DEVELOPMENT OF CERAMICS CUTTING TOOL FOR MACHINING USING ALUMINIUM OXIDE REINFORCED WITH COPPER POWDER

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
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JUNE 2016

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ABSTRACT

Powder metallurgy (processing) method was used to produce an insert for machining application. An alumina (Al2O3) powder reinforced with Copper power was used as a raw material. A complete die was produced for the insert production. Powder mixing, compaction and sintering using open air furnace were the main processing parameters in the research project. The composite insert was analyzed for density and hardness properties. The result showed that 90% of the theoretical density was achieved and 70% by weight mixed with 30% copper was measured for the higher Vickers hardness value.

ABSTRAK

Kaedah metalurgi serbuk (pemprosesan) telah digunakan untuk menghasilkan memasukkan untuk penggunaan pemesinan. Serbuk alumina (Al2O3) dikuatkan dengan kekuatan tembaga yang telah digunakan sebagai bahan mentah. Acuan lengkap telah dikeluarkan untuk menghasilkan produk. Serbuk dicampurkan, dipadatan dan dipanaskan menggunakan relau terbuka adalah parameter pemprosesan utama dalam projek penyelidikan. Mata alat komposit dianalisis untuk diuji kepadatan dan kekerasan. Hasil kajian menunjukkan bahawa 90% daripada ketumpatan teori telah dicapai dan 70% mengikut berat dicampur dengan 30% tembaga diukur untuk nilai kekerasan menggunakan mesin Vickers adalah lebih tinggi.

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CHAPTER 1

1.1 INTRODUCTION:

Powder metallurgy is the production method that have great potential for further development. It is the best alternative to all producer methods such as casting, forging, and investment casting process or other machining process. Powder metallurgy is the method that allows for certain materials and products with special properties to produce complex shape with high thermal, good reflection, good electric conductivity, excellent corrosion resistant and high compact strength. These technical processes are economical and easy to find. Waste free production, which raw material wasted is less compare by other casting and subsequence machining. This allows product can be produced in low price and competitive to market.

Powder metallurgy consists of three simple phases. First is blending between two powders, next compacting the mixture powders in die at room temperature at rate 138 Mpa to 827 Mpa, lastly sintering at the controlled temperature furnace at rate 1000 degree Celsius to make particle bonding together to reach at certain hardness [13]. Due to waste free production, these technologies only produce scrap rate at 3 percent. Because the process produces small percent of waste, it frequently completed when taken from the furnace. The process is very cheap and effective compare to other manufacturing processes which must content flash, machining chip, spread bush, gate and runner.

Obviously, powder metallurgy process contains many advantages. Powder metallurgy is the strongest advance in order to eliminate or minimize machining. Complex shape and high tolerance can easily produce by powder metallurgy. These days, close dimensional tolerance is the one of the secret to successful acceptations in the conversion of many components from contending forming latest technology [13]. This gives benefit to enhance no limits to form of alloy system that can be used to develop shaped components. The analysis material can considerable parallel in duplicate function and application demand with a material system meet needed such as corrosion resistance, hardness, mechanical properties or other particular metallurgy.

Aluminium oxide, as known as alumina natural compound that use in various industries, most particularly for production of aluminium. There are two forms of alumina, crystalline and non-crystalline. It is insulator which means, it does not conduct electricity and it also has comparatively high thermal conductivity. If it is on crystalline form, example corundum, its hardness make it worthy as an abrasive [12]. The higher melting point of aluminium oxide makes it better for fractious material for lining high-temperature appliances. In other hand, metallic aluminium and oxygen reaction, which may could gain corrosion. But still, when the aluminium bond between oxygen to form aluminium oxide, it create a thin covering that protects it from oxidation. This can keep aluminium from rusting and losing durability. The thickness and other attributes of the oxide layer can be switched by using the anodizing process.

Copper powder used to reinforce with aluminium powder because copper powder is known as the best self-lubricant holding which was the genuine application and still records for around 70% of the grainy copper powder utilisation[14]. This application exploits the capacity to make a segment with controlled interconnected and surface-joined porosity. The output of metallic channels likewise exploits this ability. The pure copper powder is utilized as the electrical and electronics component because of its good thermal conductivities. Copper is used as an alloying element in iron powder segment to empower the mechanical properties and control dimensional changes amid sintering. The summation being made either using blending or by penetration. Copper powder melting point is around 1084.62 °C or 1984.32 °F.

1.2 PROBLEM STATEMENT:

Currently, the cutting tool used advanced material such as titanium carbon nitride (TiCNi) and nano coating which are very expensive and hard to find. The properties of tool cutter are affect by it stiffness, thermal, electrical properties and strength. Basically, powder metallurgy needs a strong compact and then heat at high temperature to make bond combine and become stronger.

This project is to study the correct mixture between aluminium oxide combine with copper powder using ball milling. These combinations will determine either it will hardness or brittle. Adding a lot of copper will be resulting corrosion due to chemical reaction. Mixing both compounds also need additives to make it stick together, whether using wax or other lubricants.

For instance, all cutting tools are exposed to high temperature. Copper is used because it useful in high temperature and provide good mechanical characteristic as well as high thermal conductivities. Copper properties will enhance the strength of aluminium composite by making the surface harder compare to pure aluminium.

1.3 OBJECTIVE:

The aim of this project:

1) To develop insert using alumina reinforced with copper powder.
2) Fabrication die for the production inserts.
3) To analyze the physical and microstructural properties of insert after compaction and sintering.
4) To develop high strength cutting tool at lowest price.

1.4 PROJECT SCOPE:

The scope of this project is to study the hardness of cutting tool using aluminium powder reinforced with copper powder. Using 3 basic processes which are mix using ball mill, compaction at a constant rate, which is around 1 tonnes, and lastly sintering at high temperature of 1100 degree Celsius. Design of mold for the compaction machine at high tolerance. Microstructure change over sintering process with temperature of certain temperature at 138 Mpa or 827 C are observed using optical microscope.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION INTO POWDER METALLURGY PROCESS

Powder metallurgy is the process of forming metal part by compacting with high pressure and heat below melting point. These processes had been existed nearly 100 years ago, and yet, still used it widely which is known as superior to produce high quality parts for a variety of important application. Powder metallurgy is the most flexible manufacturing process capable of development new material, microstructural, and properties. Modern ceramic cutting tool material, with high abrasion resistant, heat resistance, and chemical stability, plays as the main role in area of improvement productivity with high speed cutting process [1]. Most of traditional hard alloys failed in processing new material, and most important thing is key of composition.

Production of powder metallurgy to convert into product need detail study of various steps of making product. Basically, analyse both powder characteristic, mixing, compaction and posteriori thermal bonding of particle by sintering process. Powder types, characterization, powder fabrication, alloying and mixing for the powder metallurgy have been analysed by various researchers in the world. The study had concluded that low alloy powder metallurgy contains such as copper, carbide, titanium, silicon, ferrous silicon are manufactured from elemental powders suitable for precision parts of cutting tool. Some are metal powder are expensive and some not expensive, and it is not promising it will be a good product. The best is the one that has been deliberately chosen to take care the job done on time, proficiently, and financially. A cutting tool must have the accompanying features with a specific finishing in order to create great quality and temperate part which is hardness, toughness, and wear resistance.

Plain carbon steel is the most former of the tool materials going back several years. In straightforward terms, a high carbon steel which contain about 1.05 percent of carbon. This high carbon allows the steel to be solidified, offering extraordinary resistance to grating wear. Spare high carbon steel filled its needed well for long time. Then again, because it is rapidly over tempered at moderately low cutting temperatures (150 to 260°C), it is currently utilized as cutting tool material excluded in saw blades, etches, and the other. The utilization of plain high carbon steel is restrained to warmth application [1].

With the advancement of the modern world, it has been expected to constantly build up and enhance the cutting tool materials and geometry which is to meet the developing demand for high profitability, quality and economy of machining. Empower compelling and productive machining of the fascinating material that are coming up with the quick and immense advancement of science and innovation for accuracy and ultra-precision machining, for example smaller scale machining proposed by the day and future. It is as now expressed that the capacity and general execution of the cutting tools depend the cutting tool materials, the cutting tool geometry, legitimate determination and use of those tool. The relative contribution of the cutting tool materials on profitability, example can be generally evaluated figure 2.1.

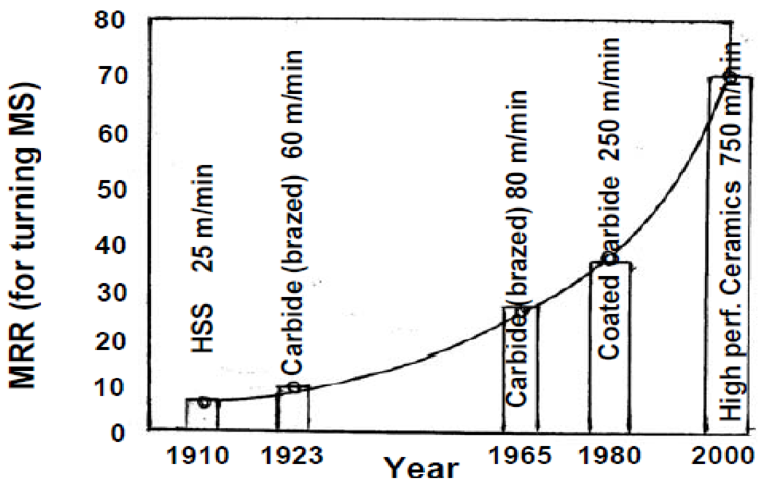


Figure 2.1: Productivity raising by cutting tool material

Source: Q. Like, L. Xikun, and P. Yang (2007)

2.2 METAL POWDER

The beginning step of overall powder metallurgy process is making metal powders. There are several reasons to use powder and powder compaction. Some materials cannot be used in other manufacturing methods because powder compaction is tested to be more economical compared to other manufacturing methods. One type of materials used in powder compactions are material with the very high melting point, or another name refractory metal, where casting would not be economical because of high melting point.

Another category of material used in powder compaction is composite that cannot mix in other manufacturing method or handled in post operation due to its constituent. The main bulk material applied in powder compaction manufacturing method is ferrous metals applied for structural parts. A new finite element model was developed to forecast the density distribution in an Alumix 321 powder metallurgy compact. The model can predict the density distribute results of single action of compaction from 100 to 500 MPa compaction pressure. The model can also determine the amount of spring back experienced by a compact upon ejection from the die at 100 and 300 MPa compaction pressure[2]. An optical densitometry method, with the based on a compaction curve, was used to experimentally predict density distributions found inside compacts, and found results that were consistent with both literature and finite element simulation. Further powder characterisation included the testing apparent density and flow rate of the powder.

2.3 CERAMIC MATRIX COMPOSITES (CMC)

Ceramic matrix composite (CMC) is important because of their properties which is wear resistant high temperatures and corrosive environments. Ceramics are strong and stiffness, although it wears in high temperature, but it generally lacks in sturdiness. Matrix material that hold their strength nearly 1700c are silicon nitride, silicon carbide, aluminum oxide, and mullite (compound of silicon, aluminium and oxygen). Carbon matrix composite retains quite a bit of the strength (2500c), in spite of needed of oxidation resistance for high temperature. Fiber material is generally carbon and aluminium oxide. Application for CMC included cutting tool and automotive engine component, jet, pressure vessel, structural components, sea mining equipment, and die for extrusion and the drawing of metals.

Ceramic particulate fortified metal matrix composite (MMC) had pulled in expanding interest, especially automobiles, high tolerance cutting tool, as high potential propelled engineering structural material by virtue of high particular strength, firmness and modulus, in addition as higher wear resistance, great isotopic properties, good advance temperature resistance, and low creation cost.

2.4 CLASSIFICATION OF METAL MATRIX COMPOSITES (MMCs)

MMCs are multi stage materials in which a solid, firm reinforcing stage, commonly a ceramic, consolidated all throughout a softer, ductile metal phase. There are however specific classes of MMC, which are different, for instance, gas as the scattered stage making a metallic foam [2]. Also the inclusion of graphitic plates, refractory metals, intermetallic or semi-conductors can be used to obtain a specific property or properties. The various classes of orthodox MMCs will discuss later.

PROPERTY	Better strength to density ratios
	Better stiffness to density ratios
	Good fatigue resistance
	Better elevated temperature properties • High strength • Lower creep rate
	Lower coefficient of thermal expansion
	Wear resistance
ADVANTAGE	Higher temperature capability
	Fire resistance
	Higher transverse stiffness and strength
	No moisture absorption
	Better radiation resistance
	No out gassing

Table 2.1: Advantage of metal matrix composite with different properties

Source: A. T. Submitted, I. N. Partial (2006)

2.4.1 Dis-continuously Reinforced MMCs.

Particulate MMCs.

This classification can be further isolated into two sub classification [3], Dispersion reinforced and extensive molecule (or real particle) composites. Dispersion strengthened composites can themselves be separated into two sub classes:

(A) Dispersion solidifying - 10 nm to 250 nm diameter particles (usually oxides) are scattered into a metal matrix

(B) Precipitation solidifying – an encourage is nucleated and developed inside of metal matrix.

In scattering strengthened composites the particle, which usually constitute -1 wt% of the material, must be closely spaced (< -1 μm). This spacing is necessary because of the strengthening process (dislocation obstruction) involved. Due to the mechanism of strengthening, these materials are not considered true composites [2]. Substantial molecule composites comprise of a metallic matrix with extensive (lμm - 50μm breadth), generally ceramic particles appropriated all through the matrix. The reinforced process here is essentially load exchange between the network and the strengthening particle [2]. These comprise of a metal matrix with ceramic fibres appropriated throughout. The fibres range in bredth from 1μm to 150μm, with aspect ratios ranging, typically, from 3 to 100. The alumina fibres are fine grained polycrystalline in struct.

2.4.1.1 Whisker Reinforced MMCs.

These MMCs are basically like to the short fibre type, the special case being that the Whisker are mono crystalline [4] and typically have a measurement < 1μm, viewpoint proportions up to few hundred. [2] Their mechanical properties have been observed to be prevalent when contrasted and polycrystalline short fibres[5].

2.4.2 Continuously Reinforced MMCs.

a) Monofilament MMCs.

Continuous monofilament reinforcements are large diameter (typically 100µm - 150µm) fibres, usually consisting of Silicon carbide or boron, which has been stored by chemical vapour deposition on to a carbon or tungsten wire core [2]. Monofilament fibres normally aligned in a unidirectional manner within the matrix. These large diameter fibres do not display a high degree of flexibility and are usually used as single fibres. They typically have a large bend radius and care must be taken to prevent over bend during processes.

b) Multifilament MMCs.

Multifilament reinforcements are small diameter which is 5µm to 30µm diameter, which can be sewed, knitted, stitched, meshed or wound. These fibres have a small bend range, which enhance their adaptability. Because of the adaptability of fibres, they can be join in a matrix in a unidirectional way, or combined for example woven into a multi directional reinforcement.

2.4.3 Layered MMCs.

Layered MMCs consist of alternate layers of, usually, two constituent materials which use in this project are aluminium powder and copper powder. These composites can contain layers from a few nanometres thickness up to thickness of several centimetres. This category of MMC includes coatings or film deposition (example ceramic coating of metals to improve wear resistance). Also included in this category is the use of fibre-reinforced tapes or fabrics when used in alternate layers [6].

2.4.4 MMCs Contains Higher Percentage of Ceramic.

This gathering of composites are generally known as cermet. In this gathering the volume percent of ceramic need to be more noteworthy than 70% [7]. Ceramic particle are held together by a little amount of metallic stage. They may be consider as high particulate volume ceramic strengthened metal matrix composites.

2.4.5 Reinforcement Influence on Directional Properties of MMCs.

The geometry of the strengthened within the matrix influences the mechanical properties of the MMC. The following are schematics of the geometry and introduction of reinforcement and their impact on MMCs mechanical properties. Particulate strengthened MMCs have pulled regarding seeing consideration as an after effect of their moderately low costs and trademark isotropic properties. In exploit to limits the structure and properties of particulate strengthened MMCs variously processing techniques have developed in the course of the most recent 2 decade ago [15]. The handling technique used to make particulate strengthened MMCs can be sorted relying upon the temperature of the metallic matrix during processes. Likewise, it can be divided into three classes:

(a) Liquid stage forms
(b) Solid state forms
(c) Two stage (solid and liquid) processes.

In figure 2.2, it shown with physical properties, reinforcing in metal matrix composites has been joined to disengagements of high thickness in the matrix starting from differential thermal contraction, plastic deformation during processing and geometrical restraint.

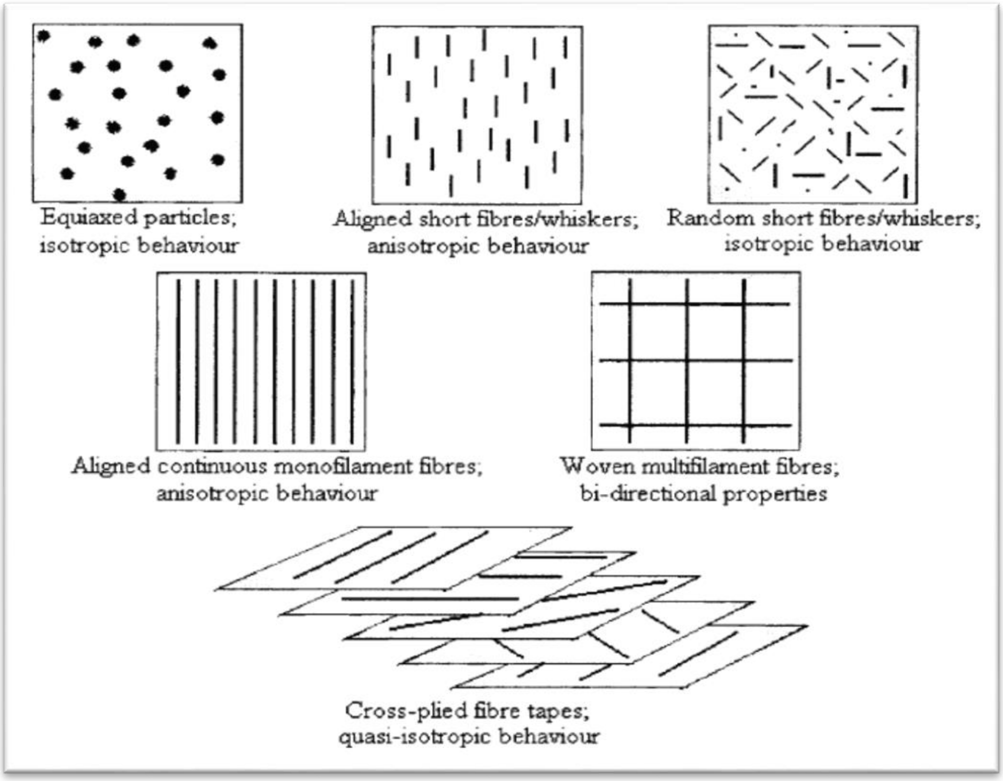


Figure 2.2: Effects of reinforcement orientation on mechanical properties.

Source: I. A. Ibrahim (1991)

2.5 CORROSION BEHAVIOUR OF ALUMINIUM BASE PARTICULATE METAL MATRIX COMPOSITES

The consumption conduct had been researched by Trzaskoma and Mccafferty [8]. The corrosion behaviour of manufactured pure Al/SiC metal matrix composite matrix by powder metallurgy was analysed. Submersion test revealed that erosion resistance expanded with expanded in volume part of SiC. Corrosion resistance was significantly increased to reduce in particle size of SiC. Further it was likewise seen that with expansion in presentation time the consumption rate is diminished, however with expansion in temperature around 50 and 75 C, erosion rate is expanded of created composite as contrast with pure aluminium.

At room temperature the corrosion rate was higher in Al/SiCp as contrast to pure aluminum. Corrosion rate was diminished with expansion in volume portion and lessen in molecule size of SiCp. The erosion behaviour of copper for covered on as strengthened in Al6061 alloy manufactured through blend cast route was examined by Z. Mohamed et al. [9]. Immersion test revealed that corrosion resistance of uncoated SiCp is more as contrast with Copper covered SiCp. If chance that the presentation time is expanded erosion resistance is likewise expanded. The mass lost is expanded after submersion in 3.5 % NaCl solution with expansion in rate of covered and uncoated SiCp. It was additionally found that 8 % Cu covered SiCp/Al6061 composite had most elevated weight reduction as contrast with 2 % SiCp/Al6061 composite and its matrix alloy. The stress erosion behaviour of Al 6061/albite composite created through fluid metallurgical course with 2, 4, and 6 % by weight of albite particles going from 90-150 μm in size was accounted for in higher temperature acidic medium utilizing autoclave. Z Mohamed watched that with expansion in thickness of HCi at presentation temperature 100° C and time 30 min.

2.6 PARTICLE SIZE AND SHAPE

First task of characterizing a powder is to obtain a small sample that representative the entire powder lots. From all powder characteristics, probably three dominate to successful powder compactions which are particle size, packing density, and particle shape. Particle size is depends on the measurement technique and particle shape.

Particle size determination is possible through several techniques, but each produces a different determination due to difference in measurement parameter. Most cutting tool particle size utilize one geometric parameter and make the assumption of a circular molecule shape. The fundamental for analysis can be projected zone, higher dimension, volume or least cross area.

For tolerance measurement, it is imperative that the powders are agglomerated by using ultrasonic agitation before analysis. The scanning electron microscope provides a tool for visualizing the actual particle characteristic. As the shape become less regular, the number of possible size parameters increase and difficulty increase in assigning a single particle size. Thus, disagreement between instruments is a common problem.

Figure below show a particle size measurement of laser light scattering.

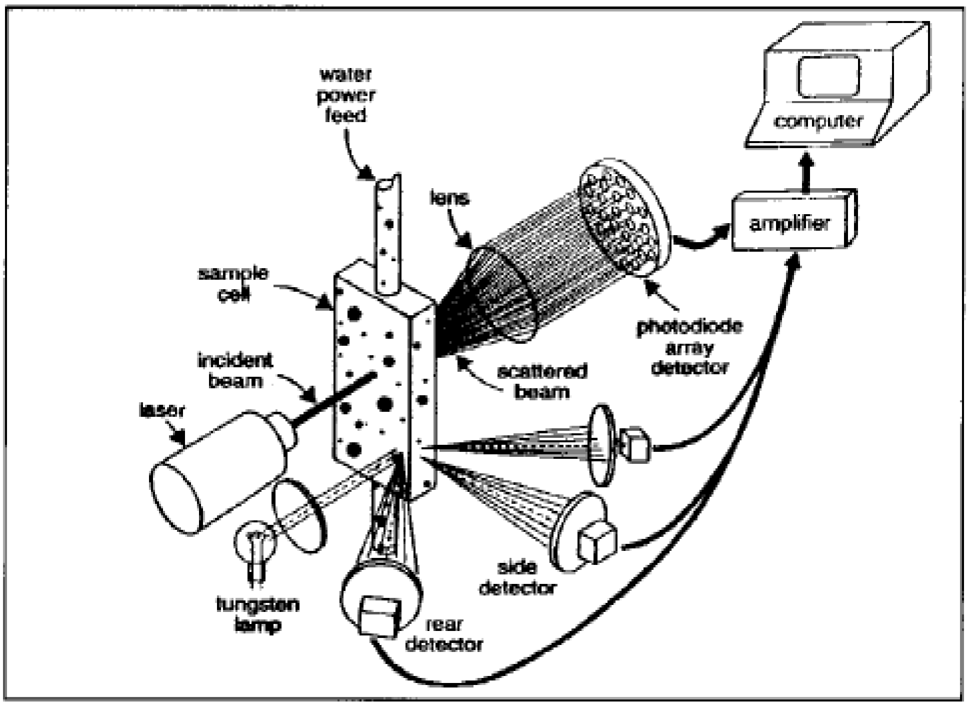


Figure 2.3: Particle size measurements

Source: German and bose (1997)

2.7 PLAIN CERAMIC

Intrinsically high compressive strength, chemical solidness and hot hardness of the ceramics production prompted powder metallurgical yield of ceramic tool since 1950. Because of increasing time, it demonstrate the advantage circumstances and weakness of alumina ceramic production as opposed to sintered carbide. Aluminium oxide or as known as alumina is preferred to silicon nitride for higher hardness and compound stability. Silicon nitride which is harder, however again hard to handle. The plain ceramics tool are fragile in nature and subsequently had constrained for applications. There are three type of ceramic tool bits are accessible in the business sector:

1) Plain alumina with traces of substance – these white or pink sintered inserts supplements are cold pressed and are utilized basically for machining cast iron and comparative materials at speeds around 200 to 250 m/min.

2) Alumina use or not additives – hot pressed, dark shading, hard and solid and used for machining steels and cast iron at around 150 to 250 m/min.

3) Carbide ceramic (alumina + 30% TiC) cool or hot pressed, dark in shading, very solid and great in strength, utilized for machining hard cast irons and plain and alloy steels at 150 to 200 m/min[16]. The plain ceramic outmatched then existing tool materials in some application zones like high speed machining of milder steels fundamentally for higher hot hardness as showed in Figure 2.4.

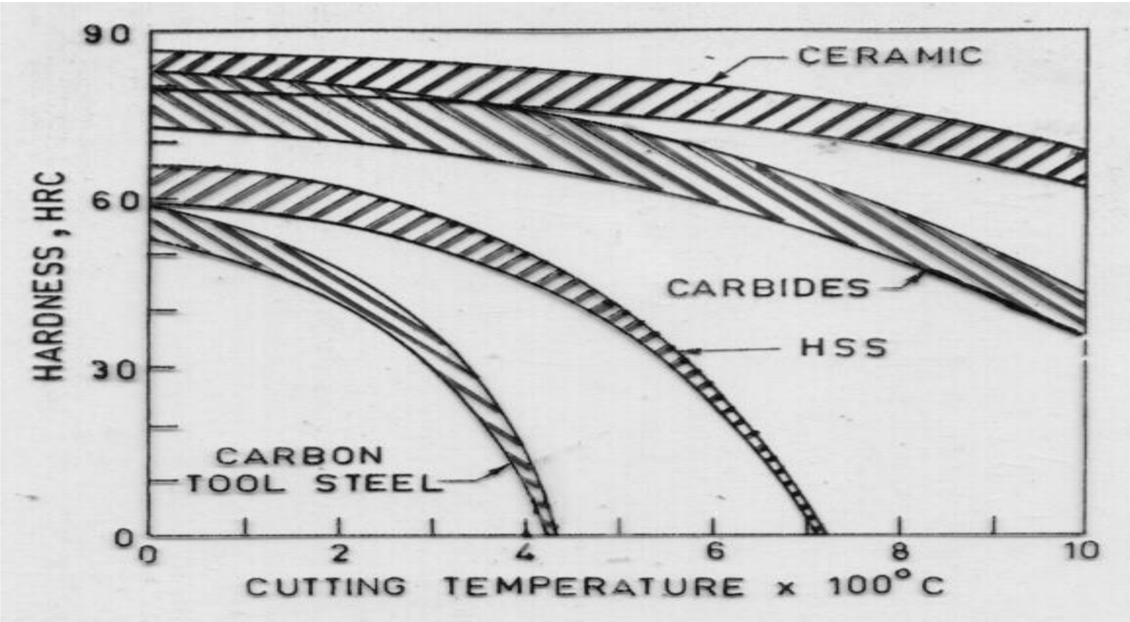


Figure 2.4: Hot hardeness use at different tool material

Source: Book by A.Bhattacharya

CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

Powder metallurgy is manufacturing process of producing solid part geometry and material from powders. Basically, it referred as powder processing that non metal powder can be involved. Powder is compacted into certain geometry and then sintering to solidify the part. The sintering process temperature is below the melting point nearly 80% of component in powder mixture. This is because the similarities between method thermal treatment and sintering production, the end bodies produced by powder metallurgy is known as metalloceramics.

The experimental procedure is shown in figure 3.1

- Mixing of powder between aluminium oxides with copper powder in order at range (70% to 80%) mixture and combine using ball milling.
- Compact the mixed powder at constant pressure at rate 138mpa to 827mpa.
- Sintering at high temperature around temperature furnace around 1100 degree Celsius.
- Analysis of hardness, strength, density and microstructure.

3.1 FLOW CHART MACHINE USAGE

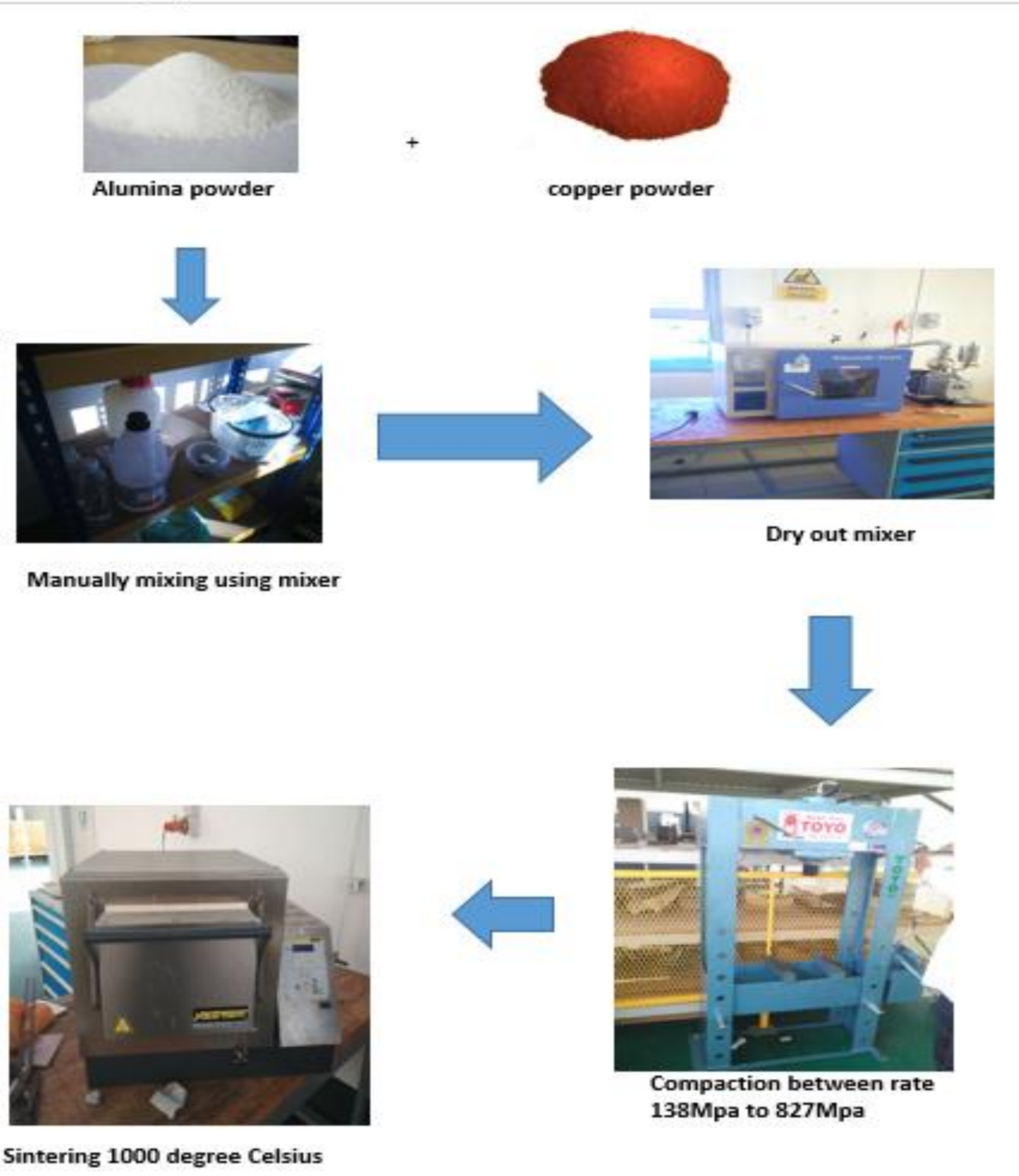


Figure 3.1: Experiment procedure: (1) mixing between compound, (2) dry out mixer, (3) Compaction, (4) sintering process

3.2 FLOW CHART FOR METHODOLOGY

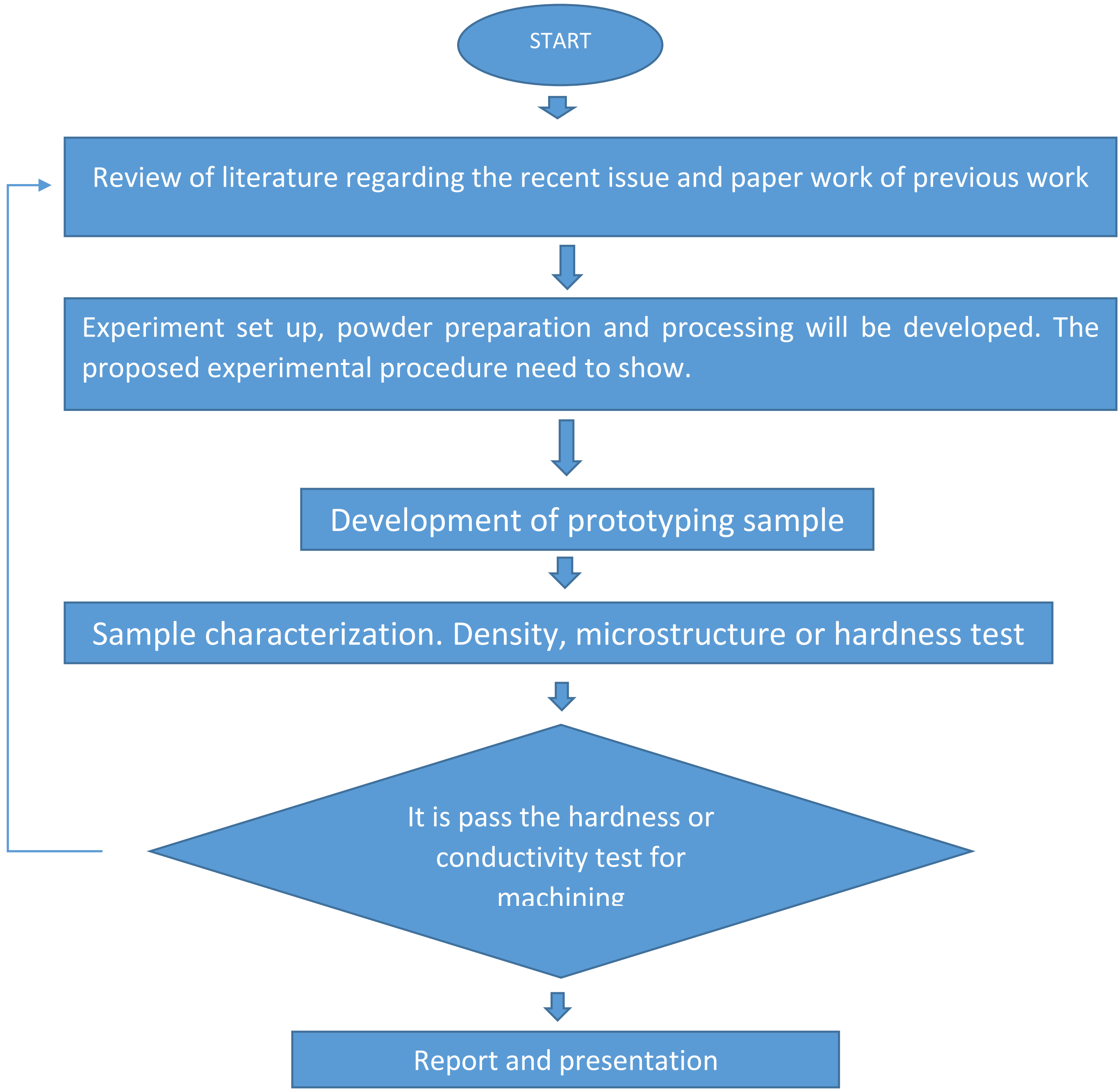


Figure 3.2: Flow chart of methodology

3.3 POWDER SELECTION

First of consideration in powder metallurgy is the powder used for the manufacturing process. There are several different of measurement that used to calculate correct quantity for properties of mixture. Powder can be alloy or pure element. This powder can be mixtured with different kinds of powder, it can combine with alloy powder, elemental powder or both powder together. Material and method powder production which are critical factor in determining the properties of powder. It also had its potential hazard. Some powders can be easily flammable and some can risk human health. Safety precaution should always be taking serious when handling or storing powders. Follow any regulations regarding the storing or handling powder. Powder selection and processing will depend on cost, desired purity and mechanical properties of finished product. When storage and handling powder, environmental control must be critical consideration [17]. Contamination of powder can be result in powder degradation and be avoided. High surface area can cause powder to react readily with another material for example oxidation that caused by oxygen present in air.

3.4 MANUFACTURING POWDER METALLURGY

Atomization is the process used to produce the largest tonnage of metal powders. In water and gas atomization (Figures 3.3 and 3.4) the raw material is melted then the liquid metal is separated into individual particles. The melt stock, in the form of elemental, multi-element metallic alloys or high quality scrap, is melted in an induction, arc, or other type of furnace. After the bath is molten and homogenous, it is transferred to a tundish which is a reservoir used to supply a constant, controlled flow of metal into the atomizing chamber. As the metal stream exits the tundish, it is struck by a high velocity stream of the atomizing medium for example water or an inert gas [17]. The molten metal stream is disintegrated into fine droplets which solidify during their fall through the atomizing tank. Particles are collected at the bottom of the tank. Alternatively, centrifugal force can be used to break up the liquid as it is removed from the periphery of a rotating electrode or spinning disk. (Figure 3.5).

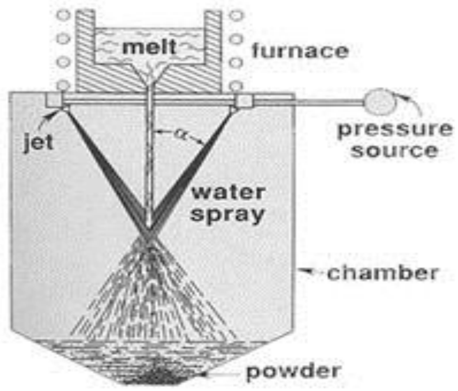


Figure 3.3: Water Atomization Process

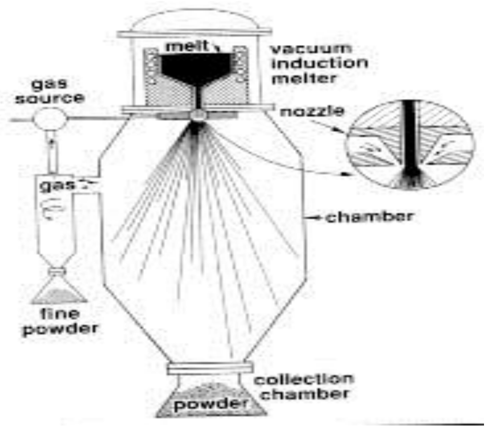


Figure 3.4: Vertical Gas Atomizer

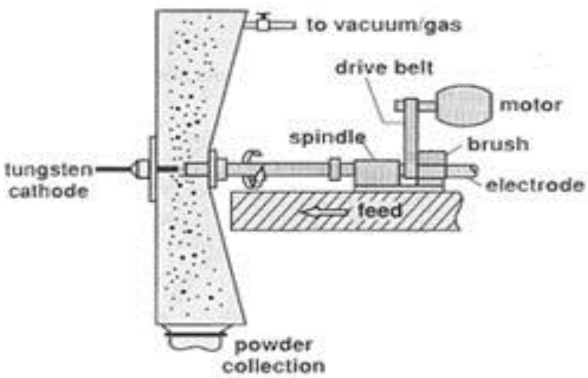


Figure 3.5: Centrifugal Atomization by the Rotating Electrode Process

Source: http://thelibraryofmanufacturing.com/powder_processes.htm

3.5 SIZE AND DISTRIBUTION

Size of particles is a factor that will affect processing of metal powders. In manufacturing practice, powders are commonly measured using a series of screens with different sized openings. In figure 3.6 it shown, each screen is a wire mesh with openings ideally of the same size. Screens for powder measurement are designated according to the number of openings per linear inch, example (30, 100). Openings per linear inch are the same in the 2 dimensions of the screen's surface, therefore the number of openings per square inch is the square of the linear number. A screen with a linear measurement of 100 has 1002 or 10,000 openings per square inch. When determining the size of an opening, the size of the screen's wire must also be considered. Mesh opening size, (MS), can be determined by MS = 1/MC - WS, where MC is the mesh count, (openings per linear inch), and WS is the thickness of the wire [17].

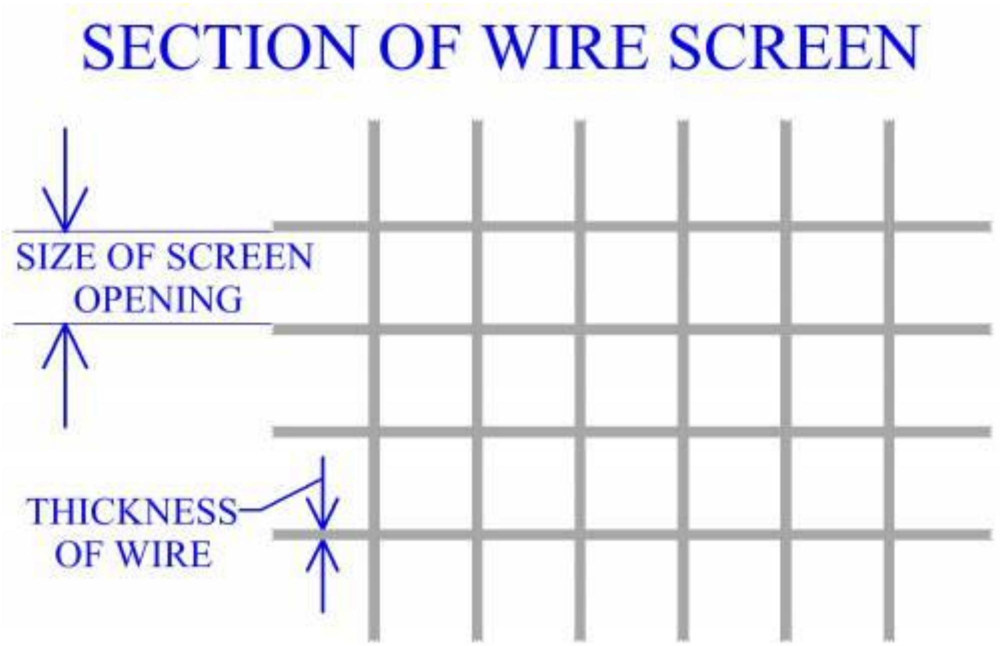


Figure 3.6: Wire Screen for Powder Particle Measurement

Source: http://thelibraryofmanufacturing.com/powder_processes.htm

The concept of powder particle measurement using a screen is quite simple. When powder is poured on the surface of the screen particles that are smaller than the screen opening will fall through, while particles that are larger than the opening will remain on the top of the screen. In this manner a single screen can separate all particles in a powder above a specific size, from all particles in that powder below that size.

3.6 MEASUREMENT OF POWDER PARTICLE

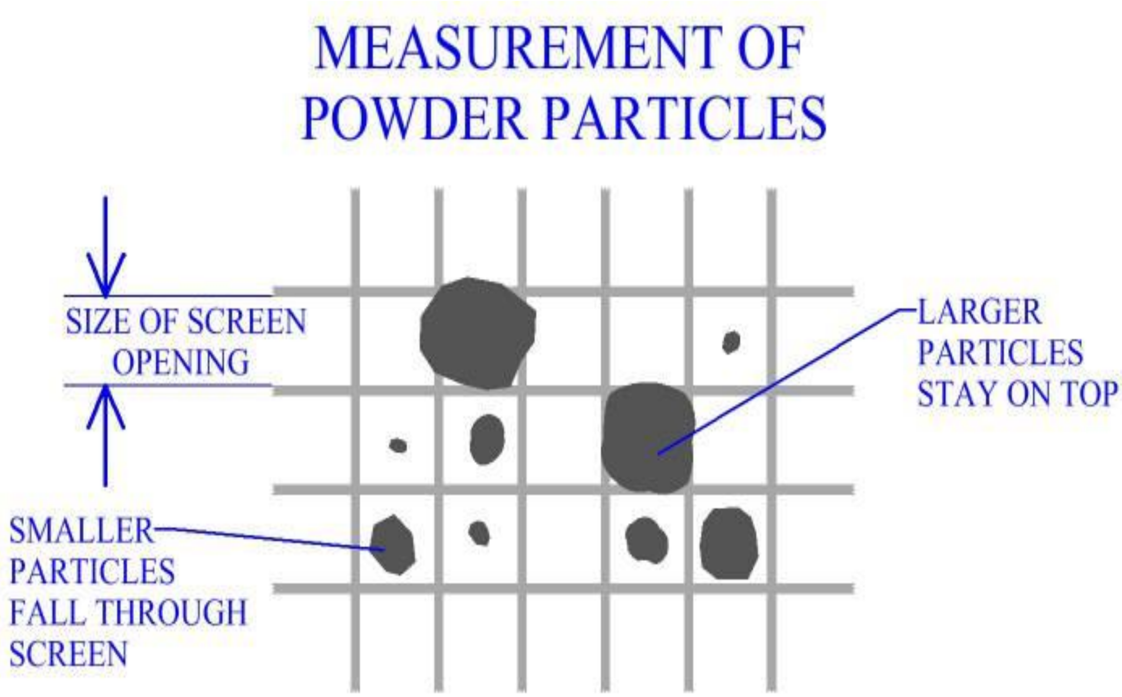


Figure 3.7: Measurement of powder particle

Source: http://thelibraryofmanufacturing.com/powder_processes.htm

These screens are stacked one over another with the screen with the largest openings on top. As the stack progresses downward, each sequential screen has a smaller opening than the one above it. A powder sample is poured on the top screen as shown in figure 3.7. A machine vibrates the stack. Powder particles will fall through the screen openings until they encounter a screen size too small to fit through [17]. Thus, each screen will collect metal powder particles of a certain size range. The sizes and distribution of sizes can then be measured. For example, the particles that pass through 90 but not 100 are said to have a size of 90-100, they may also be considered to have a size of 90. With this method particle size distribution can be measured, usually by weight percent, and quantified. Results can be represented graphically, the size range in which the highest weight percent of particles occur is called the mode size.

This system does have limitations. Imperfect screens can result in variations in the size of openings. Differently shaped particles also affect the accuracy of the powder screening technique. The difficulties involved in manufacturing screens go up in magnitude as the number of openings per inch increases. For this reason, powder particle size measurement using screens is limited to a lower range of about 400 opening per linear inch. Very small powder particles tend to agglomerate or stick together, which would make the metal powder screening method ineffective at extremely low ranges anyway.

There are several other methods by which particle size can be determined. Particles are suspended in a liquid medium and can be measured by light scattering techniques or by electrical sensors. Measurements can be made with a microscope. Other types of optical analysis may be used. X-ray measuring techniques are available. Sedimentation is also a method employed in manufacturing to measure powder particle size and distribution. Sedimentation determines size by measuring the sinking of particles in a liquid.

3.7 PARTICLE STRUCTURE

The structure, or shape, of particles is a major factor in a powder processing operation. Material and method of powder production are the main variables determining powder shape. Particles of a certain powder may have similar shapes but no particle shapes are exactly the same. Hence, there will exist a shape distribution within a powder. Different types of powders combined together may also have significant differences in particle shape, which will show in the shape distribution. Particle shape plays a larger roll in powder density and flow characteristics, it is also a major factor in pressing and sintering [17]. There are several types of basic powder particle shapes. These are ideal shapes, particles in reality are imperfect and may exhibit characteristics of more than one shape type shown in 3.8.

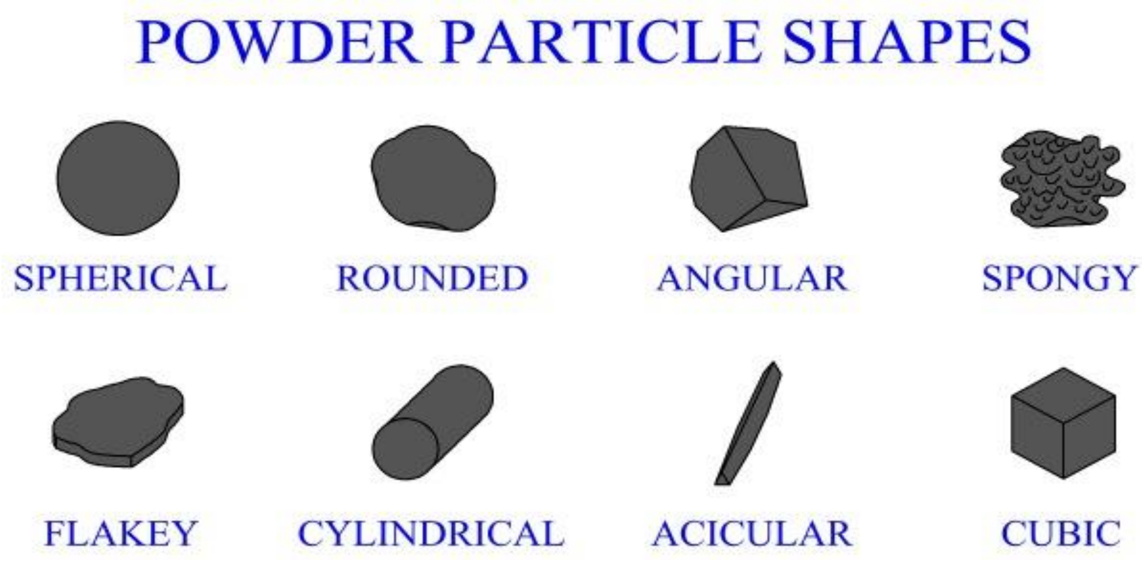


Figure 3.8: Powder particle shapes

Source: http://thelibraryofmanufacturing.com/powder_processes.htm

Two ways use, in manufacturing analysis, to quantify the shape of particles are the shape index and the aspect ratio. Shape index relates the particle's surface area to the particle's volume and compares that to a sphere, which has the lowest shape index. Aspect ratio is the ratio between a powder particle's greatest dimension and its smallest. A perfect sphere will have an aspect ratio of 1, a rounded particle may have an aspect ratio of 1.5, while acicular or flakey particles may easily have aspect ratios of 3, 5 or 10.

3.8 POROSITY

Pores or known as space, within the powder is in a large part determined by particle shape, (and size), since the shape dictates how particles will contact each other. Spaces that exist between particles of a powder and are open to the outside are called open pores. These spaces expose external surfaces of powder particles.

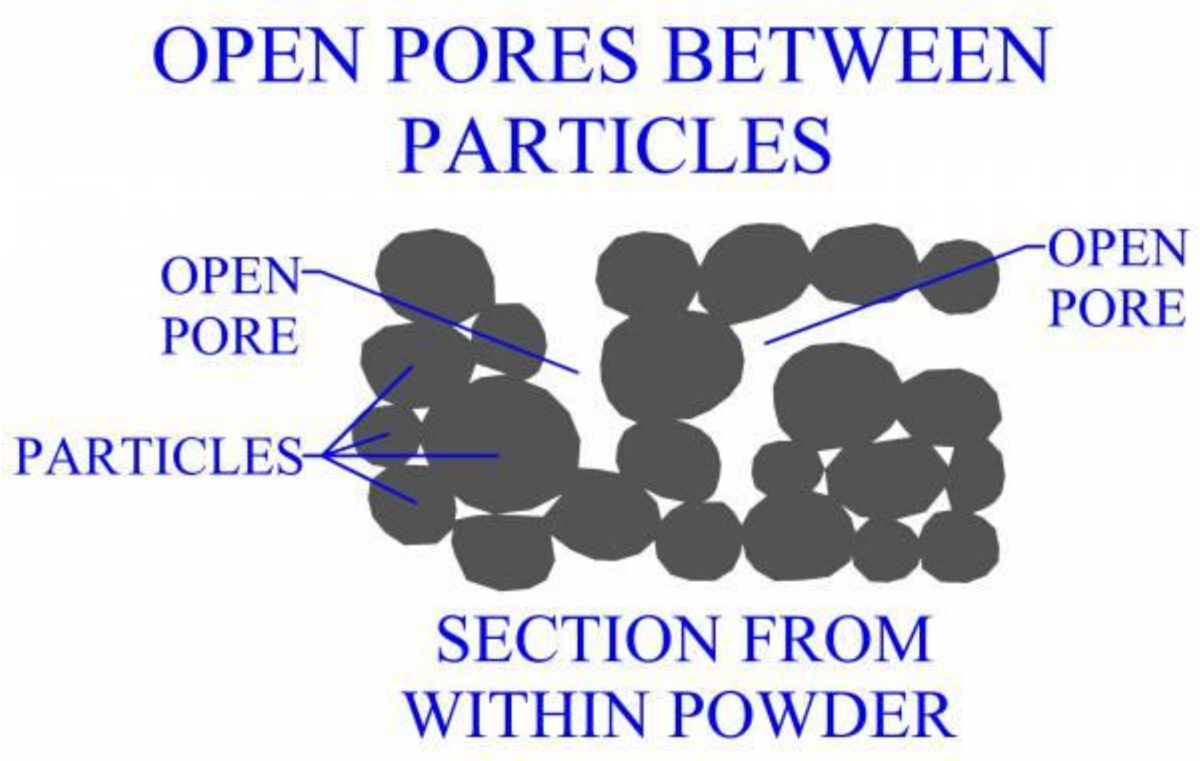


Figure 3.9: Open pores between particles

Source: http://thelibraryofmanufacturing.com/powder_processes.htm

During compaction of powder these spaces are eliminated. If any amount of this space remains after processing, it will result in porosity as show in figure 3.9 in the manufactured part. These open pores are permeable to the atmosphere. They are also permeable to fluids in general, such as liquid lubricants, water, or melted polymers, provided that the porous regions are interconnected and not isolated. The other type of vacancy that exists in a powder material is called a closed pore. These pores are not open to the outside atmosphere. Closed pores can develop during the pressing and sintering process if an open pore region becomes closed off. Another type of closed pore exists within the material of the powder particle itself. Theoretically if all the open pores and closed pores were eliminated, the density would be that of the fully dense material.

3.9 MECHANICAL METHOD (BALL MILLING)

Milling, lathe turning, and chipping, comprise the second powder manufacturing group. Milling (Figure 3.10) is the primary method for reducing the size of large particles and particle agglomerates. Ball, hammer, vibratory, attrition, and tumbler mills are some of the commercially available commuting devices. During milling, forces act on the feed metal to modify the resultant particles. Impact, attrition, shear, and compression all influence powder particle size and shape. Lathe turning is a technique used for materials such as magnesium for creating coarse particles from billets. These particles are reduced in size subsequently by milling or grinding.

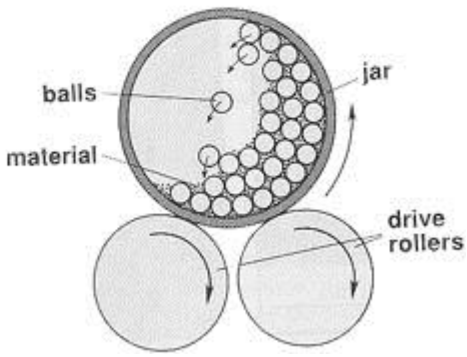


Figure 3.10: Particle Size Reduction by Jar Milling-Schematic

Source: http://thelibraryofmanufacturing.com/powder_processes.htm

3.10 POWDER PRESSING

Powder pressing is the compaction of powders into a geometric form. Pressing is usually performed at room temperature. This creates a solid part called a green compact. The strength of this pressed, is dependent on compatibility, binders may be used to increase compatibility. Typically a green compact can be broken apart by hand but is also strong enough to be handled, gently. The geometry of the green compact is similar to that of the final part, however, shrinkage will occur during the sintering phase of the manufacturing process and must be calculated in[17].

Amount of powder needed will be based on the bulk density of the powder and the amount of material in the final part. Bulk density is discussed in the previous section, it is the density of the loose powder by itself. Bulk density is important when measuring powder quantities. The effects of additives such as lubricants must always be calculated. For example, a green compact has a certain amount of lubricants and binders in it that add extra material. During sintering, these lubricants and binders are burned off. Their material is no longer in the part after sintering and this must be a consideration. To begin the manufacturing process, a certain amount of powder is filled into a die. Rate of die filling is based largely on the flowability of the powder. Powders that flow readily can be poured at higher rates. Pouring can be an automated process. Once the die is filled, a punch moves towards the powder. The punch applies pressure to the powder, compacting it to the correct geometry.

Figure 3.11: powder pressing process

Punch and die surfaces are very important in powder manufacture. Some clearance between the punch and die must exist in order for the punch to move within the die. Powder particles can become stuck within this clearance, causing problems with the proper movement of machinery. In order to prevent powder particles from becoming lodged within this gap, clearance is designed to be extremely low. Clearance values between punch and die, used for powder pressing, are typically less than 0.01 mm. Most punch and die are made from hardened tool steels, the surfaces of which are ground then polished, or lapped, in the direction of tool movement. Punches and die for more extreme powder processing operations may be made from tungsten carbide [17].

Figure 3.12: clearance between punch and die is 0.01mm

Amount of force necessary for a pressing operation is to a large degree based on material. For example, pressing aluminium powder generally requires lower force, while pressing iron powder requires relatively higher force. Pressing force also depends upon powder characteristics, additives and desired density of the green compact. Friction force will oppose movement of particles during pressing, therefore lubrication can reduce the required pressing force and also cause a more uniform distribution of particles during pressing. Lubrication should be applied in the correct quantities. Excessive lubrication will not all remain on particle surfaces, but will also collect in the interparticle spaces, (open pores), and prevent the proper compaction of powder. Pressing force is a function of pressure over the area of the part perpendicular to the direction of pressing. Usually the press is vertical, in this case the horizontal plane of the part would be considered.

Force for industrial powder manufacture typically varies between 10,000 lbs/in2, (70 MPa), and 120,000 lbs/in2, (800 MPa). Parts for this type of manufacture are mostly small, (under 5 lbs), and press requirements are typically under 10 tons. Mechanical presses with capacities on the magnitude of a few hundred tons are usually adequate for most powder processing operations. Hydraulic presses with capacities of several 50 tons are sometimes used for work requiring more force. Using one action presses, with opposing top punches, are commonly used, but for more complex parts multiple action presses may be employed. Punch speed must be regulated. Faster compaction of the work can result in higher productivity, however if the punch speed is too high, air may become trapped in the pores and prevent the part from compacting correctly.

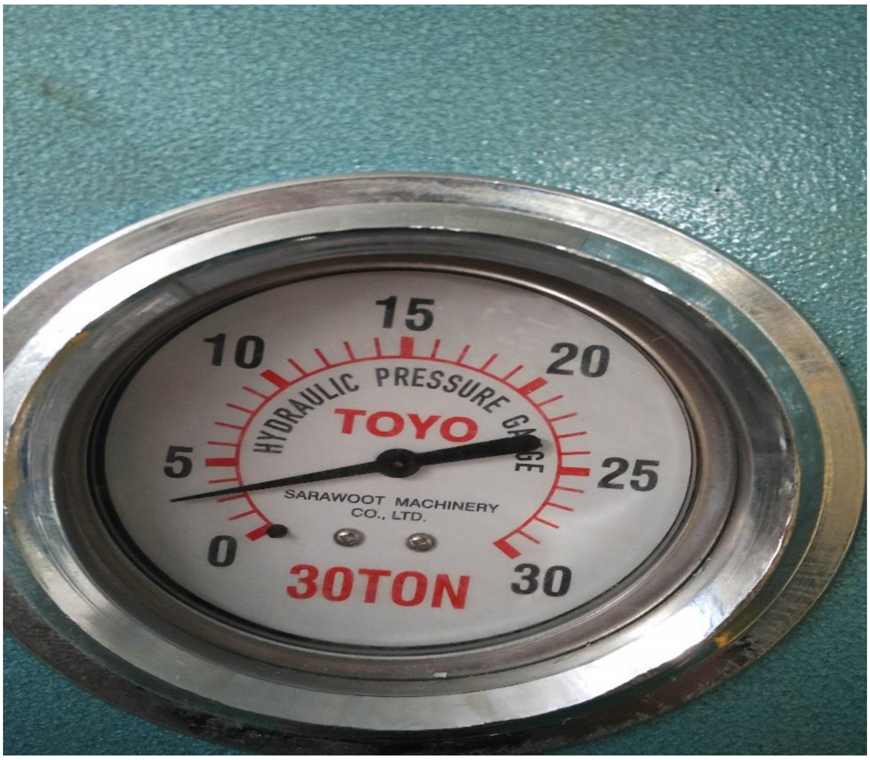


Figure 3.13: Pressure that need is maximum 4 tonnes

3.11 SINTERING PROCESS

Primary variables defining a powder sintering operation are time, temperature and furnace atmosphere. Sintering temperature is typically 0.7 to 0.9 of the powder's melting point which for copper powder is 900 Celcius. Sintering time is dependent on manufacturing process factors and material. Alumina, for example, is sintered for a relatively long time. Standard industrial powder sintering times for different processes and materials are vary from 8 minutes to 10 hours.

Figure 3.14: furnace machine

A controlled atmosphere is critical during powder sintering. The purpose of the atmosphere in sintering is to control carburization and decarburization, prevent oxidation and remove existing oxides, prevent unwanted chemical reactions and assist in the burning off of additives. Sometimes parts are also sintered in a vacuum. Vacuum sintering is mainly applicable to refractory metals and stainless steel.

Sintering of a green compact occurs in three stages. First, the powder compact is subject to preheating. Preheating will raise the part to a relatively low temperature, providing the burning off of additives. Preheating will also start to strengthen bonds within the part, increasing its integrity for the next stage. In the second stage the temperature is raised to the sintering temperature and maintained for a specific duration necessary for the desired amount of bonding to occur. Temperature is lowered as the part is allowed to cool during the third stage. Keeping the work in the controlled furnace atmosphere during cool down is critical in preventing unwanted chemical reactions between the part and the environment.

Figure 3.15: Powder cool at room temperature

In industrial powder manufacture there are two types of furnaces, batch and continuous. In a batch furnace low quantities of parts are placed in the furnace, undergo the entire sintering process and are removed. Continuous furnaces provide flow through production and have three zones for the three stages of the manufacturing process, (preheat, sinter, and cool down).

A moving belt carries a continuous supply of parts through the chambers. Heat doors can rapidly open and close to allow parts through, while keeping heat in. The belt travels at the exact speed to give parts the correct amount of time in each chamber.

Consistent products and high productivity rates make continuous furnaces the most common choice for powder sintering. While batch operated furnaces have a lower productivity rate and are less often used, they do provide more control of the atmosphere and hence part purity. Vacuum atmospheres can generally only be provided by batch furnaces.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter discusses on what method use, mechanical testing, problem and consideration of data analysis that get from the experiment. Investigation of the effect of matrix material composite reinforced with copper powder that act as reinforcing agent on the characterization and mechanical properties are the objective of the experiment. The change of mechanical properties of aluminium oxide by reinforcing with different composition ratio of copper powder was examined. This chapter will discuss on the solution when there is any problem regarding to experiment and some improvement that need to be made by presence of copper powder in aluminium oxide powder.

4.2 FABRICATION DIE RESULT

Aluminium oxide and copper powder were prepared and filled in using die that made during fabrication process. Die was designed using Catia V5 and then fabrication by milling machine. There were 4 part in die, planger, middle die, core and lower guide (figure 4.1). Different type of material will have different hardness to ensure good strength and good production during compaction process.

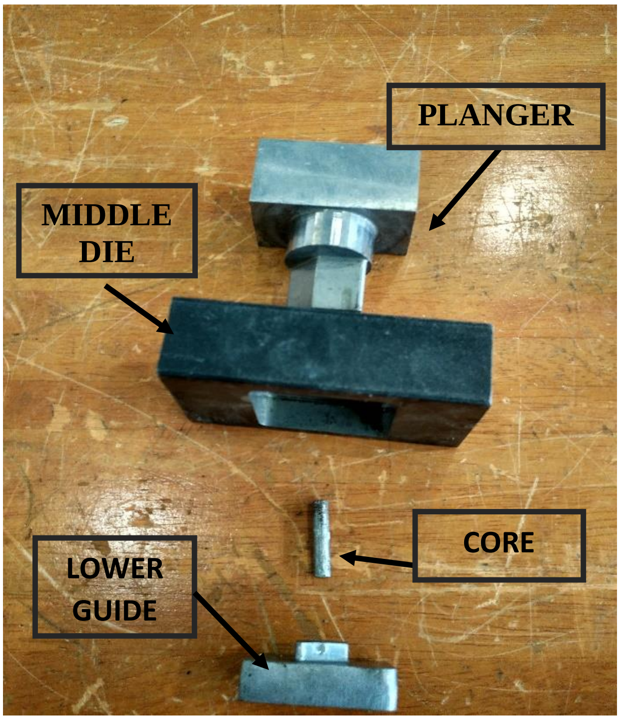


Figure 4.1: Part of die

4.2.1 PROCESS MAKING DIE (WIRE CUT MACHINE)

The shape that use for compaction is diamond shape 55 degree. The aluminium oxide and copper powder shape was shaped based on shape according to mold cavity shape which actual structure is shown in figure 4.2 and 4.3.

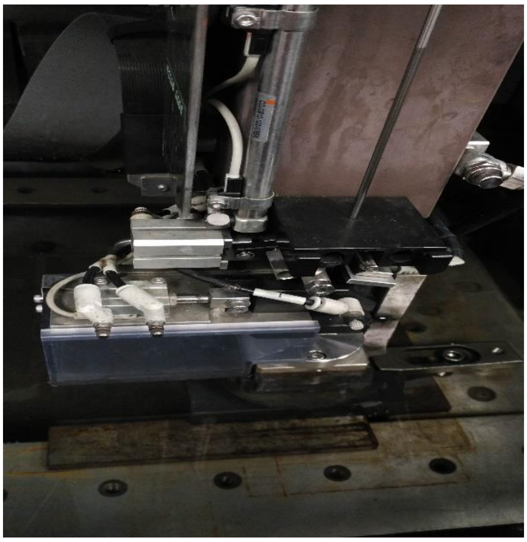


Figure 4.2: Mold of insert shape **Figure 4.3**: Wire cut proces

Wire cut machine was used to produce high precision shape in case to produce exact shape with the turning insert. There was program need to set before started machining. Wire that used was brass material which was 0.2 mm. Medium for machining fluid is water base. Thickness of material for cut is 30mm and machining type is selected as punch as shown in figure 4.4.

Figure 4.4: Setting for Sodick Wire cut machine

4.2.2 PROCESS MAKING DIE (MILLING MACHINE)

Fabrication using milling machine was easy after using software CATIA to design the shape. There needed to considerate before using milling machine. It need very precision because it will produce planger and lower guide to make it fit well. The offset setting was nearly zero or 0.01mm to make both fit well in middle die. Insert used 8 mm diameter ball mill was used to get exact shape with good finishing. Process take around 18 hour of each part to finish it. Speed of rotational was 1500 mm/min with feed rate was 70 percent.

(A)

(B)

Figure 4.5: (A) Planger material STARVAX ERS and (B) Lower guide material MILD STEEL was produce by milling machine.

4.2.3 PROCESS MAKING DIE (TURNING MACHINE)

A long aluminium rod needed to cut until 25mm using band saw. Diameter of aluminium rod was 5.13 mm which was bigger than hole of lower guide. So it needed to cut until it fit 4.8 mm using turning machine. It need to set the x axis and y axis before started to cut. Speed of machine was 1000mm/min. After get fit with lower guide die, core pin needed to cleaned to prevent bur and stuck in lower guide.

Figure 4.6: Core pin after though turning machine

4.3 HARDNESS TEST

In hardness test, a machine that suitable that can be use called Vickers Hardness Tester (Figure 4.7). It used to measure the hardness of material under range in 1 kilogram. It has variant of pressure based on material hardness. Each powder had different kind of pressure and also depend on colour of powder. If it too white for example aluminium oxide, it will give disadvantage to find diamond shape.

Figure 4.7: Vickers Micro Hardness Tester

Before doing hardness test, there was another step to get good result in getting diamond shape. First thing first, it needed to mount. For mounting, the powder that been used was acrylic resin powder combine with resin. Both needed to mix with correct concentration to make mounting hard and rapid cooling. After that, it needed to go to next process called surface roughing.

In this process, it needed to be flatted as possible and powder surface needed to be cleaned as possible to make diamond shape clearly been seen. To make it, mounting needed to go through on sand paper that put in turning machine. Different type of sand paper were use to get good result. Lastly after go through surface roughing, it needed some finishing to remove unwanted dust stick on powder and the mounting. Again it needed to clean on turning machine with the soft board, cleaned using clean water, put some soap and clean it again. It will give clear view on camera.

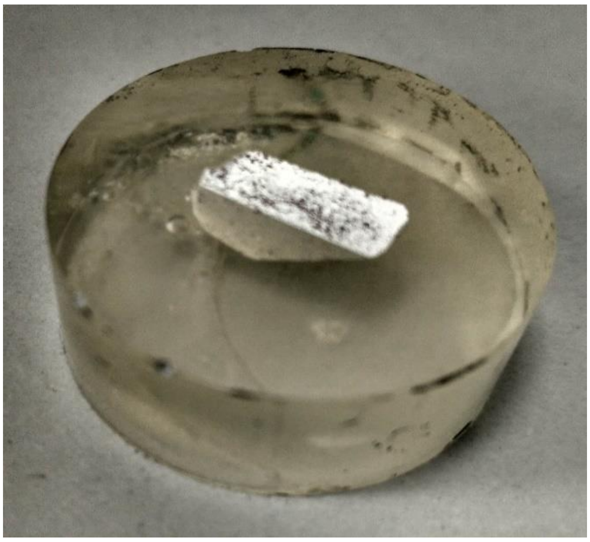


Figure 4.8: Mounting for specimen alumina 70% and copper 30%

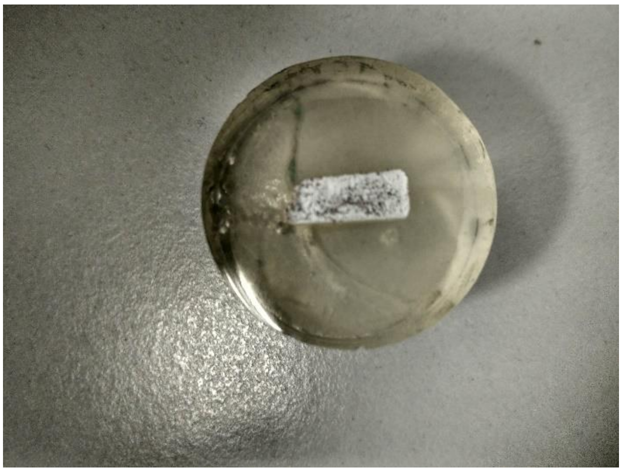


Figure 4.9: Mounting for specimen alumina 90% and copper 10%

4.3.1 Experimental Result for Vickers Hardness Test

This section will discusses about result during Vickers Hardness test. Figure 26 show the graphical result during experiment for alumina 70% and 30% of copper powder. The experiment using Vickers machine. The data was collected and recorded in table 4.1.

NUMBER OF TEST	VICKERS RESULT,HV
1	65
2	66.37
3	66.11
4	65.3
5	65.56
6	65.7
7	65.8
8	66.23
9	68.45
10	68.41
11	69.01
12	69.1
13	69.16
14	69.18
15	69.5

Table 4.1: Result for Vickers test for 70% alumina and 30% copper powder

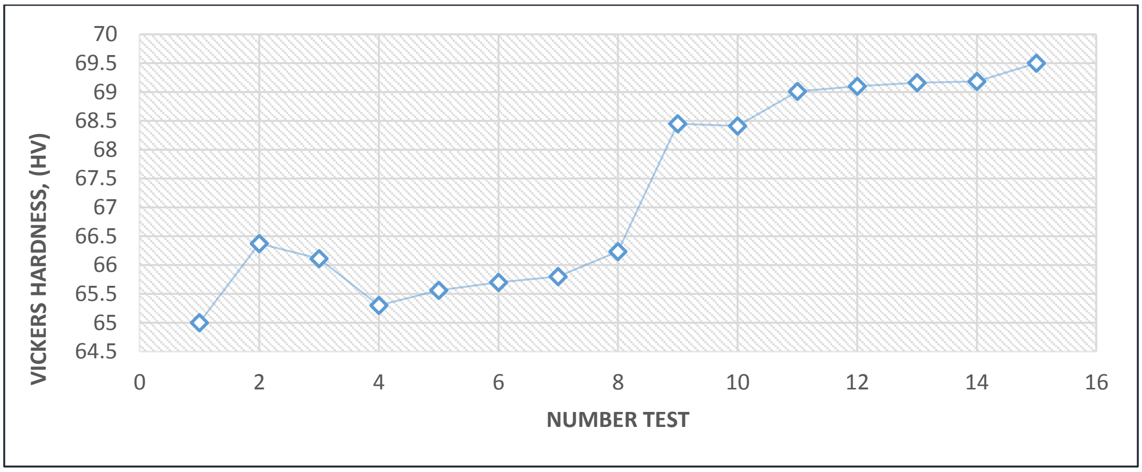


Figure 4.10: Graphical result for Vickers test for alumina 70% and copper 30% copper powder

Another mixture was made to make comparison. Specimen with mixture 90% alumina and 10% copper had done. The experiment using Vickers machine, data had been collected and recorded on table 4.2. Graphical result had shown in figure 4.11.

NUMBER OF TEST	VICKERS RESULT,HV
1	43.1
2	44.3
3	44.31
4	44.56
5	44.6
6	45.1
7	45
8	45.11
9	45.11
10	45.31
11	45.32
12	45.38
13	45.4
14	45.36
15	46.6

Table 4.2: Result for Vickers Test for alumina 90% and copper 10%

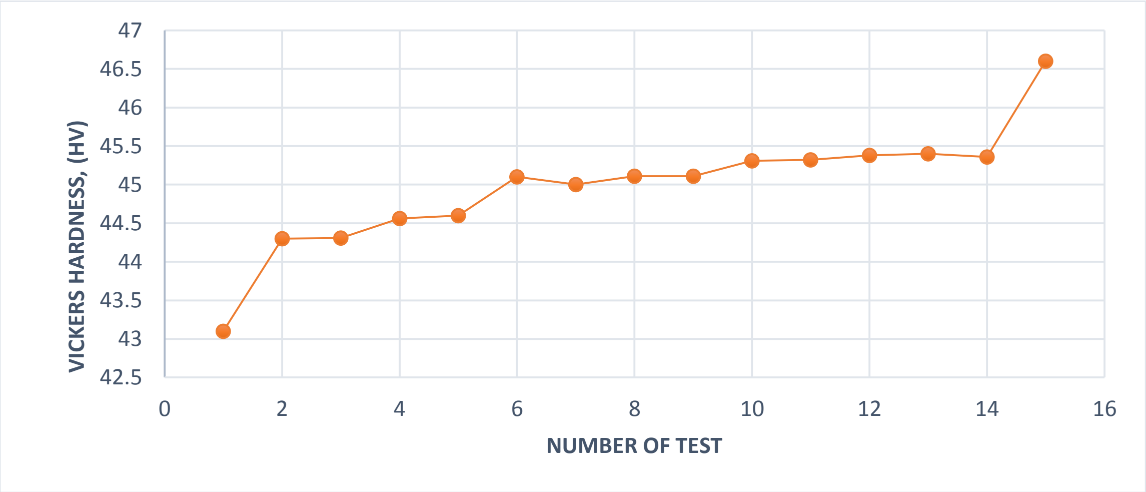


Figure 4.11: Graphical result for Vickers test for alumina 90% and copper 10% copper powder

Based on data that collected, value for the 70% of alumina with 30% of copper was more harden compare to 90% of alumina with 10% of copper. It can be proven based on graphical result figure 28. For alumina 70%, average data that collected, 67.26 HV compare to 90% which get 45.03 HV. It mean that, the more percent reinforcement of copper, the higher the hardness. Based on journal "Essentials of Materials for Science and Engineering [7], the volume percent of ceramic should be greater than 70%. To get a good hardness, it must starting at 70% and above.

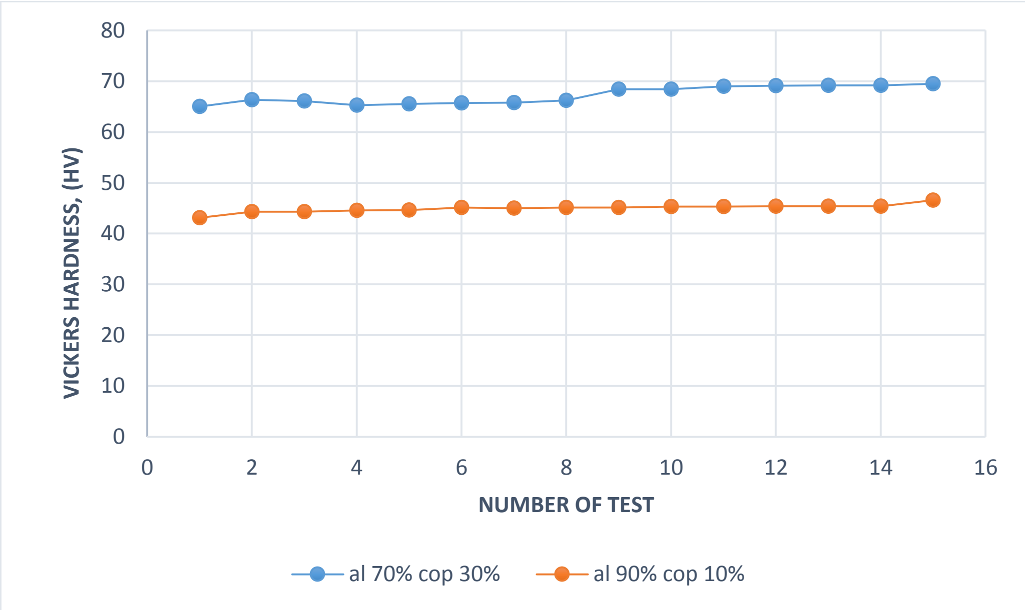


Figure 4.12: Comparison between alumina 90% and alumina 70%

4.4 DENSITY TEST

In this section, there are mathematical calculation based on green compact, and after sintering effect. The data had been recorded one by one each specimen. After sintering, once again the measurement needed to take again to compare. The tool that used was micrometre which available at FKP lab machining. The measurement was taken based on figure 4.13.

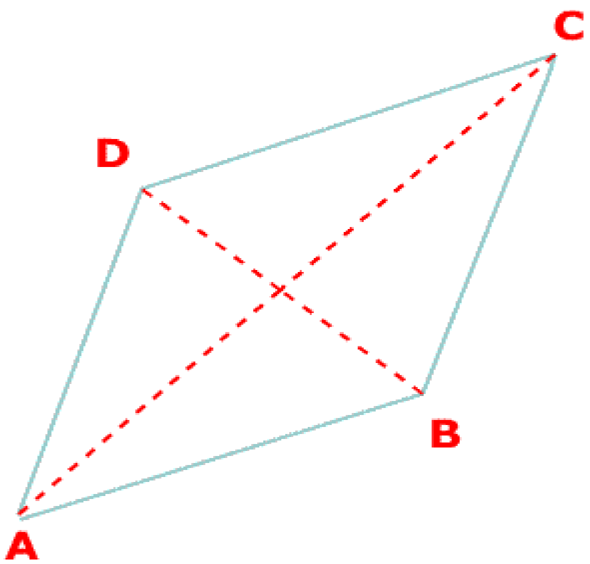


Figure 4.13: Area of rhombus

http://mathhelptutoring.blogspot.my/2013/02/learn-area-of-rhombus.html

Length AC be as diagonal A and that of BD be as diagonal B. Formula for calculating the volume of a triangle is ½ x b x h where 'b" is the base and "h" is height or altitude. Consider the rhombus as the combinations of two triangles ABC and ADC. Adding the areas of triangles ABC and ADC to get the area of the rhombus ABCD. The diagonals of rhombus bisect each other at right angles the height of triangles of ABC and ADC will be half of the diagonal BD which is equal to d2/2. It shall now calculate the area separately and summing all. Lastly, to get the volume, multiple the thickness of rhombus. List of data had been put in table 4.3.

INSERT SIZE AFTER SINTERING EFFECT		
PART NAME	**BEFORE (GREEN COMPACT)**	**AFTER (SINTERING)**
DIAGONAL A, mm	19.991	19.993
DIAGONAL B, mm	13.252	13.252
THICKNESS, mm	4.5	4.51
MASS, gram	2.93	2.935
ACTUAL DENSITY (D = M/V) Kg/m^3	4912.74	4912.49
THEORETICAL DENSITY, Kg/m^3	5458.6	5458.6

TABLE 4.3: Data recorded after take measurement of each session

Based on result taken, using theoretical density formula, it get 5458.6 Kg/m^3. It is based on calculation on 4.1. Ratio percentage of alumina multiple with alumina density adding with ratio percentage of copper multiple with copper density. It need to compare with actual to make sure it still in guideline of project. And for the actual density, from the result, it get 4912.74 $Kg/m^{3.}$ Ratio between these formulas it get around 90.1%. The calculation and method are shown in equation 4.4.1.

4.4.1 EQUATION FOR WEIGHING POWDER RATIO

The material was weighing based on theoretical powder density formula and actual density of powder.

Theoretical density, Kg/m³ = (percent ratio x alumina density) + (Percent ratio x copper density) (4.1)

$$= (0.7 \times 3.9\ ) + (0.3 \times 8.96)$$

$$= 5.453 \text{ or } 5453\ Kg/m^3$$

Actual density, Kg/m³ =

$$\frac{\boldsymbol{mass}}{\boldsymbol{1/2 \times diagonal\ A\ \times diagonal\ B\ \times thickness}}$$

$$= \frac{2.93}{\frac{1}{2}\times 19.991\times 13.252\times 4.5} \tag{4.2}$$

$$= 4912.74\ Kg/m^3$$

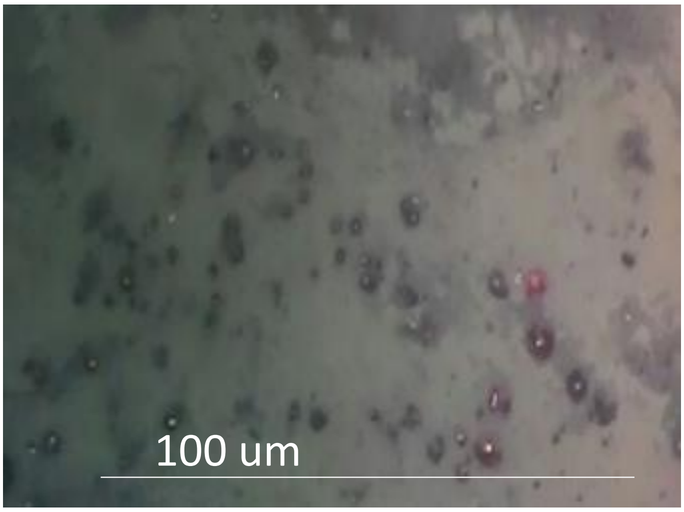
Theoretical percentage = $\frac{\boldsymbol{theoretical\ density}}{\boldsymbol{actual\ density}}$ (4.3)

$$\boldsymbol{= \frac{4912.74}{5453} \times 100}$$

$$\boldsymbol{= 90.1\%}$$

4.5 OPTICAL MICROSTRCTURAL

This section was discussed about microstructure of material after sintering. Optical microstructural was used to display the image of specimen for ratio alumina 70% and copper 30%. From the optical microstructure, some investigation had been earned such as different type of ratio and structure properties. Figure 4.14 shown the result of optical microstructure.



(A)

(B)

(C)

Figure 4.14: Optical Microstructure of alumina 70% and copper 30% with different magnification (A) 5x, (B) 10x, (C) 15x

Figure 4.14 show the optical microstructure for alumina oxide 70 % and copper 30% under reflected lens of optical. From the image, it shown the majority presence of alumina which is white in colour due to ratio 70%. The reddish brown which was copper was less due to ratio was 30%.

4.6 DISCUSSION

In this section, it reviewed about the result that achieved from the research that done. This will complete objective, which was develop insert using alumina reinforced with copper powder, fabrication die for the production inserts and lastly to analyze the physical and microstructural properties of insert after compaction and sintering.

Mixture of alumina and copper was decided based on journal “Essentials of Materials for Science and Engineering", Donald R. Askeland, Pradeep P.Phule Thomson-Engineering, 2006, he says, “The volume percent of ceramic should be greater than 70%”. From this journal, starting of mixture ratio was 70% for alumina with 30% for copper and 90% for alumina with 10% copper had done.

Fabrication of die was based on hardness of compaction. To make the green compact, it need mold to stand 4 tonnes and above. For the first trial, using mild steel both for planger and middle mold, with the same material, it start to expand. Both were stuck together cannot take out. For the improvement, second mold using STARVEX ERS for planger which stronger and hard compare to mild steel. The new mold can stand for 4 tonnes and above, and it can repeatly use without any problem.

Optical microstructure image had been investigated and determined. The structure of composition for alumina 70% with copper 30% was observed. The white colour is alumina powder and reddish brown is copper powder. The main material that used was alumina, that that why the white colour was so many. Based on observation, it was very good interfacial bonding when reinforcement material was added into alumina that can give strengthens to insert.

Hardness test was to find the hardness of specimen after though sintering process using Vickers Hardness Test. During experiment, using specimen that contains alumina, which is white in colour, was hard to find. It because, the powder was too white and hard to find in lens. It needed to put some additive colour to make sure diamond shape can detected during experiment. There also problem which it needed to find correct pressure during ticking. It needed to adjust correct pressure so it will not damage specimen.

4.7 SUMMARY

In conclusion, the specimen was developed successfully by powder metallurgy process which was used the ratio alumina 70% reinforced with copper 30%. The fabrication method was followed the methodology staled. The die was successfully fabricated using milling and wire cut machining. The green compact was achieved. The 90% of actual density was achieved based on theoretical density. The mixture ratio for 70% alumina with 30% copper more strong compare to alumina 90% with copper 10%.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter focuses on the conclusion and recommendation that had been made during fabrication of die, compacting, sintering, and lastly analysis. Finally, the result were compared for this study to get objective to develop insert using alumina powder reinforced with copper powder. From all aspect need to review again to make an insert that can be use for turning machine. There also some of recommendation and suggestion that been made for future work.

5.2 CONCLUSION

During fabrication process, the complete die was developed by machining using milling machine and wire cut. Data and analysis was obtained from mechanical properties result of aluminium oxide reinforced copper powder in Chapter 4. The result was discusses in Chapter 4 based on specimen fabrication, experiment, and lastly data analysis. Based on experiment, there were some mistaken or improvement for the next project work. Some needed to review again and some can proceed with the method given. During making powder metallurgy process, there need some to improve, there are:

a. To get high tolerance of die, during designing the offset setting need to change into 0.01 mm or nearly zero to avoid die will be bigger than actual size.

b. During sintering process, alumina need to use temperature more than 1400 Celsius to make powder melt and become solid.

c. During sintering process, powder will start to fracture if it expose to air or during quenching process cannot be done.

d. To improve on hardness, temperature need to increase into 1400 Celsius with the adding more percent of reinforcement material.

e. With increasing Alumina content, there was a measured reduction in composite densities possibly due to agglomeration of the alumina particulates, resulting in localised sintering problems.

f. During mixing process, using binding to make powder bonding together stronger and uniformly.

5.3 FUTURE WORK

a. Machinability test for the developed Insert.

b. Examine for a number of composition mix of the powders for the best properties.

c. Analyze the mechanical properties such as toughness, flexural strength and thermal properties of the insert produced.

d. Further research heat treatments of the copper coated reinforcement compared to non-coated composite materials and examine if revision of times and temperatures are required to achieve improved composite performance.

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APPENDIX

APPENDIX A1

Budget plan

Location experiment

1. University Malaysia Pahang
2. University teknologi MARA, Shah Alam
3. German Malaysian institute, GMI

Raw material (BOM)

No	Material / tools	Quantity	Price per unit	Total
1	Aluminium oxide powder	10 kg	Rm 9.70	Rm 97.00
2	Copper powder	3 kg	Rm 38.70 per kg	RM 26.1
3	Steel block	10x10 mm^2	Rm 300	Rm 300
	Total			Rm 423.10

Gant Chart FYP 1 (APPENDIX B)

No	project activities		Weeks													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	FYP briefing and Introduction Title	Plan														
		Actual														
2	Drafting the Proposal	Plan														
		Actual														
3	Presentation of Proposal	Plan														
		Actual														
4	Literature Review	Plan														
		Actual														
5	Methodology	Plan														
		Actual														
6	FYP Drafting	Plan														
		Actual														
7	Presentation	plan														
		actual														

Gantt Chart FYP 2

No	project activities		weeks													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Set up for experiment	Plan														
		Actual														
2	Experiment	Plan														
		Actual														
3	Analysis Data	Plan														
		Actual														
4	Machining test	Plan														
		Actual														
5	Draft report	Plan														
		Actual														
6	Fyp2 presentation	Plan														
		Actual														

APPENDIX C

DNMG *55° Diamond/Negative*								
Sumitomo Catalog Number	ISO Catalog Number	AC810P	AC820P	AC830P	Inscribed Circle	Thickness	Nose Radius	Insert Hole Diameter
DNMG431EFL	DNMG150404N-FL		●		.500	.1875	.0156	.2031
DNMG432EFL	DNMG150408N-FL		●		.500	.1875	.0313	.2031
DNMG431ESU	DNMG150404N-SU	●	●	●	.500	.1875	.0156	.2031
DNMG432ESU	DNMG150408N-SU	●	●	●	.500	.1875	.0313	.2031
DNMG433ESU	DNMG150412N-SU	●	●	●	.500	.1875	.0469	.2031
DNMG332ESE	DNMG110408N-SE	●	●		.375	.1875	.0313	.150
DNMG431ESE	DNMG150404N-SE	●	●		.500	.1875	.0156	.2031
DNMG432ESE	DNMG150408N-SE	●	●		.500	.1875	.0313	.2031
DNMG433ESE	DNMG150412N-SE	●	●		.500	.1875	.0469	.2031
DNMG431ELU	DNMG150404N-LU	●	●		.500	.1875	.0156	.2031
DNMG432ELU	DNMG150408N-LU	●	●		.500	.1875	.0313	.2031
DNMG433ELU	DNMG150412N-LU	●	●		.500	.1875	.0469	.2031
DNMG431ENK	DNMG150404N-SK		●		.500	.1875	.0156	.2031
DNMG432ENK	DNMG150408N-SK		●		.500	.1875	.0313	.2031
DNMG441ENK	DNMG150604N-SK		●		.500	.250	.0156	.2031
DNMG442ENK	DNMG150608N-SK		●		.500	.250	.0313	.2031
DNMG431ESX	DNMG150404N-SX	●	●	●	.500	.1875	.0156	.2031
DNMG432ESX	DNMG150408N-SX	●	●	●	.500	.1875	.0313	.2031
DNMG433ESX	DNMG150412N-SX	●	●	●	.500	.1875	.0469	.2031
DNMG431EUP	DNMG150404N-UP		●	●	.500	.1875	.0156	.2031
DNMG432EUP	DNMG150408N-UP		●	●	.500	.1875	.0313	.2031
DNMG433EUP	DNMG150412N-UP		●	●	.500	.1875	.0469	.2031
DNMG331EGU	DNMG110404N-GU		●	●	.375	.1875	.0156	.150
DNMG332EGU	DNMG110408N-GU		●	●	.375	.1875	.0313	.150
DNMG431EGU	DNMG150404N-GU	●	●	●	.500	.1875	.0156	.2031
DNMG432EGU	DNMG150408N-GU	●	●	●	.500	.1875	.0313	.2031
DNMG433EGU	DNMG150412N-GU	●	●	●	.500	.1875	.0469	.2031
DNMG442EGU	DNMG150608N-GU	★			.500	.250	.0313	.2031
DNMG332EUX	DNMG110408N-UX			●	.375	.125	.0313	.150

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering in Manufacturing.

Signature :
Name of supervisor :
Position :
Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotation 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.

Signature :
Name : MUHAMMAD AIMAN BIN ISHAK
ID Number :FA12016
Date :

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
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