To Design and Develop Fe-Cu-C Alloying Suitable for Self Lubricating Bearing through Powder Metallurgy (P/M) Technique

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(AP Dr Patthi Hussain)
Main Supervisor

Universiti Teknologi PETRONAS
Tronoh, Perak
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AZRUL NIZAM BIN OTHMAN

ABSTRACT

In this project, the research is aimed to design and develop oilless bush through powder metallurgy technique. Nowadays, oilless bush are widely use in variety of industries such as construction, automotive and maintenance. The powder metallurgy (PM) technique is widely used for automotive industry which is consuming around 80% of PM's world wide production. This project basically based on literature review and experimental basis where to give understanding to student about powder metallurgy (PM) and also to achieve the objectives. Several experiments will be conducted throughout this project for further understanding. Micro structural studies also will be carried out for on each experiment done and presented the result. At the end of this project, the conclusion must be made which the objectives stated achieved. The composition of the material powder in sample is 96%wt of Fe, 3%wt of Cu, 1%wt of Carbon and less than 0.75%wt of Stearic Acid used when run the project.

Powder metallurgy can be divided into four stages which are manufacture or preparation of the powders, blending or mixing the powder in desired composition, pressing the powder into desired shape in suitable die or mold at specified pressure and sintering the compacted samples in controlled atmosphere.

The laboratory work has been conducted throughout this project and the result was analyzed to get the conclusion of this project. The analysis involve is microscopic observation on the samples, density calculation and measurement of green sample and sintered sample and hardness measurement on sintered sample.

The objectives were to achieve the understanding the relation between porosity in self lubricating bearing with the pressure force in compaction.

ACKNOWLEDGEMENT

In the name of Allah, I would like to take this opportunity to acknowledge and thank everyone that has given me all the supports and guidance throughout the whole period of completing the final year project. Firstly, I must also acknowledge the endless help and support received from my supervisor, AP Dr Patthi Hussain throughout the whole period of completing the final year project. His guidance and advices are very much appreciated

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ABBREVIATIONS AND NOMENCLATURES

Cu = Copper
Fe = Ferum
C = Carbon
PM = Powder Metallurgy
Sn = Tin

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Powder metallurgy (PM) process generally can be simplified into four stages which are manufacture or preparation of the powders, blending or mixing the powders into desired proportion, pressing the powders into the desired shape in a suitable die at specified pressure and sintering the compacted components in controlled atmospheres

The advantages of the powder metallurgy technique are;

- Machining operation are almost eliminated
- Close dimensional accuracy can be maintained
- A high rate of production may be achieved by cutting down the production time
- It is possible to ensure uniformity of the composition and structure by controlled condition of working
- It has low tooling and setup cost and
- It have a variety of size which from small to large part size range

The disadvantage and limitation are;

- This technique is not economical for small scale production
- Complicated shapes are difficult to attain due to low flow ability of metal powders.

1.2 Problem Statement

1.2.1 Problem Definition

The properties of the part produced by powder metallurgy (PM) technique are strongly influenced by the properties of the powder material and the external factor such as temperature and pressure. This factor will affect the properties of the final product/part design. The study is to investigate the effect of compaction pressure on the properties of self lubricating bearing through powder metallurgy (PM) technique. The investigation will be done by design and producing the self lubricating bearing through powder metallurgy (PM) technique and conducting the laboratory testing with suitable equipment and procedure/standard.

1.2.2 Significance of the Project

The study is significant to relate and understand that certain pressure during compaction can give desired density with minimum porosity inside the bearing. The compaction pressure is the control item during this project and has been played important part throughout the laboratory work and the variation of pressure has been made during compaction process. For that reason, we need to understand the behaviour of the component with regard to that element.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The objectives of this project are as follow:

1. To design and develop self lubricating bearing through powder metallurgy (PM) technique.
2. To investigate the effect on the sample properties with regards to the variation of compaction pressure.
3. To understand and relate the relation between the compaction pressure with density and hardness of the samples.

1.3.2 Scope of Study

For this project, generally the scopes of works are;

1.3.2.1 Production of Self Lubricating Bearing

The self lubricating bearing has been produced through the powder metallurgy process for this project. No impregnation of oil process conducted because the no available equipment during run this project. The composition of material of bearing consists of 96%wt of Iron (Fe), 3%wt of Copper (Cu), 1%wt of Carbon(C) and 0.75%wt of Stearic Acid. The powder has been prepared with required composition and mixed up together in conventional ball mill for 1 hour with low speed.

Powders used is Iron with particle size less than 90 µm, Copper with particle size less 38 µm and Carbon with the particle size less 38 µm. Furthermore, the compaction pressure has been set in range of 5909 kg-f (13000lb-f) to 8000 kg-f (17000lb-f) using Hydraulic Hand Press Machine in laboratory equipped with existing mould. The temperature of sintering is ranging between 800 °C to 1150 °C in the furnace that available in the laboratory. The furnace environment for sintering is in nitrogen (N_2) gas atmosphere.

1.3.2.2 Laboratory Works/Tests

The laboratory test has been conducted once the samples being produced. The test has been focused on the properties of the samples which result from the compaction and sintering process. The results have been analyzed and study before making the conclusion and discussion.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Material Properties

Many materials are available for powder metallurgy nowadays. It all depends on their purpose and the usage of the part designed by using powder metallurgy method. The common example include pure iron, plain carbon steel, low-carbon steels, stainless steels and alloy with varying the levels of copper, nickel, carbon, molybdenum, and special alloy such as invar[1] .

Density provided another dimension to the material's specification and can be selected for the beneficial attributes in lubrication, sound attenuation, filtration, or flow restriction. It should not be ignored as part of material selection process. For the porous material, porosity, pore size filtration, or permeability become the dominant features in material selection process [1].

The majority of the structural components produced by fixed die pressing are iron based. The powders are elemental, pre-alloyed, or partially alloyed. Elemental powders, such as iron and copper, are easy to compress to relatively high densities, produce pressed compacts with adequate strength for handling during sintering, but do not produce very high strength sintered parts [2].

Pre-alloyed powders are harder, less compressible and hence require higher pressing loads to produce high density compacts. However, they are capable of producing high strength sintered materials. Pre-alloying is also used when the production of a

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[1] Randall M. German, 1998,*Powder Metallurgy of Iron and Steel* , The Pennsylvania State University, John Wiley & Son,Inc

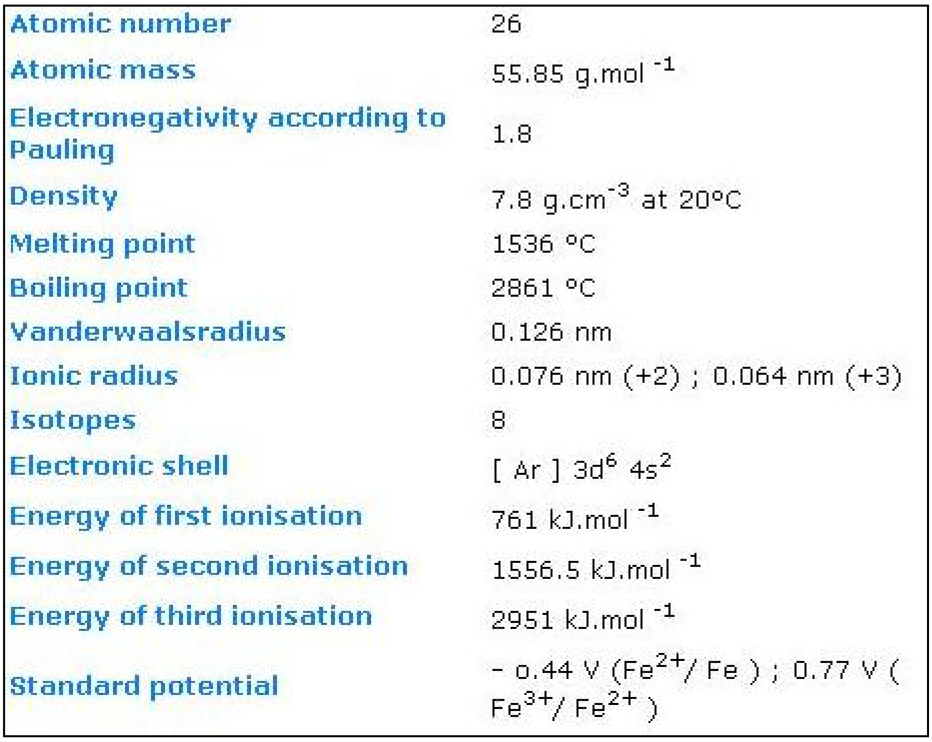
[2] F Thummler and R.Oberacker, 1998, *Introduction to Powder Metallurgy,* London, the Institute of Materials

homogeneous material from elemental powders requires very high temperatures and long sintering times. The best examples are the stainless steels, whose chromium and nickel contents have to be pre-alloyed to allow economic production by powder metallurgy [2].

2.1.1 Iron

Iron (Fe) is a lustrous, ductile, malleable, silver-gray metal. It is known to exist in four distinct crystalline forms. Iron rusts in dump air, but not in dry air. It dissolves readily in dilute acids. Iron is chemically active and forms two major series of chemical compounds, the bivalent iron (II), or ferrous, compounds and the trivalent iron (III), or ferric, compounds [3].

Iron is the most used of all the metals, including 95 % of all the metal tonnage produced worldwide. Thanks to the combination of low cost and high strength it is indispensable. Its applications go from food containers to family cars, from screwdrivers to washing machines, from cargo ships to paper staples.
Steel is the best known alloy of iron, and some of the forms that iron takes include: pig iron, cast iron, and carbon steel, and wrought iron, alloy steels, iron oxides [3].



Atomic number	26
Atomic mass	55.85 g.mol $^{-1}$
Electronegativity according to Pauling	1.8
Density	7.8 g.cm^{-3} at 20°C
Melting point	1536 °C
Boiling point	2861 °C
Vanderwaalsradius	0.126 nm
Ionic radius	0.076 nm (+2) ; 0.064 nm (+3)
Isotopes	8
Electronic shell	[Ar] 3d^6 4s^2
Energy of first ionisation	761 kJ.mol $^{-1}$
Energy of second ionisation	1556.5 kJ.mol $^{-1}$
Energy of third ionisation	2951 kJ.mol $^{-1}$
Standard potential	- 0.44 V (Fe^{2+}/ Fe) ; 0.77 V (Fe^{3+}/ Fe^{2+})

Figure 2.1: Iron (Fe) Properties [3].

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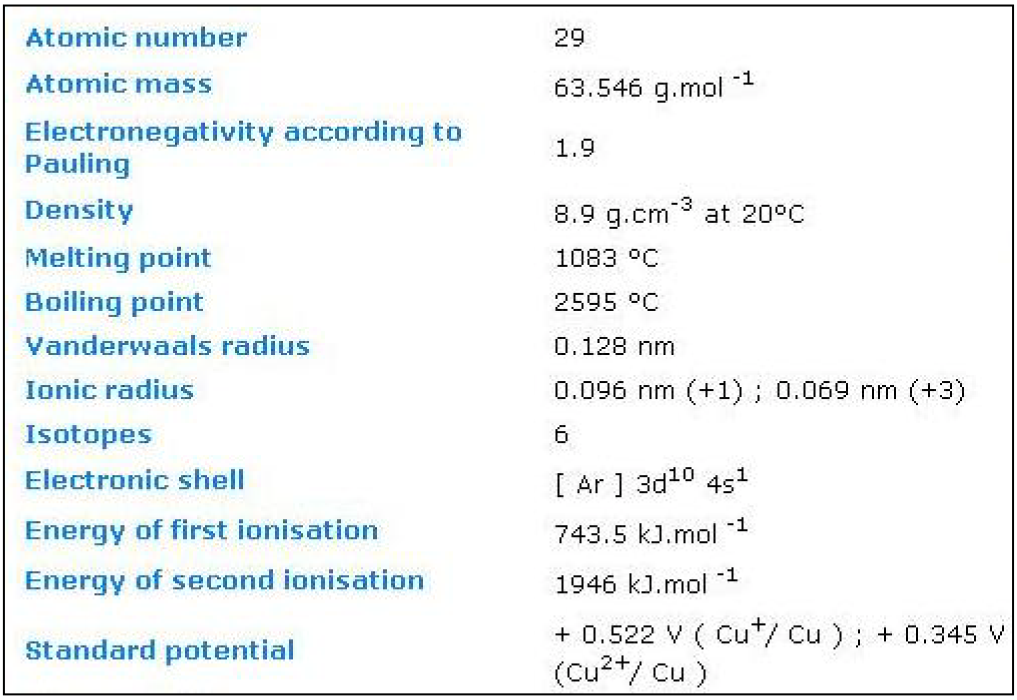
[3] http://www.lenntech.com/periodic-chart-elements/Fe-en.htm

2.1.2 Copper

Copper is a reddish metal with a face-centered cubic crystalline structure. It reflects red and orange light and absorbs other frequencies in the visible spectrum, due to its band structure, so it as a nice reddish color. It is malleable, ductile, and an extremely good conductor of both heat and electricity. It is softer than iron but harder than zinc and can be polished to a bright finish. Copper has low chemical reactivity. In moist air it slowly forms a greenish surface film called patina; this coating protects the metal from further attack [4].

Most copper is used for electrical equipment (60%); construction, such as roofing and plumbing (20%); industrial machinery, such as heat exchangers (15%) and alloys (5%). The main long established copper alloys are bronze, brass (a copper-zinc alloy), copper-tin-zinc, which was strong enough to make guns and cannons, and was known as gun metal, copper and nickel, known as cupronickel, which was the preferred metal for low-denomination coins.

Copper is ideal for electrical wiring because it is easily worked, can be drawn into fine wire and has a high electrical conductivity [4].



Atomic number	29
Atomic mass	63.546 g.mol $^{-1}$
Electronegativity according to Pauling	1.9
Density	8.9 g.cm^{-3} at 20°C
Melting point	1083 °C
Boiling point	2595 °C
Vanderwaals radius	0.128 nm
Ionic radius	0.096 nm (+1) ; 0.069 nm (+3)
Isotopes	6
Electronic shell	[Ar] $3d^{10}$ $4s^{1}$
Energy of first ionisation	743.5 kJ.mol $^{-1}$
Energy of second ionisation	1946 kJ.mol $^{-1}$
Standard potential	+ 0.522 V (Cu^{+}/ Cu) ; + 0.345 V (Cu^{2+}/ Cu)

Figure 2.2: Cupper (Cu) Properties [4].

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[4] http://www.lenntech.com/Periodic-chart-elements/Cu-en.htm

2.1.3 Carbon

Carbon is unique in its chemical properties because it forms a number of components superior than the total addition of all the other elements in combination with each other.

The biggest group of all these components is the one formed by carbon and hydrogen. We know a minimum of about 1 million organic components and this number increases rapidly every year. Although the classification is not strict, carbon forms another series of compounds considered as inorganic, in a much lower number than that of the organic compounds.

Elemental carbon exists in two well-defined allotropic crystalline forms: diamond and graphite. Other forms with little crystalline are vegetal carbon and black fume. Chemically pure carbon can be prepared by decomposition of sugar (sucrose) in absence of air. The physical and chemical properties of carbon depend on the crystalline structure of the element [5].

Its density was fluctuated between 2.25 g/cm³ (1.3 ounces/in³) for graphite and 3.51 g/cm³ (2.03 ounces/in³) for diamond. The melting point of graphite is 3500ºC (6332ºF) and the extrapolated boiling point is 4830ºC (8726ºF). Elemental carbon is an inert substance, insoluble in water, diluted acids and bases, as well as organic solvents. At high temperatures it binds with oxygen to form carbon monoxide or dioxide. With hot oxidizing agents, like nitric acid and potassium nitrate, metallic acid $C_6 (CO_2H)_6$ is obtained. Among the halogens only fluorine reacts with elemental carbon. A high number of metals combine with the element at high temperatures to form carbides [5].

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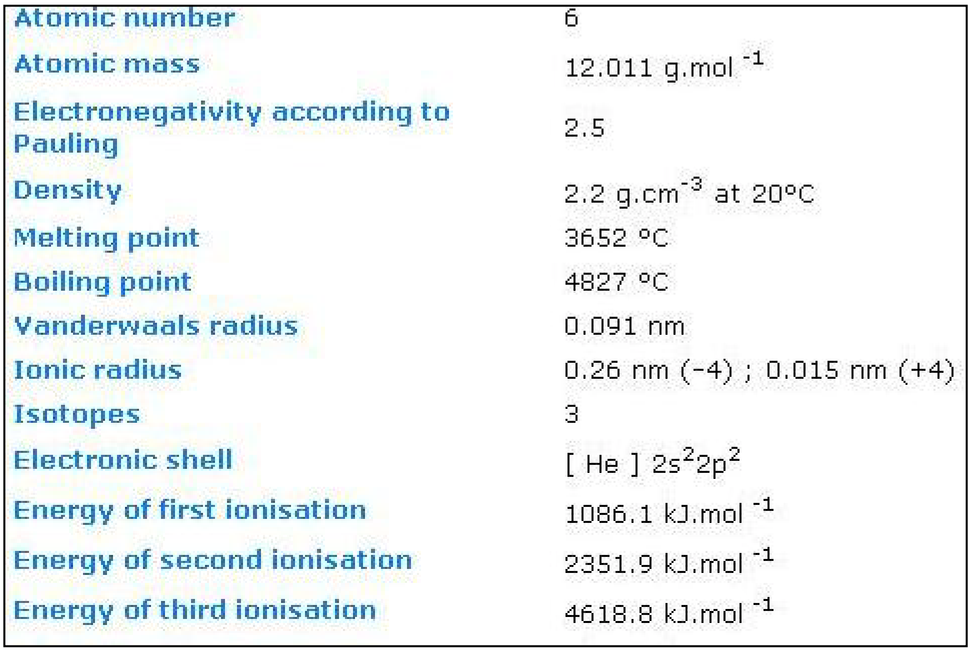
[5] http://www.lenntech.com/Periodic-chart-elements/C-en.htm



Atomic number	6
Atomic mass	12.011 g.mol $^{-1}$
Electronegativity according to Pauling	2.5
Density	2.2 g.cm^{-3} at 20°C
Melting point	3652 °C
Boiling point	4827 °C
Vanderwaals radius	0.091 nm
Ionic radius	0.26 nm (-4) ; 0.015 nm (+4)
Isotopes	3
Electronic shell	[He] $2s^2 2p^2$
Energy of first ionisation	1086.1 kJ.mol $^{-1}$
Energy of second ionisation	2351.9 kJ.mol $^{-1}$
Energy of third ionisation	4618.8 kJ.mol $^{-1}$

Figure 2.3: Carbon (C) Properties [5].

2.2 Powder Metallurgy

According to Chaman Lall, Powder Metallurgy (PM) process is distinctly different from the traditional wrought metallurgy processes because the former relies primarily on solid state diffusion, as against the fusion of molten metal species [1]. In wrought metallurgy, the raw material are generally melted at high temperature then cast into the ultimate shape or into an ingot for subsequent rolling [6].

Powder metallurgy uses sintering process for making various parts out of metal powder. The metal powder is compacted by placing in a closed metal cavity (the die) under pressure. This compacted material is placed in an oven and sintered in a controlled atmosphere at high temperatures and the metal powders coalesce and form a solid. A second pressing operation, repressing, can be done prior to sintering to improve the compaction and the material properties.

2.2.1 Powder Production

Several methods are used to commercial production of metal powder for adhesive application. These include atomization of a molten metal stream, oxide reduction, chemical decomposition, electro deposition, milling of embrittled material. Oil atomization was introduced to minimize oxidation of the powder. The pyrolysis of oil leads to residues that result in excessive carbon level. The process cannot be applied for low alloy steels due to economic reasons [2].

Water atomized powder contains excessive level of oxides which must be reduced followed by annealing step. Intermediate milling and screening steps may be necessary before re-blending and packing. Re-blending of powders of different sizes enable the optimum distribution to be achieved for compressibility and flow rate purpose.

Elemental powder or pre order alloyed powders are then mixed to achieve the composition of the desired final product.

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[6] Chaman Lall,Ph.D ,1992 , *Soft Magnetism: Fundamentals for Powder Metallurgy and Metal Injection Moulding* , New Jersey, Metal Powder Industries Federation.

2.2.2 Mixing and Blending the Powder

The purpose of mixing is to get requiring physical, mechanical and chemical properties in the parts according to the composition required. Mixing and blending the powder before compaction process is very important aspect of the main process especially when producing alloy. Accurate proportion/composition of powders is important since the ratio of the quantities will govern the properties of final products as regard both mechanical and physical properties [1].

2.2.3 Compaction/Pressing

The traditional method of compaction in rigid tooling at room temperature is the most prevalent form of consolidation for iron-based metal. A lubricant is necessary in the powder blend, to enable the pressed “green part” to be ejected from the die. Spraying the inside of the die-cavity with lubricant to permit “die-wall lubrication”, can be done but is not practiced frequently. Compaction or “molding” pressure are generally in the range of 414-828 MPa (30-60 tons per square inch), for ferrous metal.

Powder Forging (P/F) can be performed by pressing a heated pre-form with tool either at room temperature or at slightly elevated temperature. In powder forging an as-pressed component is usually heated to a forging temperature significantly below the usual sintering temperature of the material and then forged in a closed die. This produces a fully dense component with the shape of the forging die and appropriate mechanical properties. Powder forged parts generally are not as close to final size or shape as cold pressed and sintered parts. These results from the allowances made for thermal expansion effects and the need for draft angles on the forging tools. Further, minimal, machining is required but when all things are considered this route is often very cost effective [2].

High pressing pressure is required and will depend on the required density of the final product. Die compaction involves the pressurization of the powder in a rigid tool set. A conceptual of die compaction is illustrated in Figure 2.4. The selection of the punch and die material for the process is depend on the abrasives of the powder metal and the number of samples to be made.

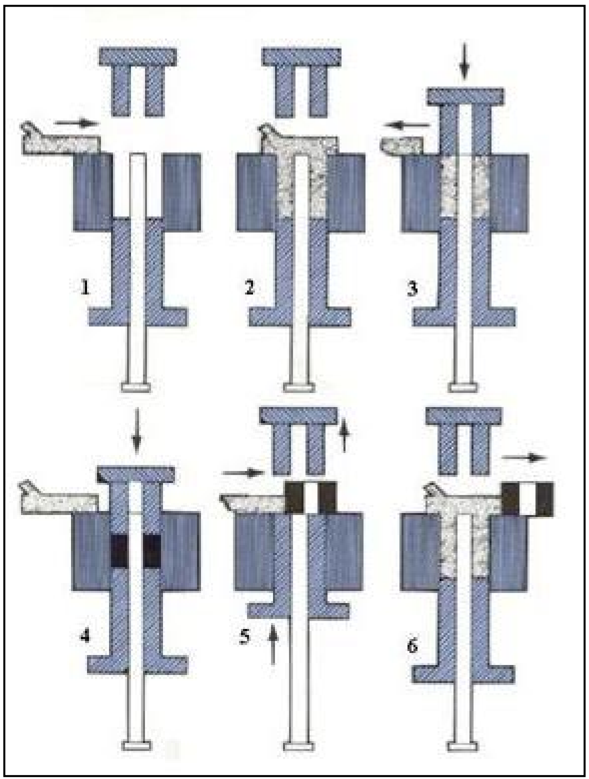

Figure 2.4: Powder Pressing Cycle [7].

2.2.4 Sintering

The process where by powder compacts are heated so that adjacent particles fuse together, thus resulting in a solid article with improved mechanical strength compared to the powder compact. This “fusing” of particles results in an increase in the density of the part and hence the process is sometimes called densification. There are some processes such as hot isostatic pressing which combine the compaction and sintering processes into a single step [2].

Sintering is the process of heating compacted component at elevated temperature, preferable below the melting point in a furnace with controlled atmospheric condition. Usually the range of temperature for sintering in the range of 60% to 90%

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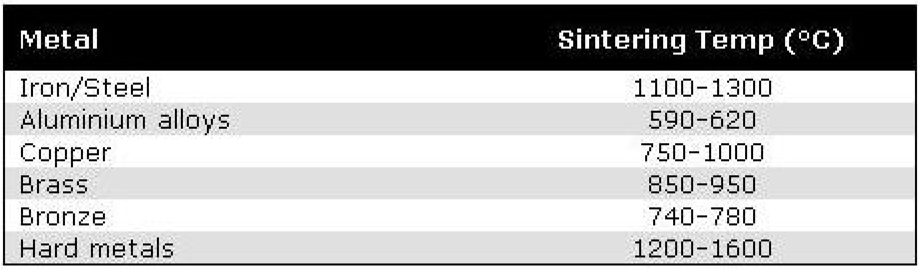
[7] http://www.turktoz.gazi.edu.tr/en_makale.htm

of the melting point of samples and the temperature in sintering furnace has been set to 1150°C.

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.

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 [1].



Metal	Sintering Temp (°C)
Iron/Steel	1100-1300
Aluminium alloys	590-620
Copper	750-1000
Brass	850-950
Bronze	740-780
Hard metals	1200-1600

Figure 2.5: Sintering Temperature for some metal [8].

Sintering is the means whereby the powder particles are welded together and a strong finished part produced. Sintering helps in bonding the individual powder particles either by melting of minor constituent, diffusion or by metallurgical reaction between the constituent to achieve structures. Atmospheric control is critical and necessarily to avoid oxidation and unneeded reaction [2].

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[8] http://www.azom.com/Details.asp?ArticleID=1727

2.2.5 Secondary Operation

Sometimes secondary operations are used to improve surface finish or make sure components fall within required tolerances. Such operations may include, drilling, grinding, repressing. Density and strength can also be increased by a secondary sintering and depressing operation. Sometimes porous metal components are deliberately produced so that they can be infiltrated with secondary materials. Further they are produced such that have interconnected pores, or capillary pores. These can be infiltrated with oil or other lower melting point metals. For this to work properly, oxide free pores are required, again requiring processing in an inert atmosphere.

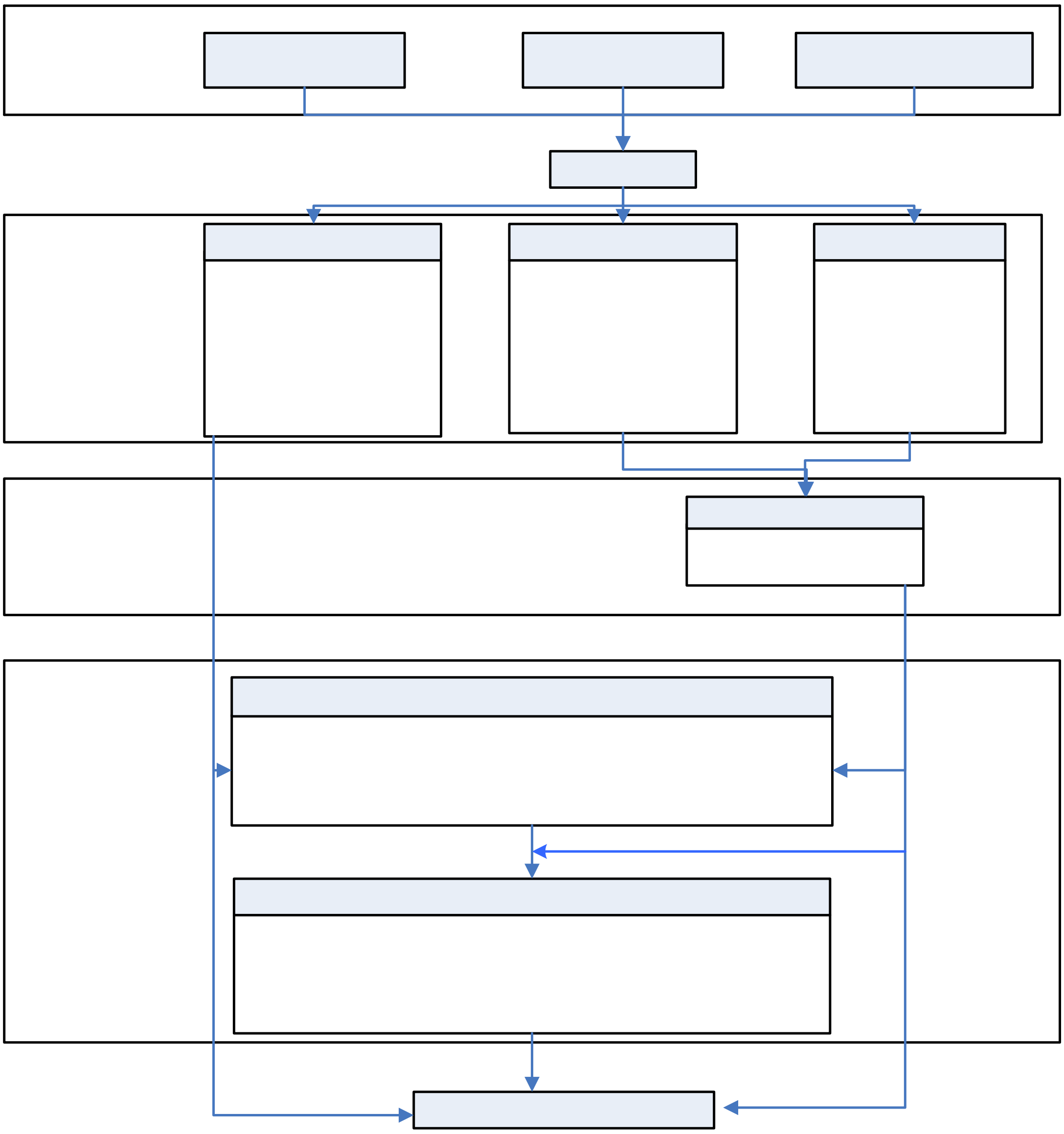

Figure 2.6: Powder Metallurgy Process [9].

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[9] http://www.mpif.org/apmi/doc2.htm

2.3 Porosity

For simple geometries, porosity is measured by determining the weight and dimension and comparing the density with theoretical value. Pores degrade the mechanical properties because of the reduced area supporting the load and the stress concentration at each pore. Ductility is also sensitive to porosity and pore shape as are most mechanical properties such as impact energy, fracture toughness, and fatigue strength [1].

The total porosity is the void part of volume related to the entire volume of any porous material. It can be subdivided in interconnect pores and closed pores. At the total porosity below about 10%, the closed pores begin to dominate. If the total porosity achieved below 5%, almost all open pores have been eliminated. Even at the high total porosity, a small proportion of the pores are often not interconnected [2].

Only the open pores and interconnected pores contributed to the flow-related properties such as filtration and permeability. Open pores allow fluid flow through the sintered structure and are most useful for self lubricating bearing, flow restrictors, gears and filters.

2.4 Hardness

Hardness is the resistance to penetration as measured by impressing a small point or ball into the surface of steel and measuring the size of the resulting imprint based on the controlled loading. Hardness test are performed more frequently than other mechanical test for several reason [10]:

1. It simple and inexpensive – no special specimen need to be prepared.
2. It is non-destructive – the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation.
3. Other mechanical properties can be estimated from hardness data.

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[10] William D Callister Jr, 2005, *Material Science and Engineering An Introduction*, New York, John Wiley & Son Inc

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW

The flow of the project is shown in the Figure 3.1. The first stage is to gather all the necessary information about the material used, equipment needed, procedure or method to be conducted and safety issue while conducting the laboratory works. The information has been picked up from various sources such as books, journal, paper works, trusted online resources and other relevant materials which related to the scope of this project.

Second stage in the project flow is the sample preparation and analysis through the project. The sample must be prepared according to required composition which containing of 96%wt Iron (Fe), 3%wt Copper (Cu), 1%wt Carbon (C). Additional of 0.75%wt Stearic Acid as the binder is required during preparation of the sample. All the powders must be well mixing in the ball mill for proper result. Then the sample went to pressing process at 5 pressure variation with constant mass of samples. The sample has been taken for density measurement. The density is recognising as green density. After density measurement done, the sample goes to sintering process with required temperature in sintering furnace. Once again, the density measurement is needed to measurement the density of sintered sample. After that, microscopic observation done using SEM machine to find some evidence to support the result. After all, the sample goes to machining process. The analysis has been done until the required result obtained.

The final stage is to compile the results and findings in report. The objective of this project must be achieved after completing the analysis and report.

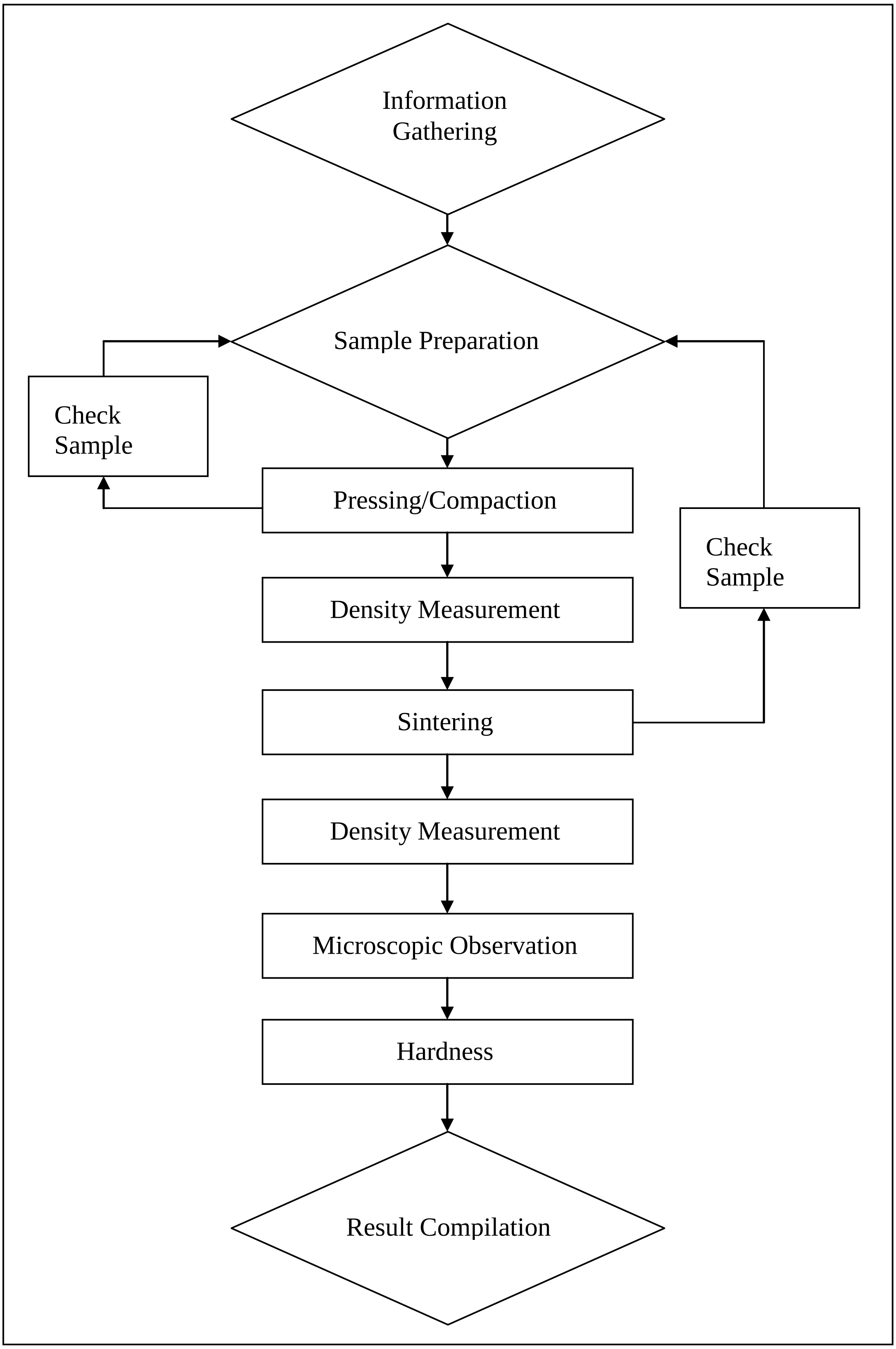

Figure 3.1: Project Flow chart

3.2 PROCEDURE IDENTIFICATION

There are several experiments conducted in the laboratory in order to achieve the objectives of this project.

3.2.1 Experiment 1: Preparation of Sample – Pressing/Compaction Process

Objective: To prepare green sample prior to sintering activity.

Equipment used: Auto Pallet Machine, mould, ball mill, weighing machine, Vanier Caliper, spatula, and beakers.

Material used: Iron (Fe), Copper (Cu) and Carbon (C) powder, and Stearic Acid powder.

Procedure:

1. The materials are prepared by weighted it’s according to desired composition which 96%wt Fe, 3%Cu, and 1%wt C.
2. Stearic acid are weighted which less than 0.75%wt of total mass of mixed sample.
3. All weighted powders are mixed using the Ball Mill mixer for 1 hour with medium speed to ensure it is properly mix.
4. After mixing, the powders take out from ball mill and put into beaker.
5. The mixed powder has been weighted 5.5 gram and places it inside the mould.
6. The powder is pressed at 5909 kg-force (13000 lb) using Auto Pallet Machine.
7. After pressed, the sample is released from mould.
8. Then the sample is measured it dimension and weight.
9. The procedure 5-8 is repeated until 3 samples produced for 1 pressing and repeated again at different load.(Refer to Table 3.1a -3.1e)

Table 3.1a: Data for pressed sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.1b: Data for pressed sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.1c: Data for pressed sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.1d: Data for pressed sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.1e: Data for pressed sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

3.2.2 Experiment 2: Density Measurement for Green Sample

Objective: To measure the apparent density of the sample

Equipment used: weighting machine and calculator

Material used: Pressed samples

Procedure:

1. Density is directly calculated from the dimension of the sample using the formula:

   $\rho = \frac{m}{v}$, where v = $(\pi/4) \times d^2 \times t$

   m = mass of the sample, g

   v = volume of sample, mm^3

   d = diameter of the sample, mm

   t = thickness of the sample, mm
2. All the data is recorded into the table provided. (Refer to Table 3.2a – 3.2e)
3. Calculation made based on the data collected and repeated for each samples.
4. The graph is plotted based on the calculation made.

Table 3.2a: Data for pressed sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density ($g\ mm^{-3}$)
1			
2			
3			

Table 3.2b: Data for pressed sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density ($g\ mm^{-3}$)
1			
2			
3			

Table 3.2c: Data for pressed sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density ($g\ mm^{-3}$)
1			
2			
3			

Table 3.2d: Data for pressed sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density ($g\ mm^{-3}$)
1			
2			
3			

Table 3.2e: Data for pressed sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density ($g\ mm^{-3}$)
1			
2			
3			

3.2.3 Experiment 3: Preparation of Sample – Sintering Process

Objective: To help in bonding the individual powder particles by introducing heat

Equipment used: “Carbolite” furnace

Material used: Pressed samples, and Nitrogen gas (N_2)

Procedure:

1. The pressed samples are placed inside the furnace.
2. The furnace temperature is set to the desired temperature and Nitrogen gas (N_2) supplied into furnace.
3. The samples are sintered at the required temperature for 180 minutes and cooling down to room temperature in the furnace for 470 minutes.
4. After completing the sintering process, the samples take out from furnace.
5. Sample has been weighted and measured it dimension. All the data recorded into table. (Refer to Table 3.3a – 3.5e)

Table 3.3a: Data for sintered sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.3b: Data for sintered sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.3c: Data for sintered sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.3d: Data for sintered sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

Table 3.3e: Data for sintered sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1			
2			
3			

3.2.4 Experiment 4: Density Measurement for Sintered Sample

Objective: To measure the density of the sintered sample

Equipment used: Weighting machine and calculator

Material used: Sintered samples

Procedure:

1. Density is directly calculated from the dimension of the sample using the formula:

$$\rho = \frac{m}{v}, \text{ where } v = (\pi/4) \times d^2 \times t \qquad (3\text{-}1)$$

m = mass of the sample, g

v = volume of sample, mm^3

d = diameter of the sample, mm

t = thickness of the sample, mm

2. All the data is recorded into the table provided. (refer to Table 3.4a – 3.4e)
3. Calculation made based on the data collected and repeated for each samples.
4. The graph is plotted based on the calculation made.

Table 3.4a: Data for sintered sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (g mm^{-3})
1			
2			
3			

Table 3.4b: Data for sintered sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (g mm^{-3})
1			
2			
3			

Table 3.4c: Data for sintered sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (g mm^{-3})
1			
2			
3			

Table 3.4d: Data for sintered sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (g mm^{-3})
1			
2			
3			

Table 3.4e: Data for sintered sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (g mm^{-3})
1			
2			
3			

3.2.5 Experiment 5: Microscopic Observation on the Sintered Samples

Objective: To observe the inter-particle bonding result in the samples

Equipment used: Scanning Electron Microscope

Material used: Sintered samples.

Procedure:

1. 5 samples from each pressure placed on the specimen holder.
2. SEM and all related equipments are switched on.
3. Sample is put inside the SEM.
4. Sample is scanned at appropriate magnification.
5. The observation image is recorded for analysis.

3.2.6 Experiment 6: Hardness Measurement

Objective: To measure the hardness of the sintered samples.

Equipment used: Hardness testing machine.

Material used: Sintered sample.

Procedure:

1. Sample is prepared from sintered samples.
2. Testing machine has been set for HRB scale and the load is 100 kg.
3. Sample is place under the indenter.
4. The indenter is bringing down to the specimen and the measurement is started.
5. Take 5 points of measurement from each sample and repeated it for all samples.
6. All the reading is recorded into the table.

Table 3.5a: Data for sintered sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1					
2					
3					

Table 3.5b: Data for sintered sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1					
2					
3					

Table 3.5c: Data for sintered sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1					
2					
3					

Table 3.5d: Data for sintered sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1					
2					
3					

Table 3.5e: Data for sintered sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1					
2					
3					

3.3 TOOL REQUIRED

3.3.1 Material used

- Iron Powder
- Copper Powder
- Carbon Powder
- Stearic Acid
- Nitrogen gas

3.3.2 Precaution for Material Handling, Storage, Use and Safety

3.3.2.1 Metal Powder

Iron (Fe)

Physical Appearance: grey crystalline powder, rod or chips
Melting point: 1535 °C
Boiling point: 3000° C
Stability: Stable. Reacts slowly with moist air and water. Dust may form an explosive or combustible mixture with air. Incompatible with organic acids, strong oxidizing agents, water, mineral acids.
Toxicology: Dust may be harmful if inhaled.
Personal protection: Avoid breathing dust or powder.

Copper (Cu)

Physical Appearance: reddish lustrous malleable metal
Melting point: 1083°C
Boiling point: 2595 °C
Stability: Stable. Incompatible with strong acids, active halogen compounds, chlorine, fluorine, iodine, bromine, ammonia. May react explosively with strong oxidizing agents.

Toxicology: Dust may cause respiratory irritation. Highly flammable. Irritating to eyes, respiratory system and skin.
Personal protection: Avoid breathing dust or powder. Suitable ventilation if handling powders. Wear safety glasses if required

Carbon

Physical Appearance: finely divided black dust or powder
Melting point:
Boiling point: 4200 °C
Stability: Stable. Combustible.
Toxicology: IARC evaluation: possible human carcinogen (Group 2B). May be harmful by ingestion or inhalation. Respiratory irritant. Typical STEL 7 mg/m3.
Note: Carbon black is generally made under controlled conditions, and has a high carbon content. By contrast, soot usually contains additional complex organic molecules, some of which may be carcinogenic. Thus, industrial and domestic soot may be presumed to present a greater risk to human health than commercially-produced carbon black.
Personal protection: Avoid breathing dust or powder. Suitable ventilation if handling powders. Wear safety glasses if required

Stearic Acid

Effect of Exposure:
Target organ: lungs, mucous membrane. Very dangerous in case of ingestion. Slighty dangerous in case of skin contact. This product may irritates eyes and skin upon contact.

First aid:
Eyes: flush with plenty of water for at least 15 minutes.
Skin: wash with soap and plenty of water while removing contamined.
Inhalation: remove to fresh air.
Ingestion: drink several glass of water or milk.

Precaution: Do not breathe dust. Avoid any contact with skin and eyes. Wear proper protective equipment.

3.3.3 Laboratory Equipment

1. Set of die
2. Pressing equipments – auto pallet machine
3. Sintering furnace
4. Other equipments: weighting machine, Vanier calliper, beakers, SEM, and related devices/machines.

3.3.4 Software Used

1. Microsoft Office
2. LEO SRV-32

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*Refer to [11]http://msds.chem.ox.ac.uk/

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Experiment 1: Preparation of Sample – Pressing/Compaction Process

Results of the production of green sample are presented in the table below. The green samples were pressed using Auto Pallet Machine.

Table 4.1a: Data for sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.37	13.1	7.00
2	5.75	13.1	7.36
3	5.45	13.1	7.00

Table 4.1b: Data for sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.52	13.1	7.10
2	5.46	13.1	7
3	5.47	13.1	6.98

Table 4.1c: Data for sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.46	13.1	6.86
2	5.51	13.1	6.88
3	5.67	13.1	6.88

Table 4.1d: Data for sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.48	13.1	6.86
2	5.46	13.1	6.88
3	5.47	13.1	6.88

Table 4.1e: Data for sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.44	13.1	6.70
2	5.42	13.1	6.68
3	5.45	13.1	6.68

4.1.2 Experiment 2: Density Measurement for Green Sample

Results of the density measurement on green sample are presented in the table below. Density is calculated using mathematical equation. (Refer equation 3-1)

Table 4.2a: Data for sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.37	943.854	5.69
2	5.75	992.396	5.79
3	5.45	943.854	5.77

Table 4.2b: Data for sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.52	957.338	5.76
2	5.46	943.854	5.78
3	5.47	941.158	5.81

Table 4.2c: Data for sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.46	927.674	5.88
2	5.51	943.854	5.84
3	5.67	965.428	5.87

Table 4.2d: Data for sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.48	924.977	5.92
2	5.46	927.674	5.91
3	5.47	927.674	5.9

Table 4.2e: Data for sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.44	903.404	6.02
2	5.42	900.707	6.02
3	5.45	900.707	6.05

4.1.3 Experiment 3: Preparation of Sample – Sintering Process

Results of the production of sintered sample are presented in the table below. The sintered samples are taken out from Carbolite Furnace.

Table 4.3a: Data for sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.657	12.66	7.10
2	5.35	12.6	6.84
3	5.28	12.6	6.82

Table 4.3b: Data for sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.431	12.6	6.96
2	5.390	12.72	6.74
3	5.376	12.7	6.84

Table 4.3c: Data for sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.376	12.68	6.62
2	5.069	12.66	6.22
3	5.586	12.6	6.86

Table 4.3d: Data for sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.394	12.66	6.64
2	5.388	12.72	6.68
3	5.390	12.66	6.68

Table 4.3e: Data for sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Diameter(mm)	Thickness(mm)
1	5.367	12.74	6.42
2	5.362	12.76	6.5
3	5.346	12.76	6.50

4.1.4 Experiment 4: Density Measurement for Sintered Sample

Results of the density measurement on sintered sample are presented in the table below. Density is calculated using mathematical equation. (Refer equation 3-1)

Table 4.4a: Data for sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.657	894.1088	6.33
2	5.35	853.2215	6.27
3	5.28	850.7267	6.21

Table 4.4b: Data for sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.431	868.1903	6.26
2	5.390	856.838	6.29
3	5.376	866.8185	6.20

Table 4.4c: Data for sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.376	836.2981	6.43
2	5.069	783.289	6.47
3	5.586	855.7163	6.53

Table 4.4d: Data for sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.394	836.1807	6.45
2	5.388	849.2104	6.34
3	5.390	841.2179	6.41

Table 4.4e: Data for sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Sample	Mass(g)	Volume(mm^3)	Density (10^{-3} g/mm^3)
1	5.367	818.7259	6.56
2	5.362	831.5327	6.45
3	5.346	831.5327	6.43

4.2.5 Experiment 5: Microscopic Observation on the Sintered Samples

Results of the microscopic observation on the sintered sample were illustrated in the figure below. The sample were examine using Scanning Electron Machine (SEM)

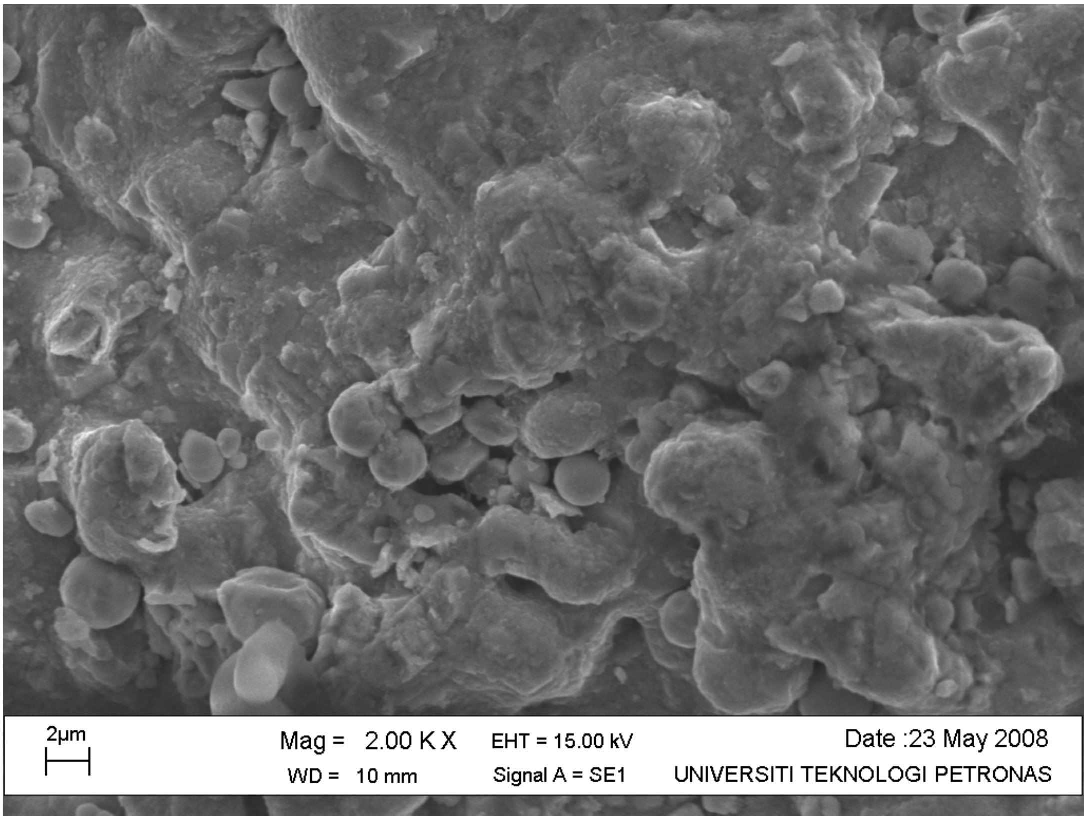

Figure 4.1: Microscopic view on the sinter sample of 15000 lb pressure compaction.

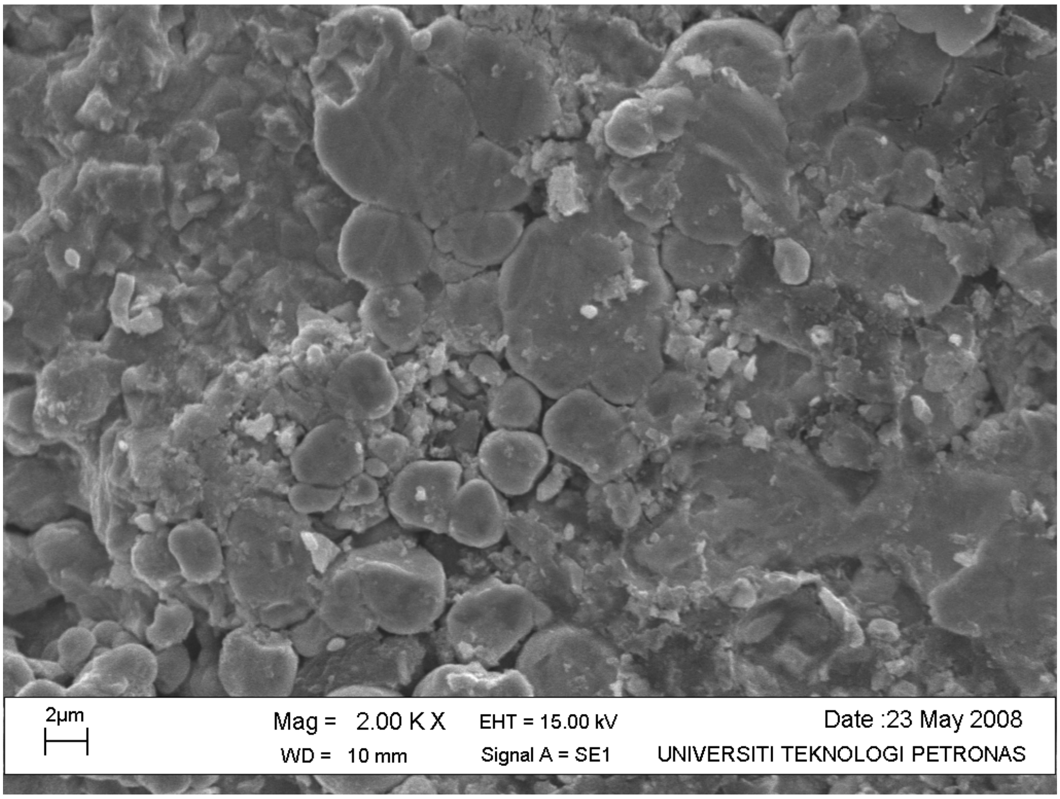

Figure 4.2: Microscopic view on the sinter sample of 16000 lb pressure compaction.

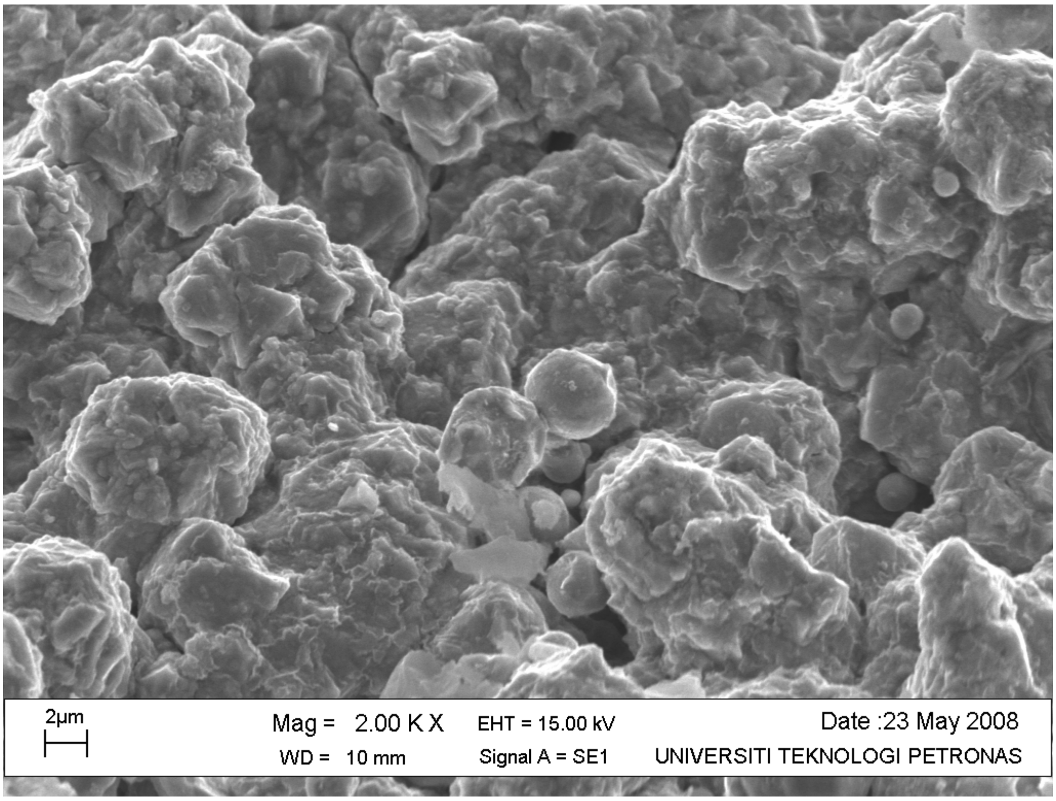

Figure 4.3: Microscopic view on the sinter sample of 17000 lb pressure compaction.

4.2.6 Experiment 6: Hardness Measurement

Results of the hardness measurement test on the sintered sample are presented in the table below. The hardness test conducted using Rockwell B with HRB scale and load is 100 kg. Hardness test conducted using universal hardness machine in the laboratory.

Table 4.5a: Data for sample at 13000 lb

Load 5909.09 kg – f (13000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1	78.2	80.5	81.8	81.1	73.7
2	77.9	76.0	82.2	82.4	81.6
3	76.1	79.4	76.0	79.9	78.3

Table 4.5b: Data for sample at 14000 lb

Load 6363.63 kg – f (14000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1	78.7	78.5	78.6	77.9	78.2
2	73.8	81.1	76.6	84.1	81.5
3	76.8	77.2	75.4	77.5	77.0

Table 4.5c: Data for sample at 15000 lb

Load 6818.18 kg – f (15000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1	79.2	77.7	79.4	79.3	80.4
2	79.4	76.8	75.2	79.8	77.5
3	78.7	77.5	78.8	77.1	79.7

Table 4.5d: Data for sample at 16000 lb

Load 7272.72 kg – f (16000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1	89.8	90.4	91.6	89.2	88.9
2	86.6	87.8	88.1	88.9	87.8
3	83.7	88.2	84.4	83.3	83.7

Table 4.5e: Data for sample at 17000 lb

Load 7727.27 kg – f (17000 lb – f)

Samples	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
1	89.5	93.2	92.1	90.8	94.8
2	78.3	82.0	82.4	80.2	80.8
3	89.5	90.2	91.6	90.0	90.6

4.2 Discussion

4.2.1 Density Measurement

Apparent density of the sample can be divided into two; green density and sintered density. Green density referred to the apparent density prior of the sample prior to sintering process, in other word, it is the density of the pressed sample. The sintered density is referred to the density of the sample after sintering process. The density for both samples is calculated using mathematical equation. (Refer equation 3-1)
All data needed for the calculation must be measured and recorded such as mass (g), diameter (mm), thickness (mm) and volume (mm^3). From the data obtain in pressing and sintering process, the graph has been plotted in order to show the trend of the density.

Figure 4.1 has shown the different of the volume (mm^3) of the samples between green samples and sintered samples. The green samples show has higher volume compared to sintered sample at the same pressing load. The reason behind this scenario is the particle deformation. When the powder is compressed, the particle is slide past one another, deform, bond and harden. The greater the compaction pressure, the harder the particle become thereby resisting further densification.

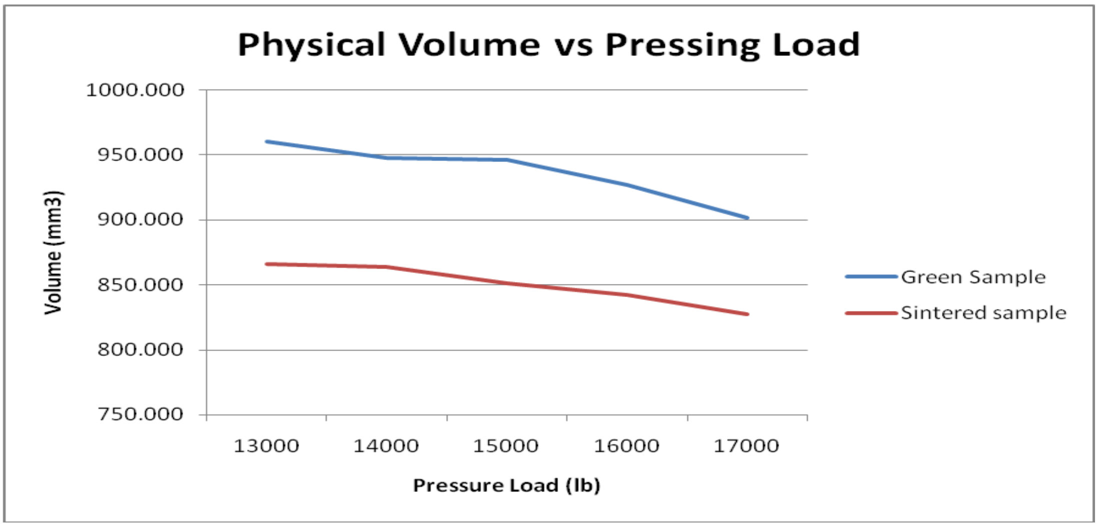

Figure 4.4: Physical volume of green and sintered sample vs. Pressure load

Compaction initially deforms the particle at their contacting point randomly. Densification during the compaction has changes in particle arrangement and shape. Higher compacted volume usually results in better green strength properties. The volume of sintered sample decreases and has a dimensional change due the shrinkage during the sintering process.

The graph above also shown, the dimensional change is negative and it indicated the shrinkage has occurred during sintering process. The dimensional change is nearly negative 10% from green sample.

Figure 4.2 show the comparison between the green density and sintered density. The samples have been sintered in the Nitrogen gas (N_2) environment.

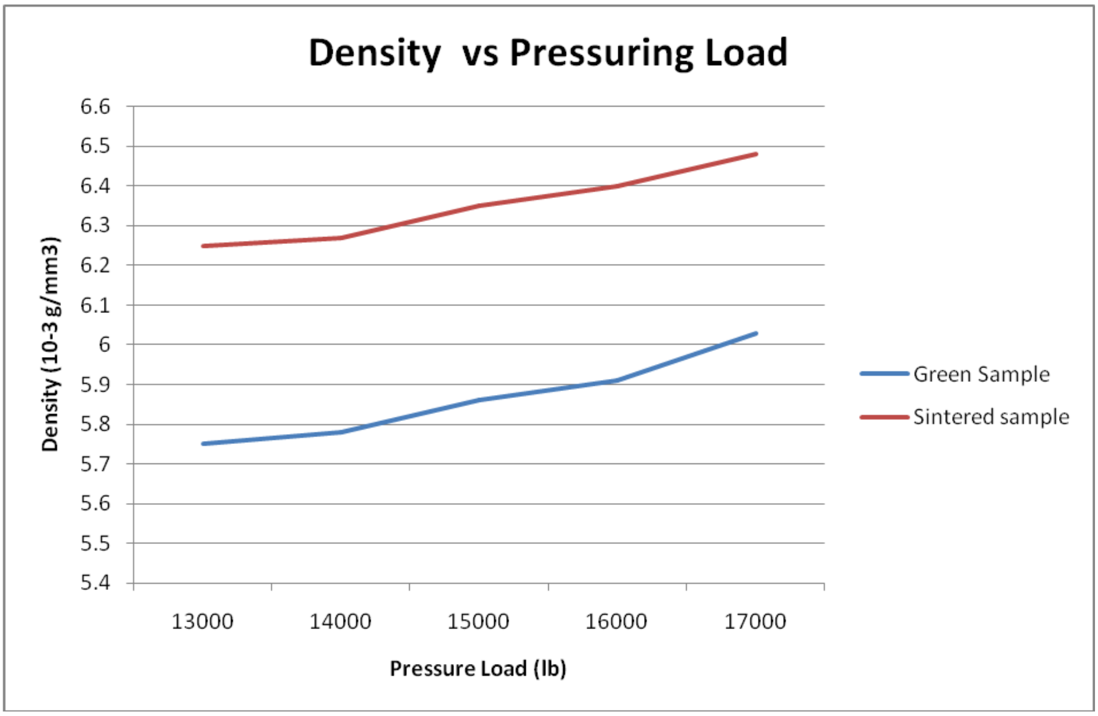

Figure 4.5: The graph of density for green and sintered sample

The graph shows the sintered samples have higher density compare to green sample. The reason behind this finding is on the sintering process. There are factors involving in sintering process which is sintering stress and atomic motion. Since the stress is weak, the atomic motion is dominant factor in sintering. For iron particle, the rate of atomic motion is very low at room temperature. As the iron is heated, atomic motion is increases dramatically. Temperature controls the rate of atomic motion and the higher temperature give more rapid sintering.

A reduction in both surface area and sintering stress occurs by growing bond between contacting bond. Two important distinctions is mass transport related to the source of the atom that forms the bonds. In surface transport, the atom comes from the pore surface meanwhile in bulk transport, the atom originates from the interior of the particles. Surface transports do not give the dimensional changes but the bulk transport produces shrinkage. The actual mechanisms include atom skipping over the pore surface, passing along the grain boundaries and even evaporating across the pores.

The sinter bond between contacting particle is the critical region. It is the point where atoms are deposited to improve the compact strength. Neck growth occurs faster at higher temperature. While both surface and bulk transport processes promote neck growth, the main difference is in shrinkage during sintering. Associated with shrinkage is an increase in density and alternatively if the compact swell then the density is decrease.

Bulk transport mechanism gives densification. They include volume diffusion, grain boundary diffusion, plastic flow and viscous flow. Grain boundary diffusion is important for densification for most steel. Surface transport processes of surface diffusion and evaporation. For iron, surface diffusion is the most important transport process at low temperature. The compact strengthening occurs in the early portion of sintering without densification or dimensional change.

Because atoms move faster at the high temperature, sintering is greatly improved by use of temperature higher than 1120°C (2050°F). But, the warpage is occurs because there is more bulk transport sintering and more dimensional change.

4.2.2 Sintering Cycle

The sintering furnace provides supervision to the time – temperature – atmosphere combination responsible for proper sintering. In the sintering furnace, the compact was heated to a peak temperature for a few minutes to allow heat to uniformly soak throughout the load. The first event during heating was the extraction of the binder and lubricant. This is accomplished at temperature below 550°C (1022°F). After that, the samples are heated to a high temperature that induces atomic motion and sinter bonding typically in the range of 1100 – 1350°C.

It is near the peak temperature in the sintering cycle that most of the particle bonding occurs. Although some time at the peak temperature is beneficial to ensure complete heating of the samples, extended time prove detrimental. Over – sintering refer to the situation in which a powder particles exhibits a loss of properties.

The sintering cycle plays a role in dimension change because of bonding, pore rounding, and pore coarsening and grain growth. Higher sintering temperature gives more shrinkage and the longer time would also increase shrinkage.

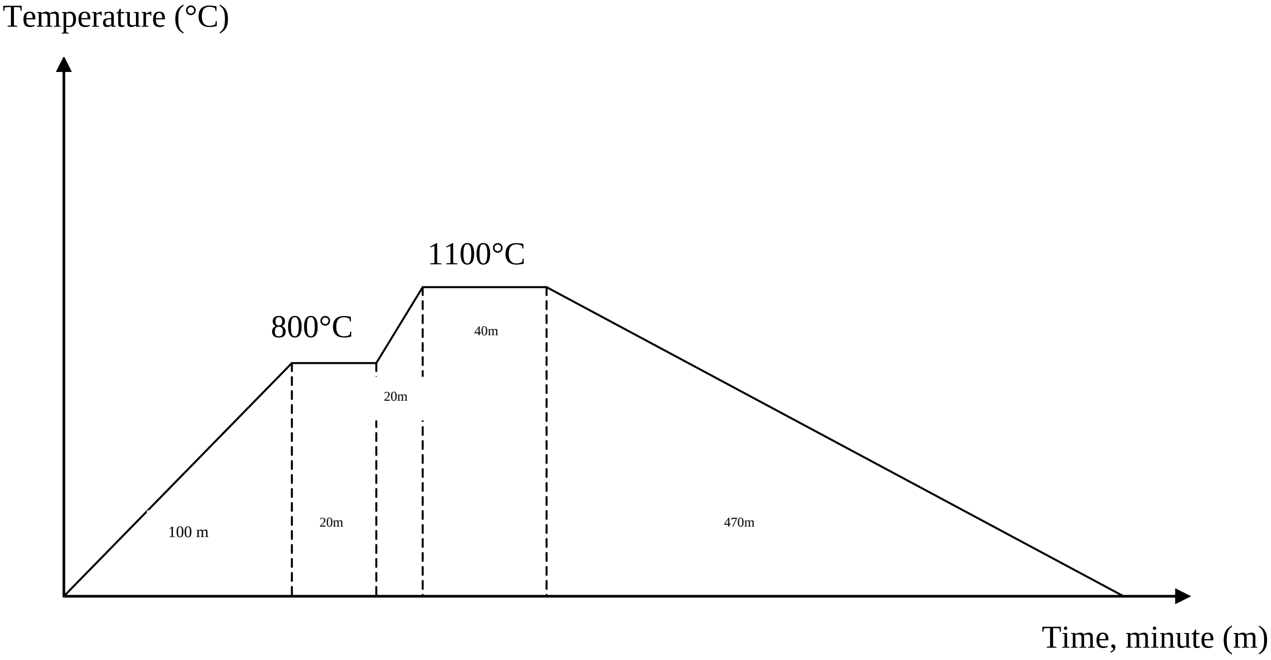

Figure 4.6: Sintering Cycle in Nitrogen gas (N_2) atmosphere

4.2.3 Hardness

For hardness test, macro hardness testing is applied. The indenter used is Rockwell B indenter. The load applied is 100 kg – force. The load is applied on the sample for about 10 second and then smoothly removed. The result of the test is summarizing in Figure 4.5.

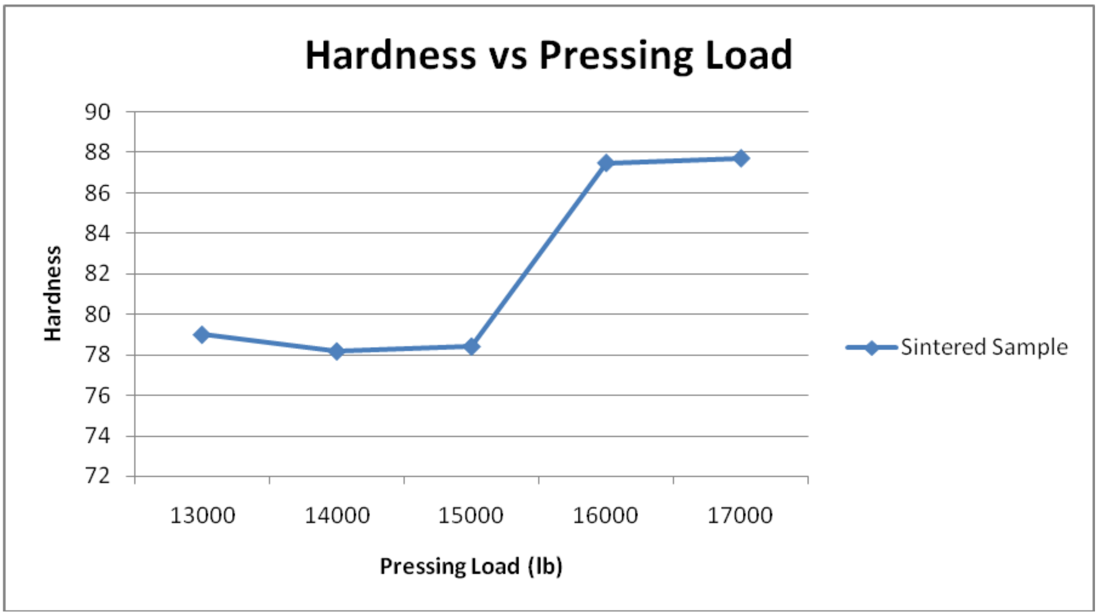

Figure 4.7: Hardness of sintered sample using Rockwell B

Hardness is probably the most important measure of successful heat treatment. For a desired carbon level, a narrow range of mechanical properties will be associated with hardness. As cooling rate from the austenitization temperature increases and more martensite form, the hardness climbs.

Sinter hardening is a concept where heat treatment is incorporated in the cooling cycle of the sintering furnace. The usual goal is to cool quickly to avoid the formation or pearlite and to generate a mixture of bainite and martensite, giving good strength. The critical cooling rate for sinter hardening is usually between 1°C and 8°C/s over the temperature range from 850 to 250°C.

In the graph, the samples have shown good strength with the range of hardness in between 78 to 88 HRB which closed standard material hardness. Carbon has given the sample more strength and help with some heat treatment from sintering cycle.

4.2.4 Porosity

The porosity of the sample was found by the differentiation in theoretical density to apparent density for both samples which green sample and sintered sample. Theoretical density is calculated by using the rules of mixture and is known as full density. For a good bearing, the value of porosity contained should be around 10 ~ 25% porosity. The porosity of the sample is showed in the Figure 4.5.

The total porosity is the void part of volume related to the entire volume of any porous material. It can be subdivided in interconnect pores and closed pores. At the total porosity below about 10%, the closed pores begin to dominate. If the total porosity achieved below 5%, almost all open pores have been eliminated. Even at the high total porosity, a small proportion of the pores are often not interconnected.

Only the open pores and interconnected pores contributed to the flow-related properties such as filtration and permeability. Open pores allow fluid flow through the sintered structure and are most useful for self lubricating bearing, flow restrictors, gears and filters.

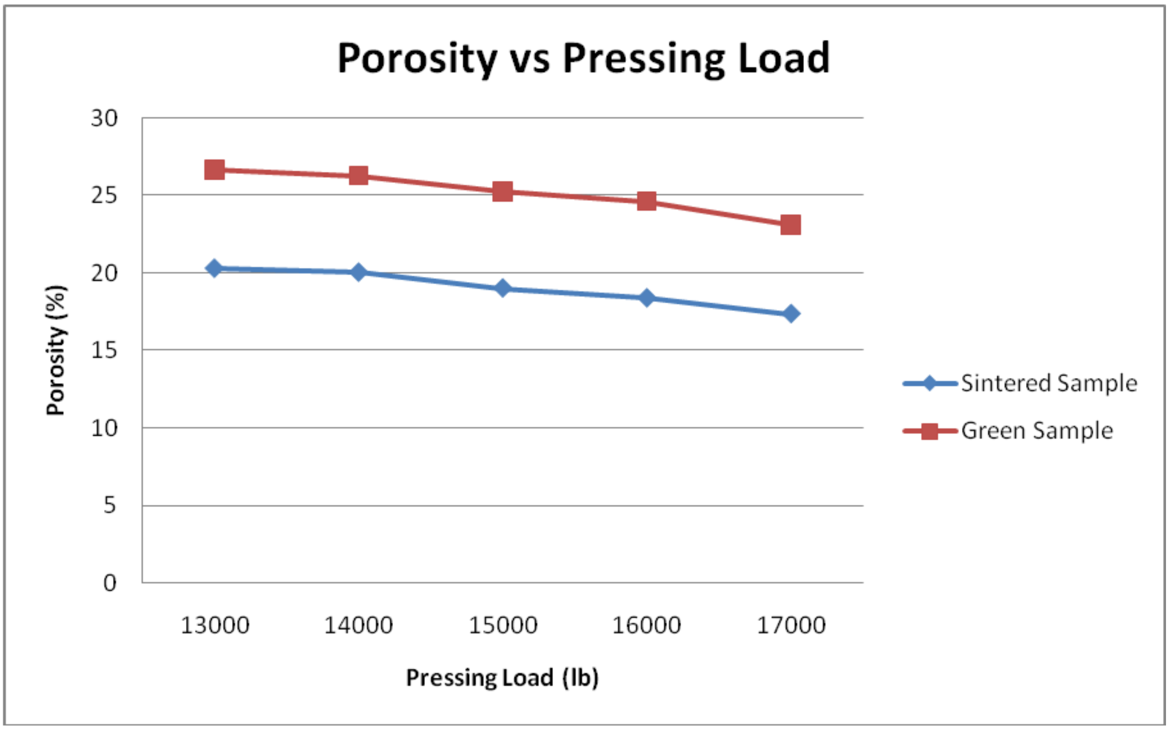

Figure 4.8: Porosity of sample

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project is to produce Fe-Cu-C suitable material for the self lubricating bearing using powder metallurgy technique. The project achieves its objectives as author manages to develop the component through powder metallurgy technique. Furthermore, several analyses have been done in order to understand the properties of the component which result from powder metallurgy technique. There are two main factors has been given influence in this project: pressing load and the sintering temperature. The green and sintered density of the samples is directly proportional to the pressing load. As the pressing load increase, more interlocking or contact will form and made the samples more compact which less volume at the same mass. It has increased the density of the samples. During the sintering cycle, the powder particle are welded together with help some heat treatment. Increasing the numbers of welded particle, it will reduce the porosity hence increase the density of the sample. When the sintering temperature increased, there will be more atoms diffuse on to each other hence increase the bonding area. This also result in decreasing of porosity and increase in density. The hardness of the sample also related to the numbers of inter-particle bonding. Sinter – hardening also give some influence to the sample hardness during the sintering cycle.

As the conclusion of this project, the sample which has 20% porosity is good for self lubricating bearing and the 13000 lb pressure during the compaction process was a suitable parameter to produce self lubricating bearing. The conclusion was made from the result obtained and analyses made for further understanding.

5.2 Recommendation

The project is to design and develop self lubricating bearing through powder metallurgy technique. Some recommendation can be considered for further improvement in result of this project. If extended effort is put into this project, the better result and understanding can be achieved.

5.2.1 Use the appropriate furnace for sintering

The appropriate furnace is important part on powder metallurgy process. The good furnace should capable of heating up the sample to 1300°C and the furnace atmosphere can be controlled using external gas supplied to it. Existing furnace only capable in handling the maximum temperature to 1200°C and the only furnace atmosphere is Nitrogen gas (N_2). The alternative furnace with suitable furnace atmosphere should be considered.

5.2.2 Availability of the equipment and powder material

In the laboratory, there should be variation of powder material supplied. The basic idea in this project is to run the experiment with some different material composition which consist Tin (Sn) powder for bronze bearing. Due to limited range of material, the scope of this project is not widening. The equipment in the laboratory in limited which student must booking/queue to use the certain equipments such as beakers, spatulas, machine, and other devices. The department should do something to avoid any problem in Final Year Project with provide a good service to students involved and university.

CHAPTER 6

REFERENCES

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APPENDICES

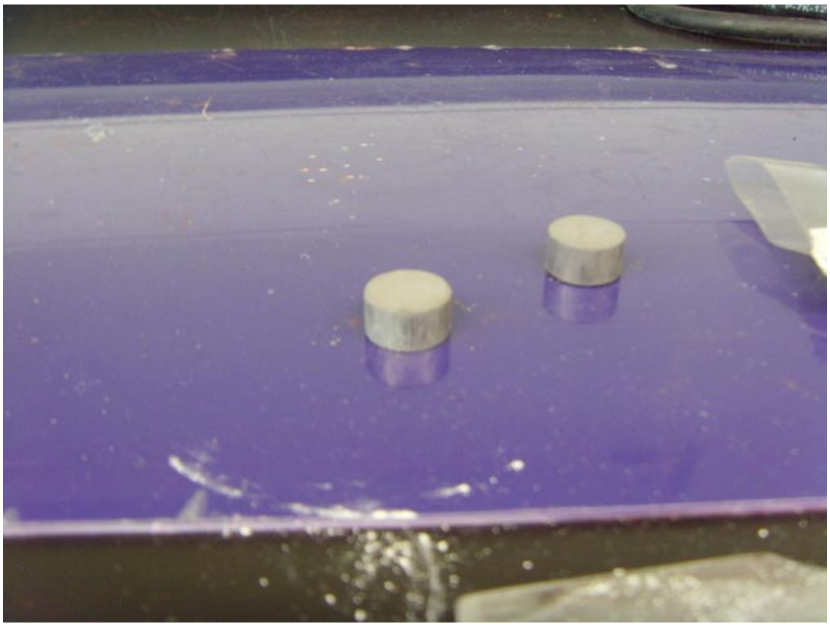
Appendix : Photographs of the Equipment during the Experiment

Ball Milling equipment during mixing process.

Weighting Device used.

The mould that used through this project.

The pressing machine used during conducted compaction process.



Samples after compaction.

Sintering Furnace