruments, gears, cam shafts, and wrist watches.

2.2.1 MILLING PROCESS

Powders made by different processes have different sizes and shapes and must be well mixed-impart special physical & mechanical properties & characteristic to the powder metallurgy product. Proper mixing is essential to ensure the uniformity of mechanical properties throughout the part. Even when a single metal is used, the powders may carry significantly in size and shape, hence they must be blended to obtain uniformity from part to part. The ideal mix is one in which all particle of each material are distributed uniformly.

Lubricants can be mixed with the powders to improve their flow characteristic. They reduce friction between the metal particles, improve flow of the powder metals into the dies and improve die life. Lubricants typically are stearic acid zinc strearate in a proportion of from 0.25 to 5% by weight. Other additives such as binder also used to develop sufficient green strength and also can be used to facilitate sintering.

Irregularly shaped particles are required to ensure that the as-pressed component has a high green strength from the interlocking and plastic deformation of individual particles with their neighbors.

One disadvantage of this technique is the differences in pressed density that can occur in different parts of the component due to particle/particle and die wall/particle frictional effects. Typical as-pressed densities for soft iron components would be 7.0 g/cc, i.e. about 90% of theoretical density. Compaction pressure rises significantly if higher as-pressed densities are required, and this practice becomes uneconomic due to higher costs for the larger presses and stronger tools to withstand the higher pressures.

The purpose of mixing is to provide a homogeneous mixture and to incorporate the lubricant. Some lubricants that are commonly used are stearic acid, stearin, metallic stearates, especially zinc stearate, and increasingly, other organic compounds of a waxy nature. The main function of the lubricant is to reduce the friction between the powder and the surfaces of the tools (e.g. die walls, core rods) along which the powder must slide during compaction. This helps with getting desired uniformity of density from the top to the bottom of the compact. It also makes it easier to eject the compact, which minimizes the tendency to form cracks.

The lubricant must be selected carefully, as it may affect both green (unsintered) and sintered strengths. This is especially true if any residue is left after the organic part has decomposed.

Over-mixing can occur and should be avoided. This increases the apparent density of the mix. Over-mixing also further reduces the green strength of the subsequent compacts probably by completely coating the whole surface of the particles, thereby reducing the area of metal-to-metal contact on which the green strength depends.

Table 1.1: Common Milling Time According to Authors

No.	Author	Raw Material Used	Milling Time
1	Adamiak et al.	Aluminum + Titanium Aluminite	2, 10, 18
2	Fogagnolo et al. (2002)	Aluminum (PM6061) + Si_3N_4	0, 2, 4, 6, 8, 10
3	Fogagnolo et al. (2003)	Aluminum + AlN	0, 1.5, 3, 4.5, 6, 8, 10
4	Hesabi et al. (2006)	Aluminum + Al_2O_3	0, 2, 8, 12, 16, 18, 20
5	Simchi et al. (2007)	Aluminum + SiC	2, 8, 12, 16
6	Zhang et al. (2004)	Cu-Al_2O_3/ Al-Al_2O_3	1, 8, 40, 80

Table 1.1 shows the common milling time that the authors used in their research. Milling time will varied with some interval or incrementation. For each increment of time to mill the powders, the product will be test to see the effect such as physical and mechanical behavior.

2.2.2 COMPACTION PROCESS

Generally, the powder metallurgy components can be produced by cold die compaction of the powder. Normally, die compaction of metal powder undergoes a number of stages, namely, initial compaction, which involves particle rearrangements. The physical properties such as, particle size and shape greatly influence this initial compaction stage. This is followed by the elasticplastic deformation, and here the mechanical properties and the quality of the particles are important factors, which control the compressibility behavior of the powder. The final stage of compaction is almost totally an upsetting of the bulk material. Hence, the work hardening of the particle affects the hardness of the final product.

As a result, the powder compacted component is produced with inhomogeneous distributions of density and porosity. This is due to the frictional forces in between particles (internal friction), and/or between the powder and the container walls (powder/container friction). This, evidently, causes shrinking during distortion of the product. However, some powder metallurgy components are required to have a certain percentage of porosities so that pores may be filled with gases, liquids and self-lubricants for specific applications. Needless to say, the green density of compact has direct influence on the densification and porosity of the product and hence the strength. It seems that all the previously developed expressions depend totally or partially on experimental factors, due to the unknown parameters.

Studies were performed involving the simulation of powder compaction using the FEM and based on the elastic-plastic behavior of large displacement, where the powder is considered as a continuum which exhibits plastic deformation under applied external pressure. (Justino et al., 2004). The cold die compaction of powder metallurgy involves several complex parameters, such as, rearrangements, fragmentation, work hardening and others making it complicated to analyze theoretically the mechanism of compaction. Previously published works in general, rely on empirical or semi-theoretical expressions to relate the green density as a function of process parameters. Recently, the authors have published an analysis of the cold die compaction of powder materials based on the axi-symmetric solution of large deformation, but it did not elaborate on other important parameters (Al-Qureshi et al., 2005).

2.2.3 SINTERING PROCESS

Sintering is the process powder compacts are heated so that adjacent particles is bonded together by forming necking, thus resulting in a solid article with improved mechanical strength compared to the powder compact. This process will results in an increase in the density of the part. There are some processes such as hot isostatic pressing which combine the compaction and sintering processes into a single step.

After compaction the components pass through a sintering furnace. This typically has two heating zones, the first removes the lubricant, and the second higher temperature zone allows diffusion and bonding between powder particles. A range of atmospheres, including vacuum, are used to sinter different materials depending on their chemical compositions. As an example, precise atmosphere control allows iron/carbon materials to be produced with specific carbon compositions and mechanical properties.

The density of the component can also change during sintering, depending on the materials and the sintering temperature. These dimensional changes can be controlled by an understanding and control of the pressing and sintering parameters, and components can be produced with dimensions that need little or no rectification to meet the dimensional tolerances. Note that in many cases all of the powder used is present in the finished product, scrap losses will only occur when secondary machining operations are necessary.

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.

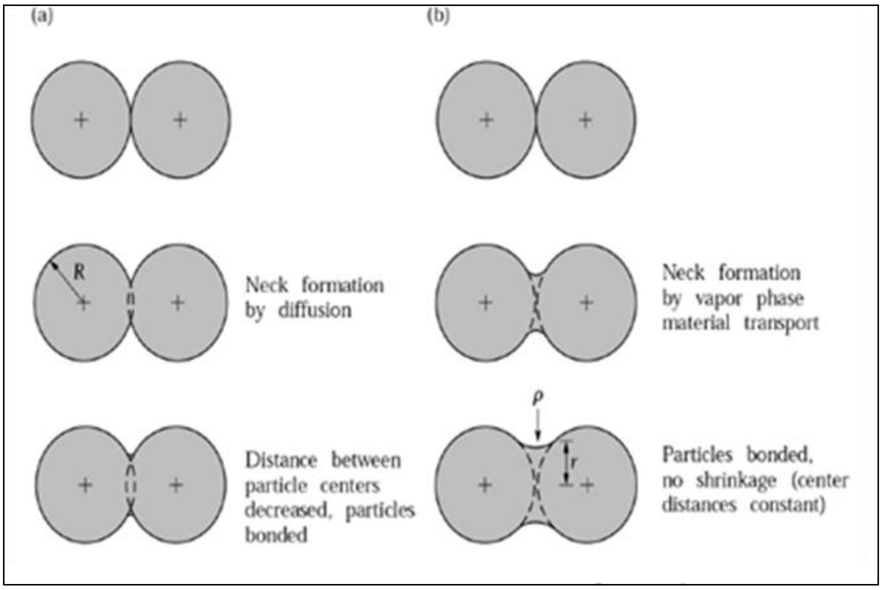


Figure 2.1: Mechanism for sintering process

Source: Manufacturing Process and Engineering, Prof. J. S. Colton

Figure 2.1 shows the formation of metallic bonding from compacted mechanical bonding during sintering process for matrix-reinforcement phase and matrix-matrix phase.

2.3 RAW MATERIAL

2.3.1 ALUMINUM

Aluminum possesses a combination of properties that make it extremely useful engineering material. Aluminum has a low density, making it particularly useful for transportation manufactured products. Aluminum also has good corrosion resistance in most natural environment due to tenacious oxide film that forms on its surface, effectively preventing further oxidation. Although pure aluminum has low strength, it can be alloyed to strength of about 690Mpa (W. F. Smith, 2004). Aluminum is nontoxic and is used extensively for food containers and packaging. The good electrical properties of aluminum make it suitable for many applications in the electrical industry. The relatively low prices of aluminum along with its many useful properties make this metal very important industrially.

Aluminum is the metal of choice for all of whom are looking for a material which combines functionality and cost-effectiveness with forward looking form and design potential. The demand for aluminum products is increasing year by year. Aluminum is an extraordinarily versatile material. The range of forms it can take (castings, extrusions and tubes, sheet & plate, foil, powder, forgings etc) and variety of surface finishes available (coatings, anodizing, polishing etc) means it lends itself to a wide range of products, many of which we use every day of our lives.

The strongest aluminum alloys are less corrosion resistant due to galvanic reactions with alloyed copper. A unique combination of properties makes aluminum and its alloys one of the most versatile engineering and construction materials available today. Aluminum is one of the lightest available commercial metals with a density approximately one third that of steel or copper. Its high strength to weight ratio makes it particularly important to transportation industries allowing increased payloads and fuel savings. In other fabrications, aluminum’s lightweight can reduce the need for special handling or lifting equipment. Aluminum can be easily fabricated into various forms such as foil, sheets, geometric shapes, rod, tube and wire. It also displays excellent machinability and plasticity ideal for bending, cutting, spinning, roll forming, hammering, forging and drawing. Aluminum can be turned, milled or bored readily, using the correct tool age. In fact, most aluminum alloys can be machined speedily and easily. Aluminum is a popular choice of material for complex-sectioned hollow extrusions.

2.3.2 ALUMINA

Aluminum oxide, commonly referred to as alumina, possesses strong ionic interatomic bonding giving rise to its desirable material characteristics. It can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. Alumina is the most cost effective and widely used material in the family of engineering ceramics. The raw materials from which this high performance technical grade ceramic is made are readily available and reasonably priced, resulting in good value for the cost in fabricated alumina shapes. With an excellent combination of properties and an attractive price, it is no surprise that fine grain technical grade alumina has a very wide range of applications.

Alumina has some good properties such as hard, wear-resistant, resists strong acid and alkali attack at elevated temperatures, good, thermal conductivity, excellent size and shape capability, high strength and stiffness and an easily metallizable composition is the most properties for demanding high temperature applications.

Typical uses of the alumina gas laser tubes, wear pads, seal rings, high temperature electrical insulators, high voltage, insulators, furnace liner tubes, thread and wire guides, electronic substrates, ballistic armor, abrasion resistant tube and elbow liners, thermometry sensors, laboratory instrument tubes and sample holders, instrumentation parts for thermal property test machines.

Alpha phase alumina is the strongest and stiffest of the oxide ceramics. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of applications. High purity alumina is usable in both oxidizing and reducing atmospheres to 1925°C. It resists attack by all gases except wet fluorine and is resistant to all common reagents except hydrofluoric acid and phosphoric acid. Elevated temperature attack occurs in the presence of alkali metal vapors particularly at lower purity levels.

The composition of the ceramic body can be changed to enhance particular desirable material characteristics. An example would be additions of chrome oxide or manganese oxide to improve hardness and change color. Other additions can be made to improve the ease and consistency of metal films fired to the ceramic for subsequent brazed and soldered assembly.

2.4 COMPOSITE

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.

There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. Engineered composite materials must be formed to shape. The matrix material can be introduced to the reinforcement before or after the reinforcement material is placed into the mold cavity or onto the mold surface. The matrix material experiences a melding event, after which the part shape is essentially set. Depending upon the nature of the matrix material, this melding event can occur in various ways such as chemical polymerization or solidification from the melted state.

A variety of molding methods can be used according to the end-item design requirements. The principal factors impacting the methodology are the natures of the chosen matrix and reinforcement materials. Another important factor is the gross quantity of material to be produced. Large quantities can be used to justify high capital expenditures for rapid and automated manufacturing technology. Small production quantities are accommodated with lower capital expenditures but higher labor and tooling costs at a correspondingly slower rate. Most commercially produced composites use a polymer matrix material often called a resin solution. There are many different polymers available depending upon the starting raw ingredients. There are several broad categories, each with numerous variations. The most common are known as polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, polypropylene, and others. The reinforcement materials are often fibers but also commonly ground minerals. The various methods described below have been developed to reduce the resin content of the final product, or the fibre content is increased. As a rule of thumb hand layup results in a product containing 60% resin and 40% fibre, whereas vacuum infusion gives a final product with 40% resin and 60% fibre content. The strength of the product is greatly dependent on this ratio, so this increase in fibre content results in a dramatically stronger product.

Fiber reinforced polymers or FRPs include wood (comprising cellulose fibers in a lignin and hemicellulose matrix), carbon-fiber reinforced plastic or CFRP, and glass reinforced plastic or GRP. If classified by matrix then there are thermoplastic composites, short fiber thermoplastics, long fiber thermoplastics or long fiber reinforced thermoplastics. There are numerous thermoset composites, but advanced systems usually incorporate aramid fibre and carbon fibre in an epoxy resin matrix.

Composites can also use metal fibres reinforcing other metals, as in metal matrix composites or MMC. Magnesium is often used in MMCs because it has similar mechanical properties as epoxy. The benefit of magnesium is that it does not degrade in outer space. Ceramic matrix composites include bone (hydroxyapatite reinforced with collagen fibers), Cermet (ceramic and metal) and concrete. Ceramic matrix composites are built primarily for toughness, not for strength. Organic matrix/ceramic aggregate composites include asphalt concrete, mastic asphalt, mastic roller hybrid, dental composite, syntactic foam and mother of pearl. Chobham armour is a special composite used in military applications.

Additionally, thermoplastic composite materials can be formulated with specific metal powders resulting in materials with a density range from 2 g/cc to 11 g/cc (same density as lead). These materials can be used in place of traditional materials such as aluminum, stainless steel, brass, bronze, copper, lead, and even tungsten in weighting, balancing, vibration dampening, and radiation shielding applications. High density composites are an economically viable option when certain materials are deemed hazardous and are banned (such as lead) or when secondary operations cost (such as machining, finishing, or coating) are a factor.

Engineered wood includes a wide variety of different products such as plywood, oriented strand board, wood plastic composite (recycled wood fiber in polyethylene matrix), Pykrete (sawdust in ice matrix), Plastic-impregnated or laminated paper or textiles, Arborite, Formica (plastic) and Micarta. Other engineered laminate composites, such as Mallite, use a central core of end grain balsa wood, bonded to surface skins of light alloy or GRP. These generate low-weight, high rigidity materials.

2.5 METAL MATRIX COMPOSITE

Metal matrix composite (MMC) combines into a single material a metallic base with a reinforcing constituent, which is usually non-metallic and is commonly a ceramic. By definition, MMCs are produced by means of processes other than

conventional metal alloying. Like their polymer matrix counterparts, these composites are often produced by combining two pre-existing constituents (e.g. a metal and a ceramic fiber). Processes commonly used include powder metallurgy, diffusion bonding, liquid phase sintering, squeeze-infiltration and stir-casting. Alternatively, the typically high reactivity of metals at processing temperatures can be exploited to form the reinforcement or the matrix *in situ*, i.e. by chemical reaction within a precursor of the composite. There are several reasons why MMCs have generated considerable interest within the materials community for nearly 30 years.
The “composite” approach to metallurgical processing is the only pathway for the production of entire classes of metallic materials. Only in this way can aluminum, copper, or magnesium be combined with significant volume fractions of carbide, oxide or nitride phases because, unlike iron, the solubility of carbon, nitrogen or oxygen in the molten metal is (with the exception of O in Cu) far too low. The approach facilitates significant alterations in the physical properties of metallic materials. Composites also offer the only pathway for producing materials with tailored physical property combinations: an example is that of low thermal expansively combined with high thermal conductivity, a combination of importance for electronic packaging. MMCs offer significant improvements over their polymer matrix counterparts with regard to several properties, including tolerance of high temperature, transverse strength, chemical inertness, hardness and wear resistance, while significantly outperforming ceramic matrix composites in terms of toughness and ductility.

MMCs come in several distinct classes, generally defined with reference to the shape of their reinforcement: Particle-Reinforced metals (PRM) contain approximately equiaxed reinforcements, with an aspect less than about 5. These are generally ceramic (SiC, Al_2O_3, etc.). PRMs commonly contain below 25vol% ceramic reinforcement when used for structural applications, but can have as much as 80vol% ceramic when used for electronic packaging. In general, PRMs are at least approximately isotropic. They are produced using both solid state (powder metallurgy) and liquid metal techniques (stir casting, infiltration). Their mechanical properties, while often inferior to those of fibre-reinforced metals, are more or less isotropic and often represent, at moderate cost, significant improvements over those of corresponding unreinforced metals. Short Fibre- and Whisker-Reinforced metals contain reinforcements with an aspect ratio of greater than 5, but are not continuous. These composites are commonly produced by squeeze infiltration. They often form part of a locally reinforced component, generally produced to net or near-net shape. Their use in automotive engines is now well established. Continuous Fibre-Reinforced Metals contain continuous fibres (of alumina, SiC, carbon, etc.) with a diameter below about 20 μm. The fibres can either be parallel, or pre-woven before production of the composite; this is generally achieved by squeeze infiltration. Monofilament-Reinforced metals contain fibres that are relatively large in diameter (typically around 100 μm), available as individual elements. Due to their thickness, the bending flexibility of monofilaments is low, which limits the range of shapes that can be produced. Monofilament reinforced metals can be produced by solid state processes requiring diffusion bonding: they are commonly based on titanium alloy matrices, which are well-suited to such techniques. Interpenetrating phase composites are ones in which the metal is reinforced with a three-dimensionally percolating phase, for example ceramic foam.

MMCs have been extensively studied for recent year. SiC monofilament reinforced titanium has been the subject of many investigations, as have aluminum alloys containing up to 25 vol% SiC and Al_2O_3 particles. These materials have been produced by industry in relatively large quantities, such that they have been made available for testing at research laboratories and universities. Their novelty, and their interesting mechanical behavior (at both micro- and macroscopic levels), have led to many publications, exploring many features of their microstructure, deformation, and fracture behavior. Many mechanisms responsible for their mechanical characteristics are now well understood, including the roles of damage development, internal stresses, reinforcement clustering, interfacial bond strength and the effects of the presence of the reinforcement on aging of the matrix.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will discuss about methodology of powder metallurgy process of Aluminum Metal Matrix Composite from the raw material which is Aluminum powders and Alumina powders. This raw material will undergo milling process with varied of time for 1 hour, 2 hours, 3 hours and 4 hours. After that, milled powder will be compacted for pressure in about 300kg/cm^2 pressure at the compaction process. Compaction process will produces the green compacted material and this product will be sintered for 10 minutes in furnace with temperature about 550^{o}C. Then the product will be mounted, surface cleaning and tested.

3.2 RAW MATERIAL CHARACTERIZATION

3.2.1 ALUMINUM

Aluminum is too reactive chemically to occur in nature as the free metal. Instead, it is found combined in over 270 different minerals. The chief source of aluminum is bauxite ore. Aluminum is remarkable for its ability to resist corrosion (due to the phenomenon of passivation) and its light weight. Structural components made from aluminum and its alloys are vital to the aerospace industry and very important in other areas of transportation and building. Its reactive nature makes it useful as a catalyst or additive in chemical mixtures, including being used in ammonium nitrate explosives to enhance blast power.

Aluminum is a soft, lightweight, malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. Aluminum is nontoxic, nonmagnetic, and nonsparking. It is also insoluble in alcohol, though it can be soluble in water in certain forms. The yield strength of pure aluminum is 7–11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa.

Aluminum has about one-third 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 aluminum alloys are less corrosion resistant due to galvanic reactions with alloyed copper.

Aluminum atoms are arranged in a face-centered cubic (FCC) structure. Aluminum has high stacking-fault energy of approximately 200 mJ/m^2. Aluminum is one of the few metals that retain full silvery reflectance in finely powdered form, making it an important component of silver paints. Aluminum mirror finish has the highest reflectance of any metal

Table 3.1: Physical properties of Aluminum

Physical Properties	**Aluminum (Al)**
Density	2.70 $g \cdot cm^{-3}$
Melting Point	660.32 °C
Boiling Point	2519 °C

3.2.2 ALUMINA

Aluminum oxide is an amphoteric oxide of aluminum with the chemical formula Al_2O_3. It is also commonly referred to as alumina or aloxite in the mining, ceramic and materials science communities. It is produced by the Bayer process from bauxite; its most significant use is in the production of aluminum metal. Being very hard, it is used as an abrasive. Having a high melting point, it is used as a refractory material.

Aluminum oxide is an electrical insulator but has a relatively high thermal conductivity. In its most commonly occurring crystalline form, called corundum or αaluminum oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools.

Aluminum oxide is responsible for metallic aluminum's resistance to weathering. Metallic aluminum is very reactive with atmospheric oxygen, and a thin passivation layer of alumina quickly forms on any exposed aluminum surface. This layer protects the metal from further oxidation. The thickness and properties of this oxide layer can be enhanced using a process called anodising. A number of alloys, such as aluminum bronzes, exploit this property by including a proportion of aluminum in the alloy to enhance corrosion resistance. The alumina generated by anodising is typically amorphous, but discharge assisted oxidation processes such as plasma electrolytic oxidation result in a significant proportion of crystalline alumina in the coating, enhancing its hardness.

Aluminum oxide, also known as alumina, is the main component of bauxite, the principal ore of aluminum. The largest manufacturers in the world of alumina are Alcoa, Alcan and Rusal. Companies which specialise in the production of speciality aluminum oxides and aluminum hydroxides include Alcan and Almatis. The bauxite ore is made up of impure Al_2O_3, Fe_2O_3, and SiO_2. Bauxite is purified by the Bayer process:

$$Al_2O_3 + 3\ H_2O + 2\ NaOH \rightarrow 2NaAl(OH)_4$$

The Fe_2O_3 does not dissolve in the base. The SiO_2 dissolves as silicate $Si(OH)_6^{2-}$. Upon filtering, Fe_2O_3 is removed. When the Bayer liquor is cooled, $Al(OH)_3$ precipitates, leaving the silicates in solution. The mixture is then calcined (heated strongly) to give aluminum oxide. The formed Al_2O_3 is alumina.

$$2Al(OH)_3 + heat \rightarrow Al_2O_3 + 3H_2O$$

Table 3.2: Physical properties of Alumina

Physical Properties	**Alumina (Al_2O_3)**
Density	3.97 $g.cm^{-3}$
Melting Point	2054 °C
Boiling Point	2980 °C

3.3 MILLING PROCESS

Powders made by different processes have different sizes and shapes and must be well mixed-impart special physical & mechanical properties & characteristic to the powder metallurgy product. Proper mixing is essential to ensure the uniformity of mechanical properties throughout the part. Even when a single metal is used, the powders may carry significantly in size and shape, hence they must be blended to obtain uniformity from part to part. The ideal mix is one in which all particle of each material are distributed uniformly.

Lubricants can be mixed with the powders to improve their flow characteristic. They reduce friction between the metal particles, improve flow of the powder metals into the dies and improve die life. Lubricants typically are stearic acid zinc strearate in a proportion of from 0.25 to 5% by weight. Other additives such as binder also used to develop sufficient green strength and also can be used to facilitate sintering.

Figure 3.1: Milling process using ball milled

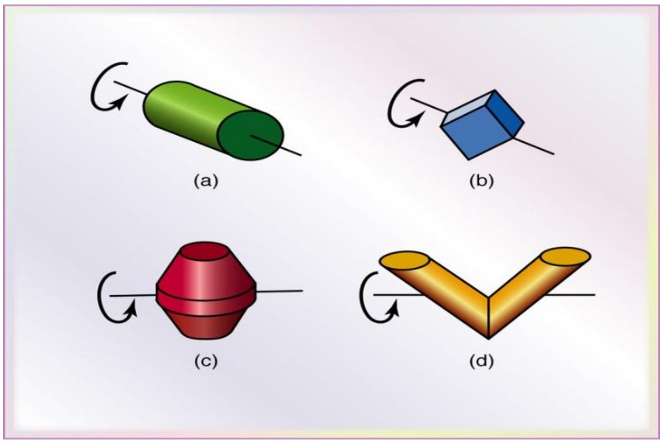


Figure 3.2: Some common bowl geometries for milling process

Source: Courtesy of Gardner Mixers, Inc.

3.4 COMPACTION PROCESS

Generally, the powder metallurgy components can be produced by cold die compaction of the powder. Normally, die compaction of metal powder undergoes a number of stages, namely, initial compaction, which involves particle rearrangements. The physical properties such as particle size and shape greatly influence this initial stage. This is followed by the elasticplastic deformation, and here the mechanical properties and the quality of the particles are important factors, which control the compressibility behavior of the powder. The final stage of compaction is almost totally an upsetting of the bulk material. Hence, the work hardening of the particle affects the hardness of the final product.

As a result, the powder compacted component is produced with inhomogeneous distributions of density and porosity. This is due to the frictional forces in between particles (internal friction), and/or between the powder and the container walls (powder/container friction). This, evidently, causes shrinking during distortion of the product. However, some powder metallurgy components are required to have a certain percentage of porosities so that pores may be filled with gases, liquids and self-lubricants for specific applications. Needless to say, the green density of compact has direct influence on the densification and porosity of the product and hence the strength

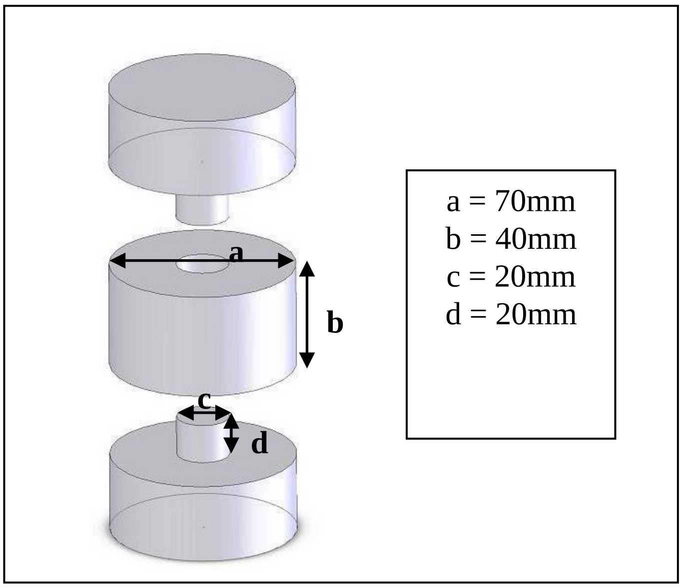


Figure 3.3: Compaction process using mold and die

Figure 3.4: Compaction process using hidraulic press

3.5 SINTERING PROCESS

Sintering is the process powder compacts are heated so that adjacent particles is bonded together by forming necking, thus resulting in a solid article with improved mechanical strength compared to the powder compact. This process will results in an increase in the density of the part. There are some processes such as hot isostatic pressing which combine the compaction and sintering processes into a single step.

After compaction the components pass through a sintering furnace. This typically has two heating zones, the first removes the lubricant, and the second higher temperature zone allows diffusion and bonding between powder particles. A range of atmospheres, including vacuum, are used to sinter different materials depending on their chemical compositions. As an example, precise atmosphere control allows iron/carbon materials to be produced with specific carbon compositions and mechanical properties.

Figure 3.5: Sintering process using furnace

3.6 HARDNESS ANALYSIS

Hardness is resistance of material to plastic deformation caused by indentation. Sometimes hardness refers to resistance of material to scratching or abrasion. In some cases relatively quick and simple hardness test may substitute tensile test. Hardness may be measured from a small sample of material without destroying it. There are hardness methods, allowing to measure hardness onsite. Principle of any hardness test method is forcing an indenter into the sample surface followed by measuring dimensions of the indentation (depth or actual surface area of the indentation). Hardness is not fundamental property and its value depends on the combination of yield strength, tensile strength and modulus of elasticity. Depending on the loading force value and the indentation dimensions, hardness is defined as a macro- , micro- or nano-hardness.

The principle of the Vickers Hardness method is similar to the Brinell method. The Vickers hardness test uses a diamond, with the shape of square-based pyramid with an angle of 136° between opposite faces as an indenter (22° between the indenter face and surface). It is based on the principle that impressions made by this indenter are geometrically similar regardless of load. Accordingly, loads of various magnitudes are applied to a flat surface, depending on the hardness of the material to be measured.

Figure 3.6: Hardness Vickers Test

3.7 MICROSTUCTURE ANALYSIS

Microscope image processing is a broad term that covers the use of digital image processing techniques to process, analyze and present images obtained from a microscope. Such processing is now commonplace in a number of diverse fields such as medicine, biological research, cancer research, drug testing and metallurgy. A number of manufacturers of microscopes now specifically design in features that allow the microscopes to interface to an image processing system. Analysis of images will vary considerably according to application.

Typical analysis includes determining where the edges of an object are, counting similar objects, calculating the area, perimeter length and other useful measurements of each object.

Figure 3.7: Microscope Image Analyzer

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to show the result of the experiment data from the hardness test and microscope image analyzer. The analysis carried out from the graph and microstructure figure also discussion related to the result.

In order to analysis the physical and mechanical behavior of the Aluminum metal matrix composite produced the result is divided into several categories which are:

i. Hardness

ii. Microstructure

iii. Summary of the result

The hardness of the Al MMC produce is obtain from the hardness test data and the microstructure properties can be obtain from the microscope image analyzer.

4.2 HARDNESS ANALYSIS

Hardness is resistance of material to plastic deformation caused by indentation. Sometimes hardness refers to resistance of material to scratching or abrasion. Hardness of a metal gives it the ability to resist being permanently, deformed such as bent or broken when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation.

There are several categories hardness such as scratch hardness, rebound hardness and indentation hardness. Indentation hardness will be analyzed because the deformation due to a constant load from a sharp object which is indenter (from the Vicker Harness) is pressed in a material surface.

Al MMC produced from powder metallurgy process is tested using Vickers Hardness Tester to get the hardness number data. There are four samples which is Sample A, B, C and D was milled for different milling intervals. Sample A is referring to Al MMC sample that was milled for 1 hour, Sample B for 2 hours, Sample C for 3 hours and 4 hours for Sample D, respectively.

For each sample, the reading was taken for five reading for each sample and the average of the hardness numbers value was determine. Result of the hardness test is shown in Table 4.1.

Table 4.1: Hardness of Al-Al_2O_3 composite for 1h, 2h, 3h and 4h

Sampl e	**Milling Time (h)**	**Hardness Number (HV)**					**Average Reading (HV)**
		1	**2**	**3**	**4**	**5**	
A	1	73.3	85.4	105.9	59.2	57.8	76.32
B	2	82.4	90.7	88	61.9	99.5	84.70
C	3	110.8	112.7	90.2	91.5	98.7	100.78
D	4	143.6	159.3	143	145.2	153.8	148.98

The average reading each specimen is calculating using formula 4.1, the hardness value was taken for five reading and the average reading determine for the value hardness number of the composite.

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

Sample calculation for the Vickers hardness of specimen A is shown below:

$$HVave, A = \frac{73.3 + 85.4 + 105.9 + 59.2 + 57.8}{5} = 76.32HV$$

Hardness for Al-Al_2O_3 with 1hour milling time is 76.32HV. While milling time increase to 2 hours, the hardness of the material increases to 84.70HV and 100.78HV for 3 hours milling time. After powder was milled for 4 hours, the hardness of the material read as 248.98HV. From the result obtain, the highest value of hardness is specimen D. The milling time for sample D is 4 hours.

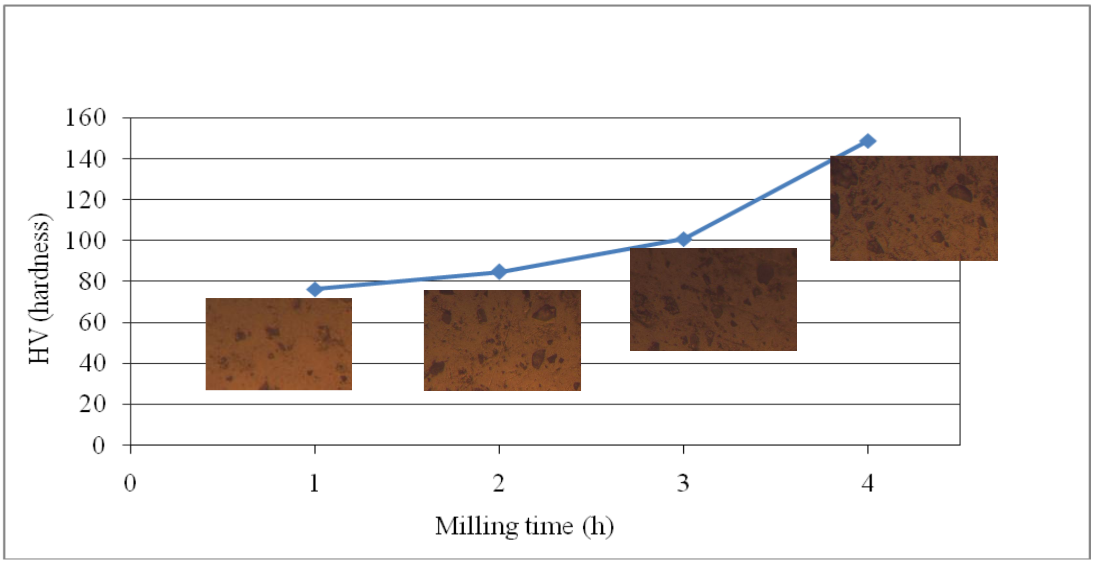


Figure 4.1: Effect of milling time on the hardness of Al-Al_2O_3 composite

Figure 4.1 shows the variation of hardness number Aluminum metal matrix composite reinforced with alumina (Al_2O_3) for 1h, 2h, 3h and 4h. Data shows that increasing milling time will increase the hardness of the Al-Al_2O_3 composite. The hardness of Al- Al_2O_3 increase proportionally by increasing the milling time of the powders. As the hardness increases, the specimen becomes stronger while the hardness lower, the specimen become brittle. The introducing Al_2O_3 reinforcement into the Al matrix result the increasing in mechanical properties such as hardness and strength.

The variation of hardness of Al MMCs increased linearly with the milling time resulted from refinement of the Al powders and Al_2O_3. A higher hardness was also associated with the lower porosity. The porosity of the composite decreased with the increasing milling time is related to the flowing behavior of the composite. The smaller powder particle produce will reduce the amount of porosity in the material.

Table 4.2: Hardness of Al-Al_2O_3 composite from the experiment and previous research

Milling Time (h)	Hardness Number (HV)		Difference(%)
	Experiment	Previous Research	
1	76.32	68	12.23
2	84.70	75	12.93
3	100.78	84	19.98
4	148.98	95	56.83

Source: Scripta Materialia, J. B. Fogagnolo

Table 4.2 shows the comparison of hardness values of the composite between the experiment result and the previous research. For 1 hour milling time, the difference percentage of hardness is 12.23% while for 2 hours milling time the difference is 12.93%. The difference value between the result and the previous research for 3 hours is 19.98% and 4 hours milling time is 56.83%.

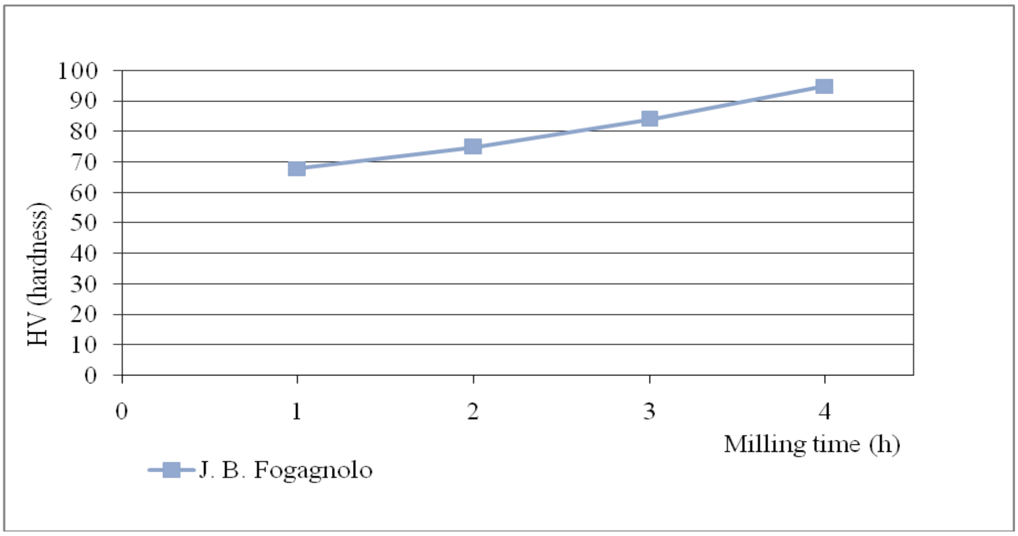


Figure 4.2: Effect of milling time on the hardness of Al-Al_2O_3 composite based on the data from previous research

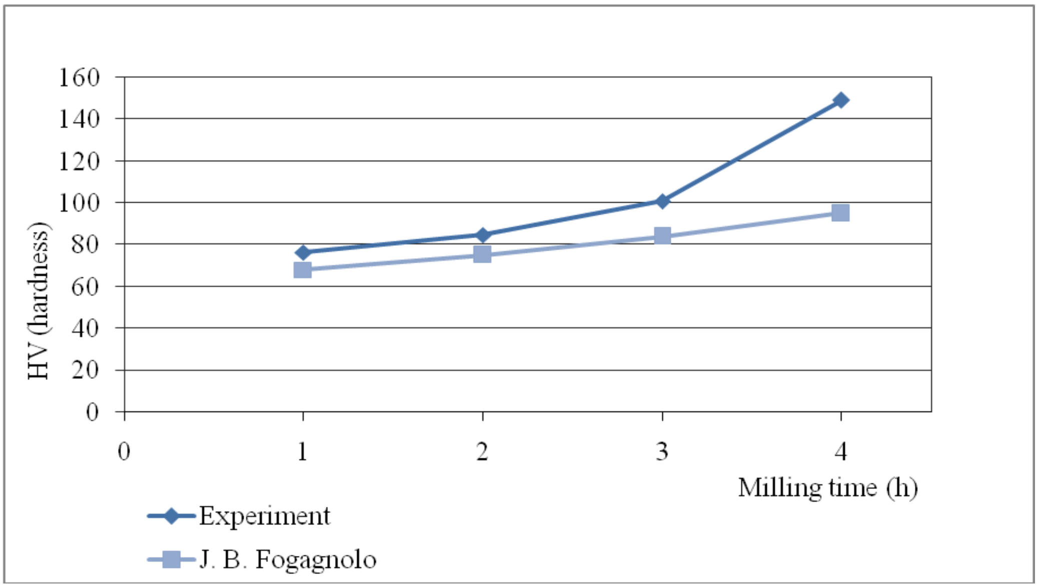


Figure 4.3: Effect of milling time on the hardness of Al-Al_2O_3 composite based on experiment and the data from previous research

Figure 4.3 shows the variation of hardness versus milling time between experimental results compared to the previous research. Both of the graphs show the same pattern of linearity of hardness. The hardness of the Al MMC composite is improved by increasing the milling time of the powders.

\

4.3 MICROSTRUCTURE ANALYSIS

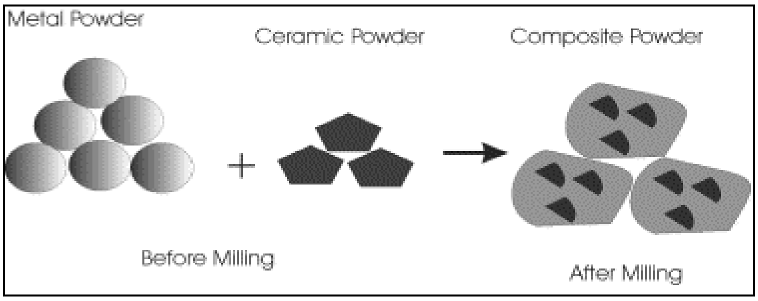


Figure 4.4: Schematic diagram showing the formation of composite powder after milling process.

Source: D. L. Zhang (2004)

Figure 4.2 shows milling process in Al-Al_2O_3 (metal–ceramic) composite powders will allows incorporation process of the metal and the ceramic phases into each powder particle. In the initial stage, the composite powder and metal powders is not mix together. Only a few Aluminum (Al) particles are incorporated into each of the Alumina (Al2O3) particles. With further milling, the metal phase is deformed and fractured, while the ceramic phase is mainly fractured. In metal matrix composite, the ceramic particles are continually fractured into smaller particles, so the ceramic particle size will keep decreasing until such a point that the fracture strength of the small particles will be equal to or greater than the stress caused by the collision.

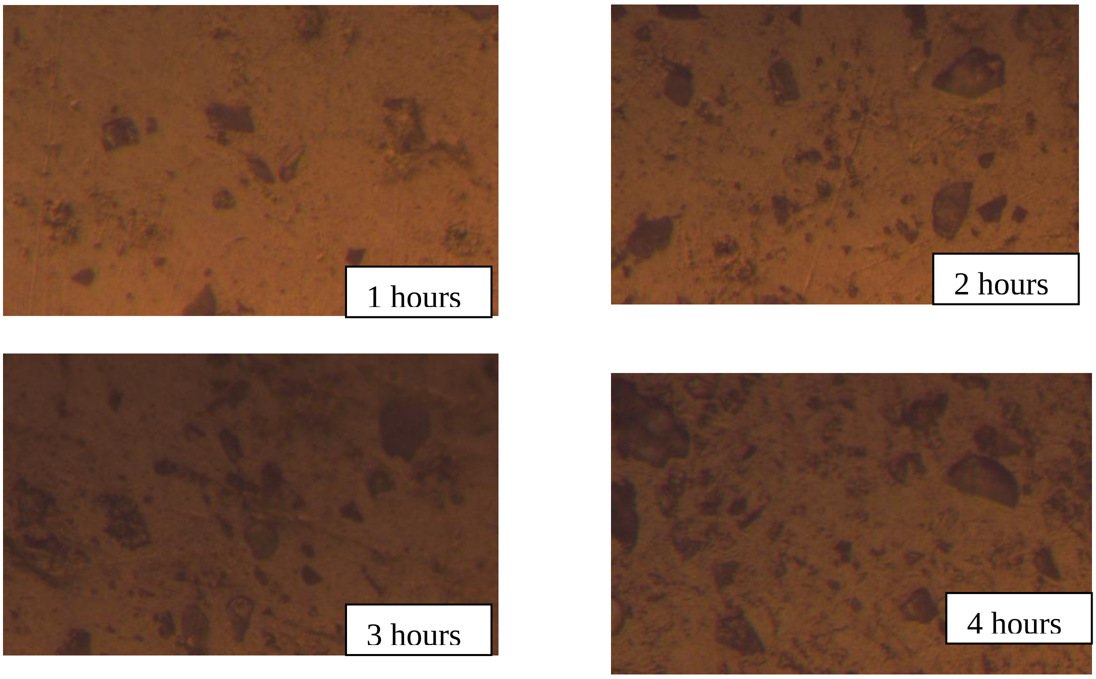


Figure 4.5: The microstructures of the powder particles during milling process of Al-Al_2O_3 composite. The dark phase is Al_2O_3 and the bright phase is Al.

Figure 4.3 shows microstructure of an Al-10wt%Al_2O_3 composite. In the initial stage of milling, only a few Al_2O_3 particles are incorporated into Al particles. Then with further milling, which causes working hardening of the Al and Al_2O_3 phases, most of the Al_2O_3 particles are deformed, fractured and incorporated into the Al matrix, forming Al/ Al_2O_3 composite powder particles as shown in Figure 4.2. With continued milling, the size of the Al_2O_3 particles is reduced to smaller size through continued fracturing.

The more refined microstructure improved dispersion of the reinforcement particles and improved mechanical properties (Adamiak et al., 2004). Recall from previous chapter, Alumina or Aluminum Oxide (Al_2O_3) know as material with higher hardness properties. This experiment used Al_2O_3 as reinforcement material to the matrix material which is Aluminum powders. Further milling process will result finer reinforcement microstructure and reinforcement particle dispersion in matrix will increase the hardness of the material (Adamiak et al., 2004).

4.4 SUMMARY OF THE RESULT

The objective of this analysis is to get the hardness and microstructure variation of the Al MMC reinforce with Al_2O_3 for different sample that have been produced using powder metallurgy method. The value of hardness and the microstructure for each sample is compared to each other to find which one is the sample that has better physical and mechanical behavior.

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

i. Sample A, which is milled for 1 hour, the hardness value is 76.32 HV.
ii. Sample B is milled for 2 hours and the hardness value is 84.70 HV.
iii. Sample C is milled for 3 hours and the hardness value is 100.78 HV.
iv. Sample D is milled for 4 hours and the hardness value is 148.98 HV.

For the microstructure, the observation was using Microscope Image Analyzer. Microstructure analysis showed that the Al_2O_3 particle distributions were more homogeneous and uniform with increasing of the milling time. 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

The variation of milling process in powder metallurgy processing of aluminum composite offers obtaining composite material with better mechanical and physical properties. Hardness of the Aluminum metal matrix composite reinforce with alumina improved by increasing the milling time. Milling process provided better distribution of the reinforcement powders throughout the whole powder particle. During the milling process, whenever the reinforcement particles are situated between the aluminum particles and the collision between balls mills occur the matrix and reinforcement particle are integrated in the resulting welded particle, forming a composite particle. With work hardening due to deformation and welding process that particle undergo, repeated fractures process will increase and resulted finer matrix-reinforcement particles. It can be seen that the longer milling time has create finer particles and better distributions of the particle. This will result to reducing the defect of the particle such as porosity and lamination crack. Thus better material will be produced and result the increasing of the hardness of material.

5.2 RECOMMENDATION

Powder metallurgy process provided widely ways to improve the last product. The others parameters should be considered during the process. Powders metallurgy start with milling process of the matrix and reinforcement powders. After that the compaction of milled powders, the pressure during compaction also can be varied to experiments the way to improve the Aluminum metal matrix composite produced. Sintering process will be next stage of the powder metallurgy, time to sinter and temperature of sintering process also should be considered to improve the product. During this major step, the more precaution and errors making should be reduce to get near expected result. This included the process during weighing the powders to get weight percentage (wt%) needed, the design of the mold also should be done in proper ways such as automatic press and injector of the mold.

REFERENCES

Al-Qureshi, Galiotto, H.A., Klein, A., Klein, A.N. 2005. Journal of Materials Processing Technology. **166**: 135–143.

Suryanarayana, C. 2001. Progress in Materials Science: 1–184.

Zhang, D. L. 2004. Progress in Materials Science: 537-560.

Lee, J., Kim, S., Park, C., and Bae, C. 1995. Journal of Material Process Manufacturing: 55–67.

Fogagnolo, J. B., Ruiz-Navas, E. M., Robert, M. H. and Torralba, J. M. 2002. Scripta Materialia: 243-248

Justino, J.G., Alves, M.K., Klein, A.N., Al-Qureshi, H.A. 2004. Journal Machine Tools Manufacturing: 307–316.

Surappa, M. K. 2003. Sadhana: 319-334.

Suresh, S. Mortensen, A. and Needleman Eds, A. 1993. Fundamentals of Metal Matrix Composites.

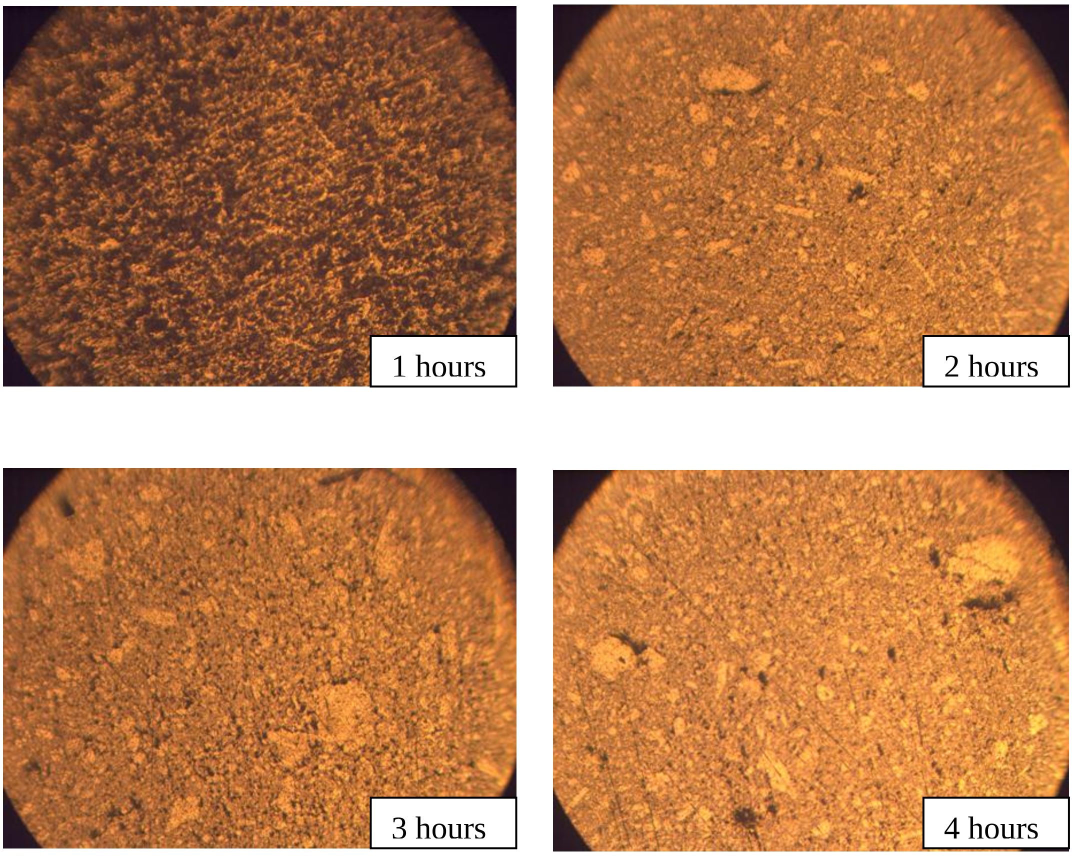
Smith, W. F. 2004. Foundations of Materials Science and Engineering, Third Edition: 479- 480.

Razavi Hesabi, Z. Simchi, A. and Seyed Reihani, S.M. 2006. Materials Science and Engineering: 159-168.

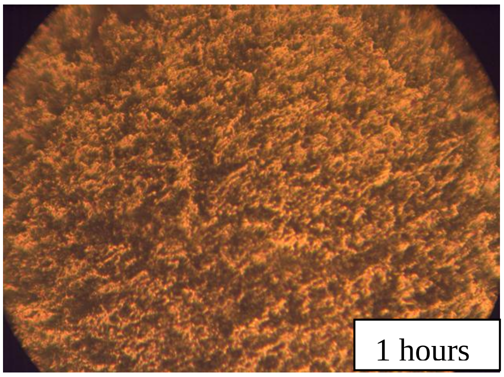
Verlinden, B. and Froyen L. 1994. TALAT Lecture 1401: Aluminum Powder Metallurgy.

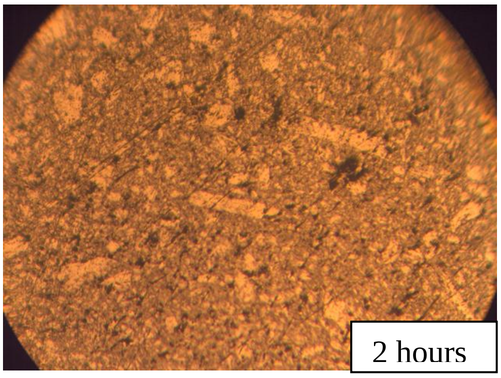
APPENDICES

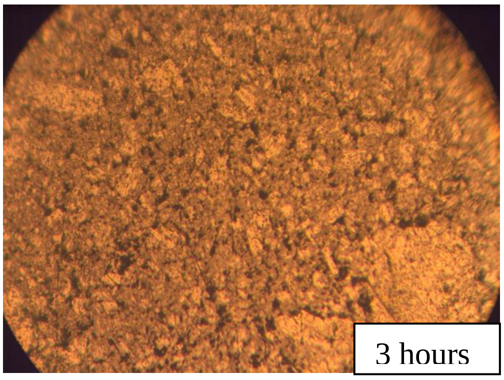
Microstructure of Al MMC reinforced with Alumina for 10X magnification

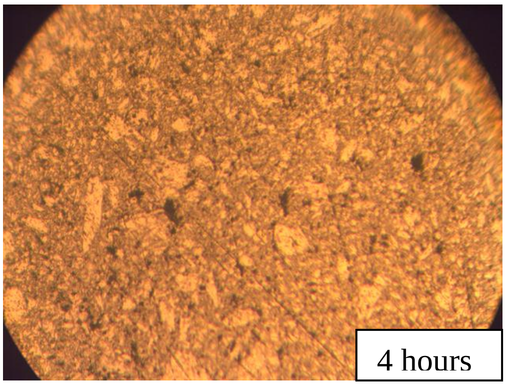


Microstructure of Al MMC reinforced with Alumina for 20X magnification









Microstructure of Al MMC reinforced with Alumina for 50X magnification