Investigating the Effects of Addition of Different Copper Amount in Fe-Cu-C by Powder Metallurgy

by

Muhammad Ahnaf bin Mohd Nasir

16413

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical)

JANUARY 2016

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Investigating the Effects of Addition of Different Copper Amount in Fe-Cu-C by Powder Metallurgy

by

Muhammad Ahnaf bin Mohd Nasir
16413

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL)

Approved by,

_____

(Dr. Mazli Mustapha)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2016

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.

_____

MUHAMMAD AHNAF BIN MOHD NASIR

ACKNOWLEDGEMENT

First and foremost, I would like to thank God for His blessing, that this project is completed. Next, I would like to express my highest gratitude towards my supervisor, Dr Mazli Mustapha for his utmost guidance and encouragement throughout FYP1 and FYP2 periods. Not to forget, my gratitude also goes to the lab technicians and staff for their assistance. Their help and knowledge has aided me to complete this project with better understanding and helped me through all the lab experiments. My thanks and appreciations also go to Universiti Teknologi PETRONAS for me being able to complete this final year project successfully. This final year project has given me a great amount of knowledge and experience in working on a research project.

ABSTRACT

Powder metallurgy is one of the most used method to produce metal products for its high machinability and low cost. Fe-Cu-C is one of the most used alloys out there. In the system, Cu is added to enhance the properties of Fe. However, Cu addition cause swelling during liquid phase sintering. Fortunately, the addition of C into the system reduces the swelling. This paper studies the effect of copper to the system, Fe-Cu-C prepared by powder metallurgy, with different amount of copper wt%. The scope of study includes microstructure, physical, and mechanical properties of the system with different copper amount i.e. 5%, 10%, 15%, 20% copper wt%.

Keywords: Fe-Cu-C; Powder Metallurgy; Microstructure; Densification; Wear; Hardness

TABLE OF CONTENT

List of Figures

Figure 19: Scratch result of 5% copper with progressive force.

List of Tables

CHAPTER 1

INTRODUCTION

Powder metallurgy (PM) method in utilizing powdered metals is a large industry. This is due to its simplicity, low cost, high machinability and ease of application. This technique of producing alloys have been widely used from decades until now ranging from construction materials to kitchen appliances. Fe-Cu-C which is one of the most commonly used alloy is produced using powder metallurgy method. One of the reason is that Fe-Cu-C which includes liquid phase sintering by copper which promotes the sintering of the iron matrix and strengthen its overall properties.

1.1 Background Study

Press and sinter method was abundantly and one of the first method used in PM. Press and sinter includes the process includes compacting of base raw material powders into die cavity of desired shapes. This will produce green body which will be sent to furnace. There, it will be sintered to fuse the particles together. Alloys are mostly made by this method as it does not require large amount of energy and labour. It also produces material with near-net-shape, thus reducing the number of machining to produce components. Copper and Carbon is added to iron to produce one ot the most widely used system in the industry, both contributing to the betterment of the system. Copper itself is a good additive to iron for it promotes and enhances the properties of the system. Considering that addition of carbon into the system reduces swelling and enhances the properties of the system, carbon is considered as an outstanding additive to the system Fe-Cu.

1.2 Problem Statement

Fe-Cu-C is widely used in the industry because of its exemplary properties. Based on Narasimhan et al.(2007), the addition of copper has some adverse side effects on the sintering of iron alloy in terms of the densification of alloy and the growth that associated with it. However, with the addition of carbon, the swelling can be reduced. Thus, making the system favourable to be utilised. With that being said, the effect of copper to the system is to be investigated in pursuance of better understanding of how the addition of copper affects the system. Thus, this study investigates the effect of copper to the system by varying the composition of the system of its copper content.

1.3 Objectives

1. Investigate the effects of different amount of copper addition to the ternary system of Fe-Cu-C with regards to its microstructure, physical, and mechanical properties.
2. To propose the best composition of Fe-Cu-C system with the copper composition ranging from 5% to 20% of weight percentage.

1.4 Scope of Study

This study will present the investigation of Fe-Cu-C of different copper composition. Different copper content will result in different properties of Fe-Cu-C. The aspects that will be covered in this study is the microstructure, physical and mechanical properties of the ternary system of Fe-Cu-C. Fe-Cu-C samples will be produced by press and sinter powder metallurgy which involves liquid phase sintering. Four samples were produced with different composition. The samples contain 5%, 10%, 15%, and 20% weight percentage of copper respectively. Microstructure of the samples will be investigated using optical microscopy and

scanning electron microscope. Physical properties will be investigated by the difference of dimension and density of the samples before and after sintering. Wear test and hardness test will be done to determine the mechanical properties of the samples.

CHAPTER 2

LITERATURE REVIEW

2.1 Fe-Cu-C System

For press and sinter metallurgy method of alloying, Fe-Cu-C hybrid alloy is one of the most commonly used. The inclusion of copper were among the earliest inclusion into the sintering of steel to promote sintered steels' strength. Aside from that, graphite inclusions to Fe-Cu sintered steels are also desirable. This is because of the promotion of pearlitic microstructure done by the carbon as well as giving supplementary hardness and strength to the sintered steel. Nonetheless, this alloy is in some way inconvenient due to its inherent dimensional variability. However, varying the technique of copper addition to the alloy will influence the dimensional stability of this alloy, Marucci et al (2010).

2.2 Powder Metallurgy Method

"The material processing technology to engineer brand-new materials and parts by using various metal powders as raw components through a process called sintering.", Tsutsui, (2012). Jonalagadda (2012) points out that powder metallurgy is a gighly developed technique for ferrous and non-ferrous parts production with a positive credibility. Continuing, an average powder metallurgy process is firstly the mixing of raw ingredients in the form of powder which are then compacted into a die. The said product is then will be heated in a furnace using appropriate parameters, which is also called the sintering process. The final product has many advantages, e.g. it retains the shape of compacted materials, called green body, and generates strength whilst in the process of sintering. Also, the parts produced can be further administrated to following heat treatment, if desired, for better mechanical properties.

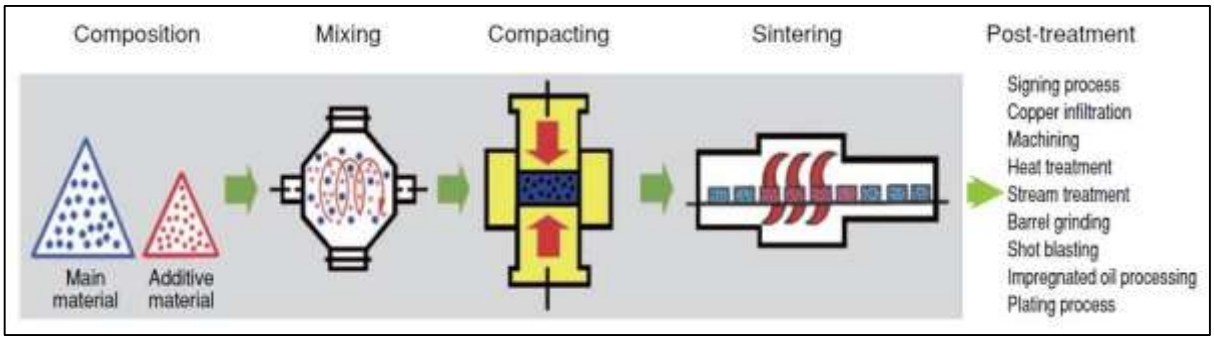

Figure 1: Fundamental process of powder metallurgy Tsutsui, (2012).

The usage of powder metallurgy products are diversely large, ranging from structural components, automotive parts, to home appliances. The rapid growth of powder metallurgy is mainly due to its noticeable mechanical advantages, practicality and its cost-effectiveness. The figure below shows how powder metallurgy technique compares to other methods in regards of usage and the energy requirement per kg of finished part. Clearly shown that the technique said earlier requires less energy per kg of finished part and is the most favourable way utilizing raw material.

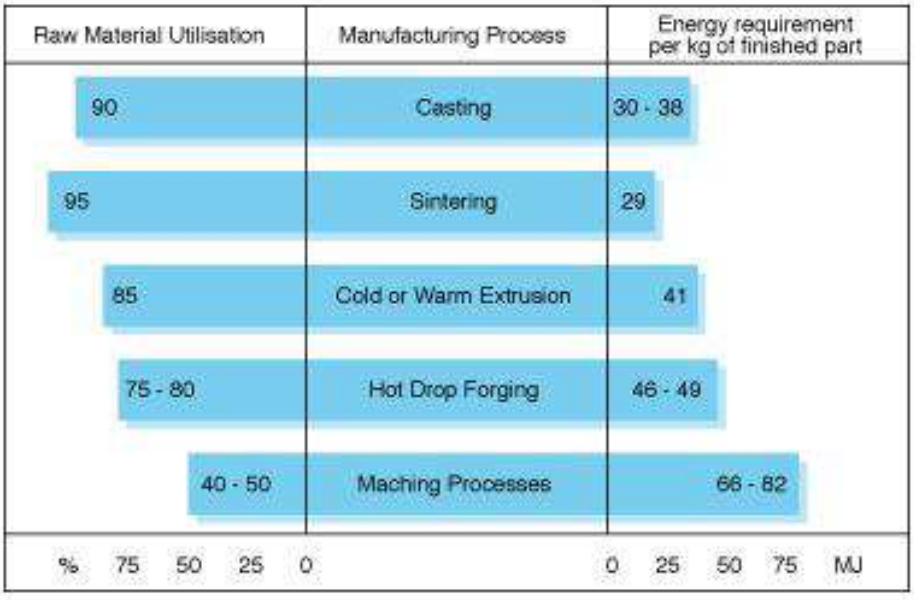

Figure 2: Raw metal utilization and energy requirements of various manufacturing process.

2.3 Liquid Phase Sintering

Based on the writing of Narashiman K.S. et al (2007), the usual parameters for sintering Fe-Cu-C alloy are in the range of 1100 to 1300^{o}C while the melting temperature of copper is at 1084^{o}C. With that being said, in the process of sintering, its behaviour will be different than that of a normal sintering with the existence of liquid phase. Generally speaking, the existence of liquid phase in sintering could cause some serious side effects. Nonetheless, the effects may vary from a beneficial effects to totally hindering effects, depending on some several factors, mainly their volume fraction, their properties of surface tension and their relative solubility. For the case of Fe-Cu-C sintering, two of the main factors are non favourable, which are the surface tension and the relative solubility. Additionally, the behaviour of copper and the presence of liquid further effect the sintering product of Fe-Cu-C adversely. However, according to Narashiman K.S. et al (2007), the volume fraction of the liquid of 2% copper into the system is fairly low and the effects are in the reasonable range though it is generally negative. Apart from that, liquid phase of copper's ability to dissolve and carry the solid phase and also penetrate the interparticle boundaries of it decides the effects of the liquid phase sintering. With all that being said, the presence of carbon into the system greatly helps in reducing the swelling causes by copper while further strengthening the properties of the Fe-Cu-C system.

CHAPTER 3

METHODOLOGY

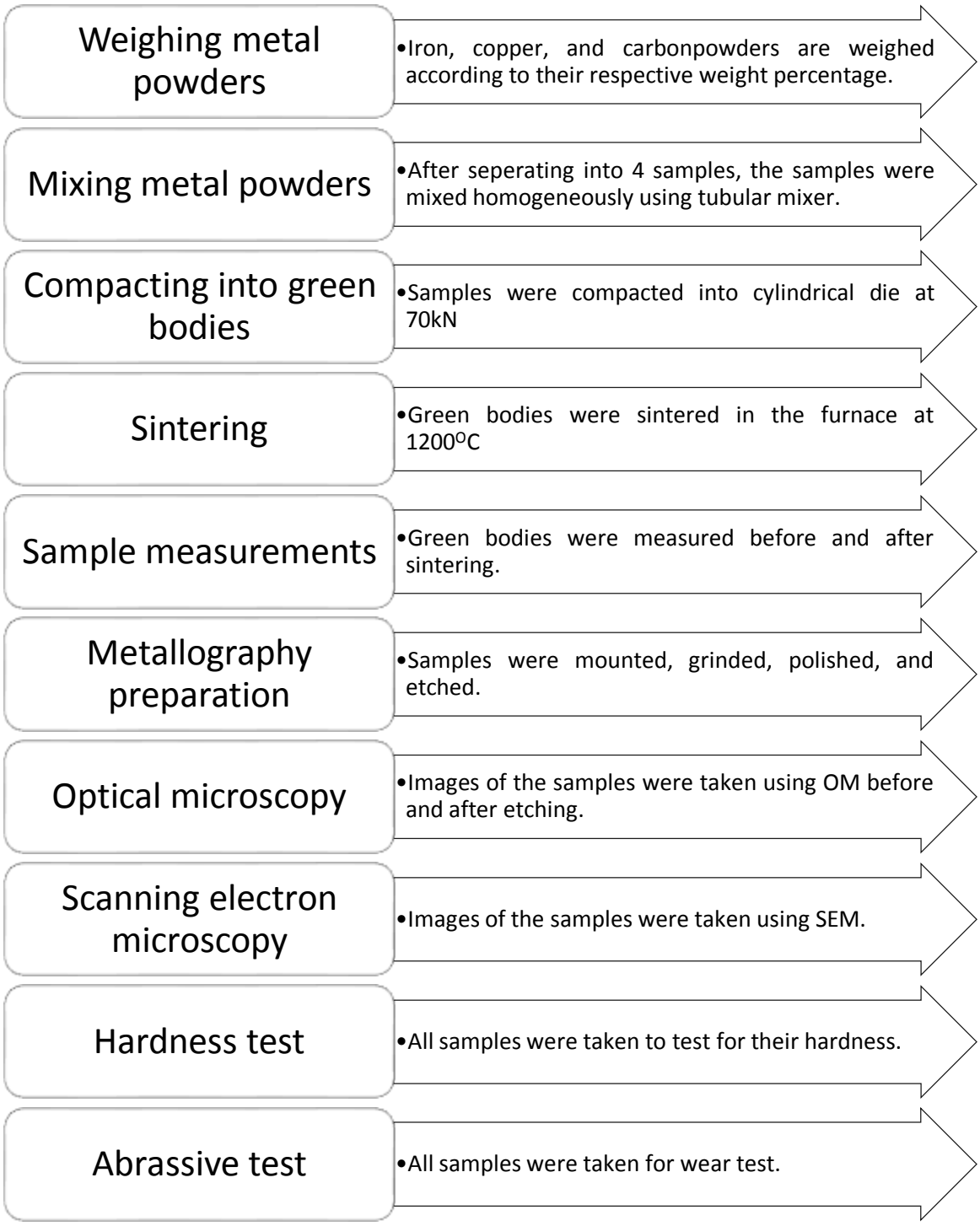

Figure 3: Flow chart of project.

3.1 Sample Production

3.1.1 Raw materials

Three main materials were used for this system. They are iron, copper, and carbon. All raw materials are in the form of powder. Zinc stearate was also used as lubricant to be mixed with the raw materials.

The pure iron powder that was used for this experiment was obtained from the laboratory. The powders were supplied from Merck KGaA, Darmstadt, Germany. The average size of the particle is 10μm. The color of the iron powder was grey and irregular spherical in shape. The iron powder melts at 1535˚C. Because of its resource availability and high mechanical properties iron is commonly used in manufacturing industries. Iron was made favourable for most manufacturing industries because of the alloying ability of iron with carbon to produce greater mechanical properties. Iron can be form to steel and cast iron depending on the weight percentage of carbon. The amount of the iron powder for each sample were dependent of the amount of copper.

The pure copper powder used was also obtained from the laboratory which was supplied from Merck KGaA, Darmstadt, Germany. The average size of the particle is 63μm. The color of the copper powder was brown and flake in shape. The iron powder melts at 1083˚C. Copper is added to enhance the mechanical properties of iron. In this study, the amount of copper will be varied in each sample i.e. 5%, 10%, 15% and 20% weight percentage.

The carbon powder that was used also were available in the laboratory and were supplied from Merck KGaA, Darmstadt, Germany. The average size of carbon particle was not specified and its shape was irregular. Carbon has no melting point at atmospheric pressure. It has been found that carbon can be an excellent additive to Fe-Cu considering it reduces swelling and improves the properties of the alloy. The weight percentage of carbon that was used for this study is only 1% for all.

Lubricant was used in order to produce Fe-Cu-C by means of powder metallurgy. In this study, the lubricant used was zinc stearate. Prior to compacting,

lubricant can be either mixed with the base materials or applied onto the walls of compacting die. Lubricant acts as a binder to hold the green body after compacting. The lubricant will be burnt during sintering, leaving only the base materials as the product.

3.1.2 Weighing

The amount of raw materials needed was first calculated. The samples were to be made of 5g each, therefore calculations were done accordingly. The weight of each powder for each samples are shown in the table below. Mettler Toledo precision balance was used to carry out the measurement of the weight of each powder. This equipment can measure as precise as 1mg.

Table 1: Composition of Fe-Cu-C matrix samples.

Sample	**Weight percentage (wt %)**			**Mass (g)**		
	Iron	**Copper**	**Carbon**	**Iron**	**Copper**	**Carbon**
1	94	5	1	4.70	0.25	0.05
2	89	10	1	4.45	0.50	0.05
3	84	15	1	4.20	0.75	0.05
4	79	20	1	3.95	1.00	0.05

3.1.3 Mixing

All samples were brought to a tubular mixer after weighing. There, powders were mixed homogeneously for a few minutes. The powders will be put into a container and the container will be shaken at different angles. This will uniformly and homogeneously mix the powders. This process is paramount as the sample needs to be distributed uniformly so that the concentration of the powders will be consistent throughout the sample.

3.1.4 Compacting

Compacting comes next in powder metallurgical method in producing materials. Raw materials were filled inside a die cavity where the first densification occurs. The cylindrical die was made of high carbon steel. The diameter of the die used was 12mm. Uniaxial compression was applied to the powder in a single action compacting technique. The upper part of the die were applied pressure and pushed inwards while the lower part of the die remains stationary to achieve uniaxial pressure. In prior, the walls of the die were applied with lubricant as to facilitate the compaction and ejection of the green body. It was also done to protect the die wall from any damage done in the process. The pressure applied to all of the samples were 70kN.

3.1.5 Sintering

After compacting, all the green bodies were sent to tube furnace to be sintered. All samples were put on ceramic crucible. The ceramic was placed in the middle of the furnace for an even heat transfer. After the furnace was closed, air was purged out by purging in nitrogen and hydrogen gases, 95% and 5% respectively into the heating chamber. Then, the temperature was increase at the rate of 10^{o}C/min. The temperature was increased at the same rate until 800^{o}C where the temperature was put to still for 10 minutes. The temperature was then increased at the same rate until the temperature of 1200^{o}C was reached. At that time, the sintering process was continued for another 60 minutes for the materials to be completely sintered. Lastly, the furnace was let to cool down to room temperature before the samples were taken out.

3.1.6 Measuring

Linear and mass measurement were done to the samples before and after sintering. Samples were measured of their diameter and height, and that would give the volume of the samples. The mass of each samples were also measured. By those data, the density can be calculated. Thus, further calculation of densification and shrinkage can be done.

$$Volume, v = \pi d^2/4$$

$$Density, \rho = m/v$$

$$Shrinkage = \frac{v_o - v_f}{v_o} \times 100$$

$$Densification = \frac{\rho_o - \rho_f}{\rho_o} \times 100$$

Where; d is the diameter of the sample

m is the mass of the sample

v_o is the volume of the sample before sintering

v_f is the volume of the sample after sintering

ρ_o is the density of the sample before sintering

ρ_f is the density of the sample after sintering

3.2 Metallography

3.2.1 Preparation

Before conducting metallography, the samples were prepared. There are a few steps in the preparation of samples for metallography. In this study, the steps taken were as follows:

I. Mounting
II. Grinding

III. Polishing

IV. Etching

3.2.1.1 Mounting

Mounting was done to ease the process of metallography and its preparation as the mounting will provide a flat surface to be used i.e. grinding, polishing, OM, SEM. Automatic Mounting Press (SIMPLIMET 1000) was used to hot mount the samples. The mounting were made of phenolic resin with cylindrical shape mold which has a diameter of 30mm.

Before hot mounting, samples were cleaned off from any debris, oil, and grease. This was done by washing the samples with distilled water and ethanol. Then, the samples were dried. Cleaning was also done to the mounting machine. The surfaces of the cylindrical die was cleaned and was coated with release agent right after.

The ram was raised out of the machine and each sample was put in the middle of the ram. The ram was then lowered to the lowest level and was filled with phenolic powder as the molding compound for a few teaspoons. After that, the cylinder was closed and tightened. The mounting process was set for 15 minutes and at 150^{o}C and 4000 psi.

3.2.1.2 Grinding

Subsequently, mounted samples were taken for grinding. The equipment that was used for grinding was Grinder and Polisher machine model Metaserv 2000. The surface of the samples were grinded manually using SiC paper with running water. The water will act as cooling agent during the grinding process

Once the sample has been mounted, the surface of the samples must be grinded to produce flat surface. Grinding process was performed by using Grinder and Polisher

machine model Metaserv 2000. Coarse SiC paper was used at the first grind to get an even surface. Then, the grit size of SiC paper was increased up to 1200 grits to eliminate any scratches done by using course SiC paper.

SiC paper used ranging from the coarsest grit paper, 200 grits to 1200 grits to eliminate the scratches from the previous grinding stage otherwise they will not be removed in polishing.

3.2.1.3 Polishing

The same equipment for grinding was also used for polishing, which is the Grinder and Polisher machine model Metaserv 2000. It has two rotating disc. Both of which can be used for grinding but only one of them can be used for polishing. This is because a ferromagnetic disc can be positioned onto it with a soft cloth attached. 6 micron diamond paste was applied to the sample before polishing. Samples were polished until the samples can produce mirror-like image.

3.2.1.4 Etching

The samples were first cleaned off by using distilled water and ethanol. 3% nital was used to etch Fe-Cu-C. The nital was prepared using 100ml ethanol and 10ml nitric acid. The etching process was done under a fume hood all the time. Gloves were worn for safety reasons. A small amount of etchant was applied to the tip of a cotton bud. The tip of the cotton bud was then used to wipe the surface of the samples for a few seconds. All the samples were dried after the etching process.

3.2.2 Optical Microscopy (OM)

All samples were observed under a microscope prior of etching and after etching was done. The photomicrograph for each samples were taken at 10x, 50x, and 100x magnification. The photomicrographs of all samples were then analysed.

3.2.3 Scanning Electron Microscopy (SEM)

Scanning electron microscope was used to analyse the surface of all the samples. As the samples were mounted, the process of SEM analysis is easier as it was easier to place the samples. The analysis was done one by one. The images of the samples were taken at 500x, 1000x, 1500x, 3000x, and 5000x magnification. Spot analysis was also done at different part in order to determine the composition of the area.

3.3 Hardness Testing

Hardness testing was done to find out the mechanical properties of the samples. Rockwell type B was performed. In this test, a 1/16" steel ball was employed with the load of 100kg onto the samples. For each sample, testing was done three times to get an average value. The results were then analysed. The test was done according to ASME E-18 standard. Theoretical tensile strength can also be determined by using a brinnel hardness and tensile strength relation equation as follows.

$$Tensile\ Strength\ (MPA) = 3.45 \times HB$$

Where; HB is the Brinnel hardness value.

3.4 Wear Testing

Wear testing was done by doing scratch test to the samples. The surface of the sample was scratched by a moving diamond stylus. The scratching was done along a path with either constant force or progressive force on a constant speed. The standard test method used for scratch testing is ASTM G171-03.

3.5 Gantt Chart

Table 2: Gantt Chart.

Project Attribute	FYP 1														FYP 2													
	Week																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature review																												
Procurement of raw metals																												
Mixing powder samples																												
Compacting powder samples																												
Sintering green samples																												
Measurement & data collection											▲																	
Metallography Preparation																												
Optical Microscope																												
Scanning Electron Microscope																												
Hardness test																												
Wear test																												
Data analysis																							▲				▲	

▲ = key milestone;

1) Densification and shrinkage calculated
2) Microstructure analysed
3) Mechanical properties investigated

CHAPTER 4

RESULTS & DISCUSSION

4.1 Physical Properties

The results of linear and mass measurement before and after sintering are as follows.

Table 3: Measurements of green samples.

Copper (%)	Diameter (mm)	Height (mm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
5	12	6.409	0.725	5	6.897
10	12	6.377	0.721	5	6.935
15	12	6.340	0.717	5	6.974
20	12	6.304	0.713	5	7.013

Table 4: Measurements of sintered samples.

Copper (%)	Diameter (mm)	Height (mm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
5	11.79	6.380	0.697	5	7.174
10	11.83	6.274	0.690	5	7.246
15	11.86	6.187	0.684	5	7.310
20	11.90	6.102	0.679	5	7.364

Table 5: Shrinkage & Densification.

Copper (%)	Initial Volume (cm^3)	Final Volume (cm^3)	Shrinkage (%)	Initial Density (g/cm^3)	Final Density (g/cm^3)	Densification (%)
5	0.725	0.697	3.861	6.897	7.174	4.02
10	0.721	0.690	4.300	6.935	7.246	4.49
15	0.717	0.684	4.603	6.974	7.310	4.83
20	0.708	0.679	4.769	7.013	7.364	5.01

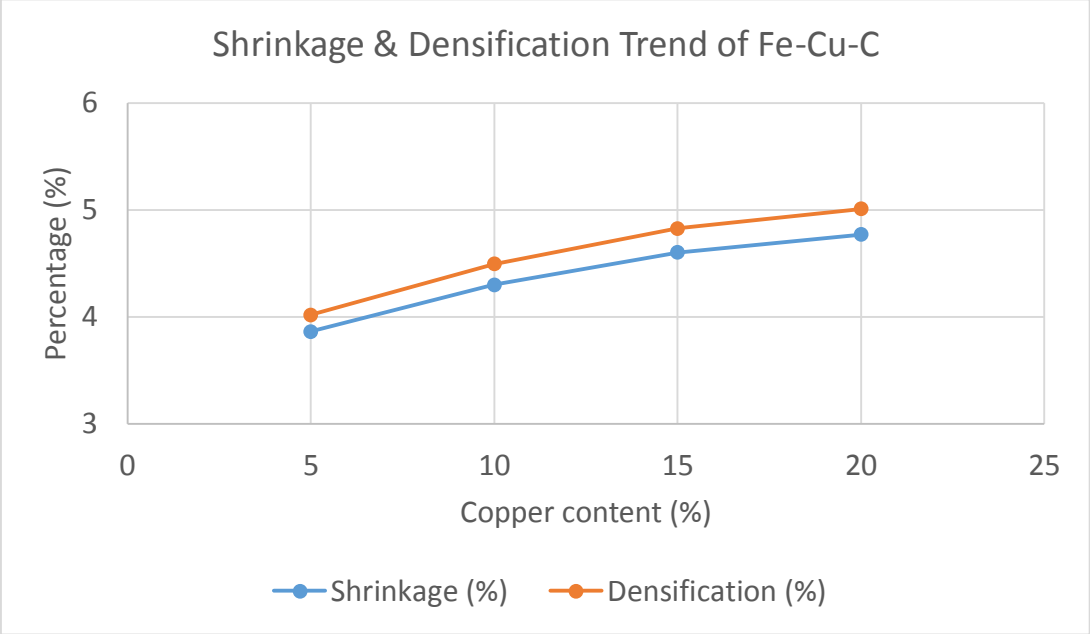

Figure 4: Chart of shrinkage and densification of all Fe-Cu-C samples.

The measurements of all samples were taken after compacting and also after sintering. The parameters of the measurements taken were diameter, height, and mass. Table 3 shows the results of the measurements after compacting. Their volumes and densities were also calculated. Table 4 shows the exact parameters of the samples after sintering has occurred. In table 5, comparison of the parameters of the samples before and after sintering was made.

From the chart above, it is clearly shown that by increasing the copper content in the system, the shrinkage of the samples after sintering also increases. Densification also occurred with the same trend. This happened because the green body experiences liquid phase sintering. The sintering temperature of Fe-Cu-C in this study was at 1200^{o}C, which is higher than the melting point of copper. This causes copper to melt and occupies the interparticle boundaries of copper. Therefore, the cvolume of the sintered products will be lower, causing the increase in the density.

4.2 Microstructure

4.2.1 Optical Microscope

4.2.1.1 Before etching

For the photomicrograph of the samples before etching, magnification of 10x produced the clearest image for analysis.

Figure 5: 10x magnification OM image of 5% copper before etch.

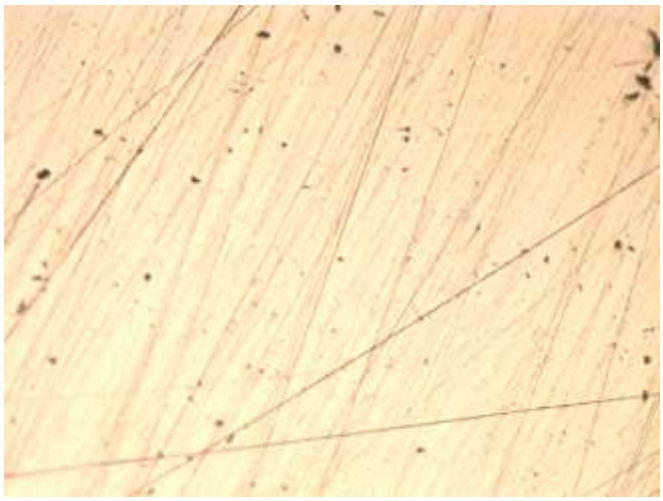

Figure 6: 10x magnification OM image of 10% copper before etch.

Figure 7: 10x magnification OM image of 15% copper before etch.

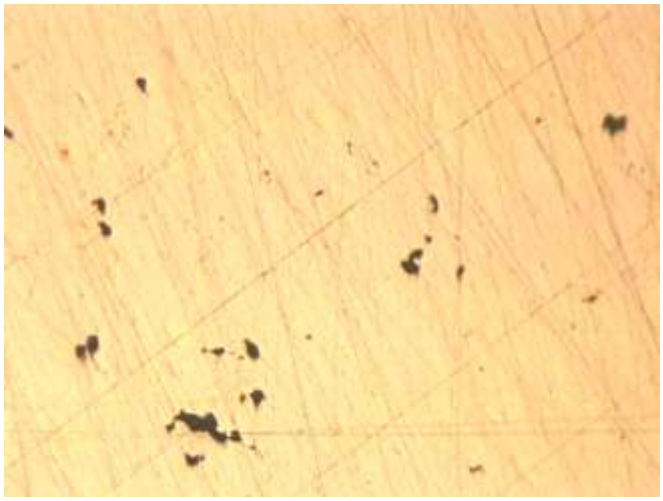

Figure 8: 10x magnification OM image of 20% copper before etch.

OM images before etching may not be the most suitable image to use for analysis. However, upon close investigation, the figures shown that there are bright yellow areas. These areas are copper that was melted during liquid phase sintering. The most distinguished image of melted copper was in 20% copper content. Furthermore, we can also see that by increasing the copper amount, there are less pores seen from the figures above. This is due to more copper filling the pores between irons.

4.2.1.2 After etching

After etching, OM images were taken again to be compared and analysed. The magnification that will be compared and analyse will be 10x magnification. The result of OM images are as follows.

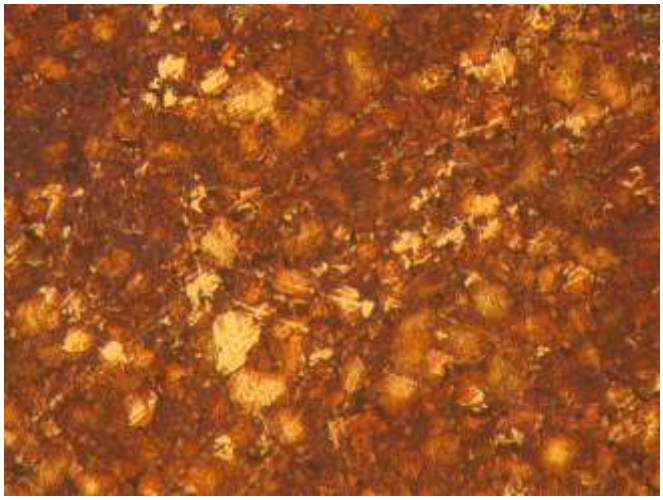

Figure 9: 10x magnification OM image of 5% copper after etch.

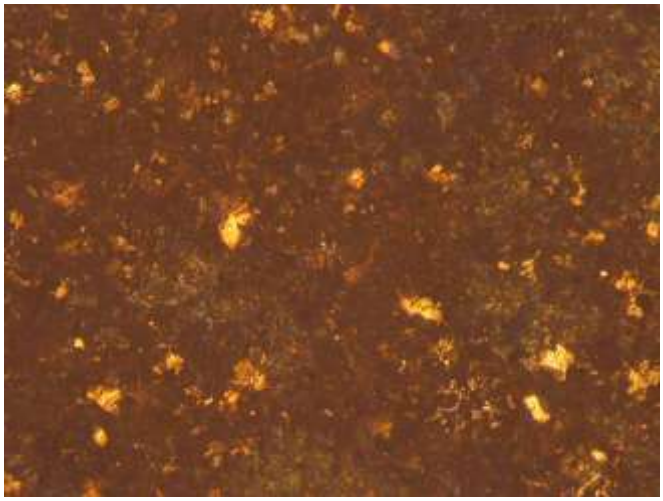

Figure 10: 10x magnification OM image of 10% copper after etch.

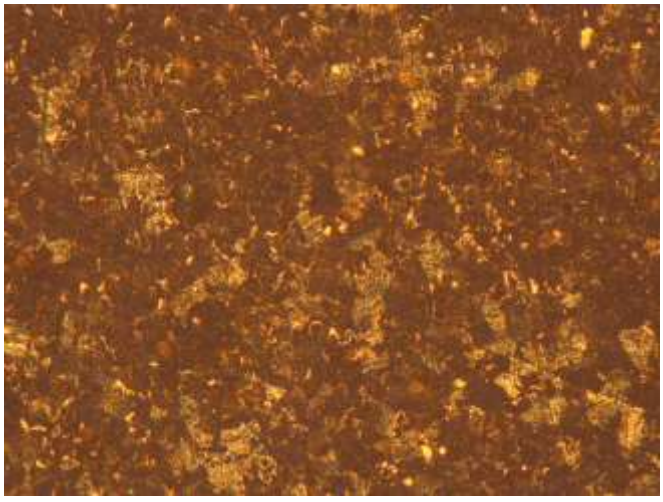

Figure 11: 10x magnification OM image of 15% copper after etch.

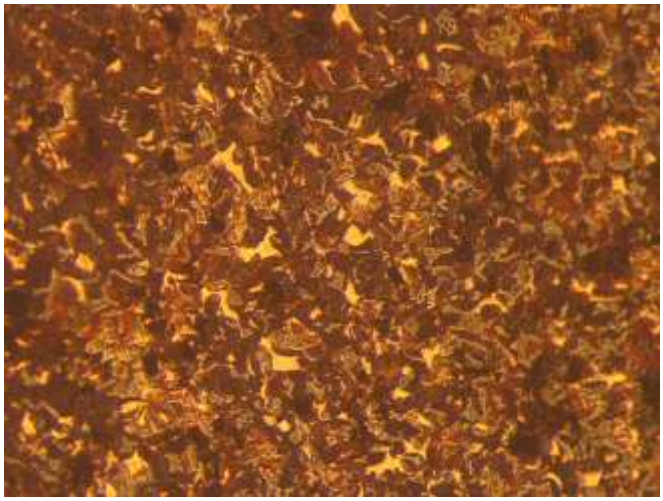

Figure 12: 10x magnification OM image of 20% copper after etch.

OM images of the microstructure of the samples are better shown after the samples have been etched. Etching facilitates the corrosion process of the samples as to clearly map the microstructure. 3% nital was used to speed up the process of iron corrosion. Thus giving distinguishing the types of microstructure of the samples accordingly.

4.2.2 Scanning Electron Microscope

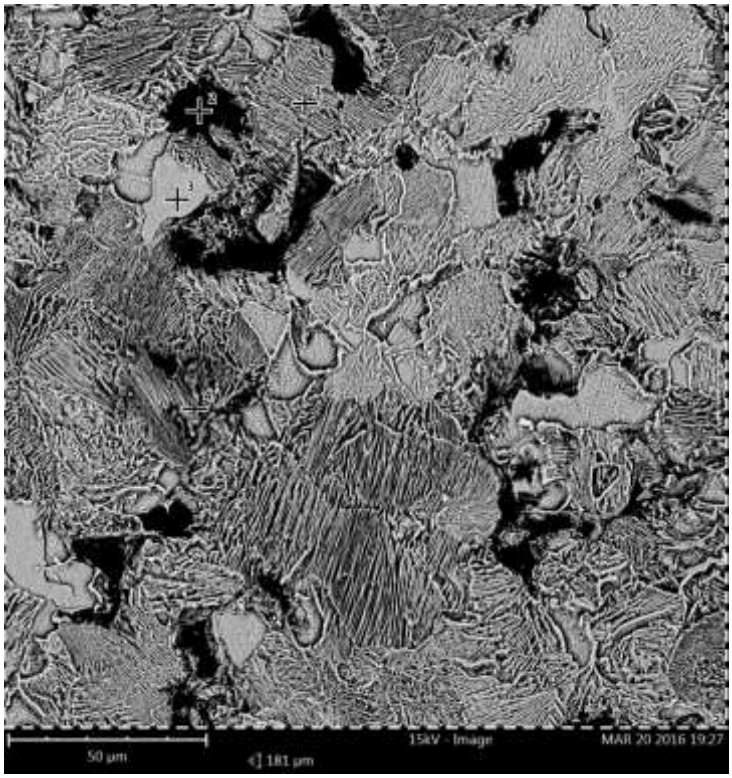

Figure 13: 1500x magnification SEM image of 5% copper.

Table 6: EDS analysis of 5% copper.

Spot	Element Number	Element Symbol	Element Name	Weight Concentration	Error
1	26	Fe	Iron	75.7	0.0
	29	Cu	Copper	24.3	0.3
	6	C	Carbon	0.0	0.0
2	26	Fe	Iron	53.2	0.1
	6	C	Carbon	39.1	0.5
	29	Cu	Copper	7.7	1.0
3	26	Fe	Iron	81.1	0.0
	29	Cu	Copper	18.9	0.3
	6	C	Carbon	0.0	0.0
4	26	Fe	Iron	88.1	0.0
	29	Cu	Copper	11.9	0.8
	6	C	Carbon	0.0	0.0

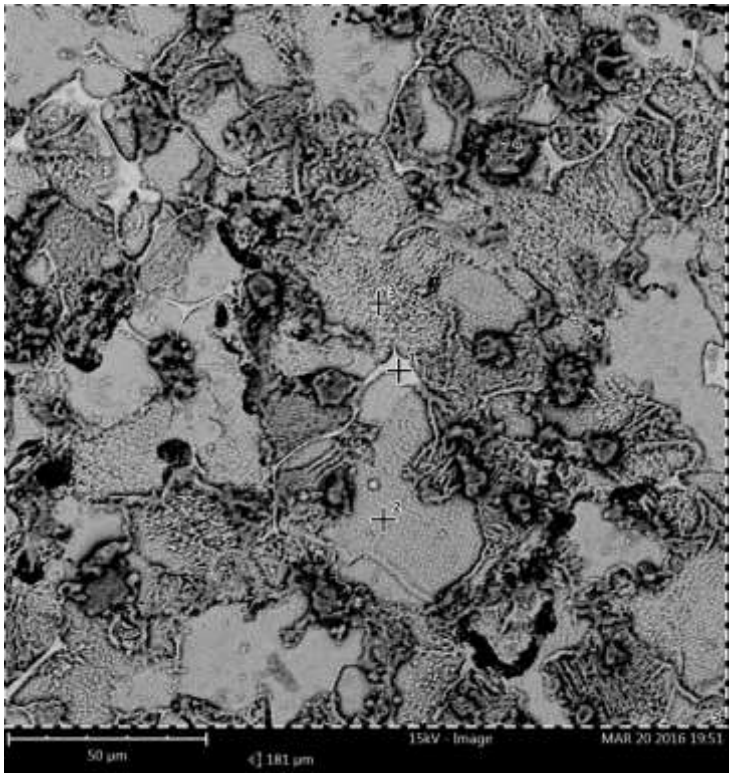

Figure 14: 1500x magnification SEM image of 10% copper.

Table 7: EDS analysis of 10% copper.

Spot	Element Number	Element Symbol	Element Name	Weight Concentration	Error
1	29	Cu	Copper	69.9	0.7
	26	Fe	Iron	28.8	1.0
	6	C	Carbon	1.2	0.7
2	26	Fe	Iron	80.5	0.7
	29	Cu	Copper	14.3	0.7
	6	C	Carbon	5.1	0.5
3	26	Fe	Iron	75.7	0.7
	29	Cu	Copper	19.9	1.1
	6	C	Carbon	3.2	0.2
4	26	Fe	Iron	64.9	0.7
	29	Cu	Copper	18.9	0.9
	6	C	Carbon	16.2	0.7

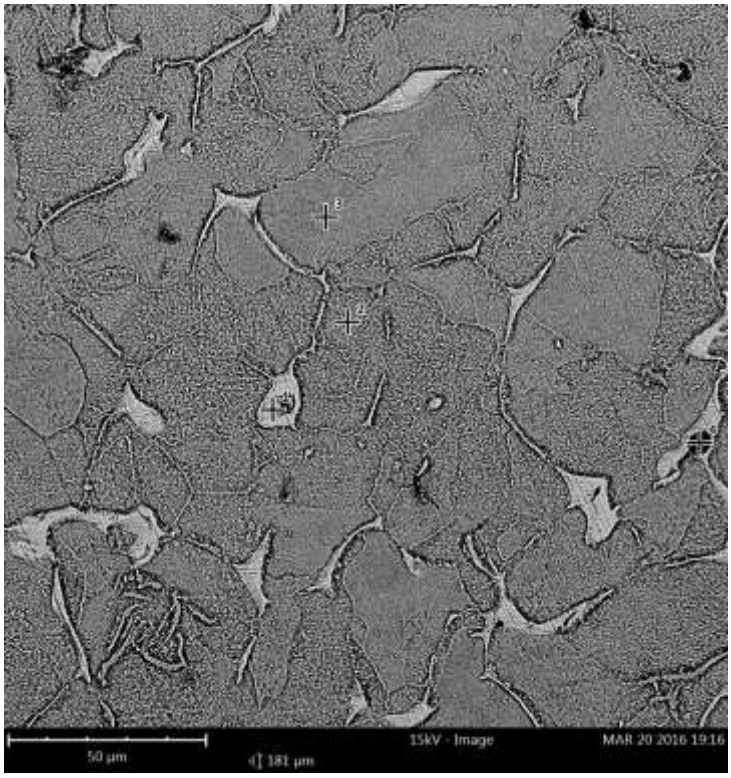

Figure 15: 1500x magnification SEM image of 15% copper.

Table 8: EDS analysis of 15% copper.

Spot	Element Number	Element Symbol	Element Name	Weight Concentration	Error
1	29	Cu	Copper	90.8	0.0
	26	Fe	Iron	8.8	0.1
	6	C	Carbon	0.3	0.0
2	26	Fe	Iron	89.2	0.0
	29	Cu	Copper	10.6	0.5
	6	C	Carbon	0.0	0.0
3	26	Fe	Iron	96.5	0.0
	29	Cu	Copper	3.1	0.6
	6	C	Carbon	0.4	0.1
4	26	Fe	Iron	80.1	0.0
	29	Cu	Copper	18.6	0.3
	6	C	Carbon	1.3	0.0

Figure 16: 1500x magnification SEM image of 20% copper.

Table 9: EDS analysis of 20% copper.

Spot	Element Number	Element Symbol	Element Name	Weight Concentration	Error
1	29	Cu	Copper	90.8	0.8
	26	Fe	Iron	6.3	0.9
	6	C	Carbon	1.9	0.4
2	26	Fe	Iron	58.9	0.7
	29	Cu	Copper	37.4	0.8
	8	O	Oxygen	3.6	0.6
3	26	Fe	Iron	81.8	0.6
	29	Cu	Copper	15.5	0.8
	6	C	Carbon	2.7	0.4
4	26	Fe	Iron	66.4	0.6
	29	Cu	Copper	31.9	1.1
	6	C	Carbon	1.7	0.3

From the figures above, it is shown that the microstructure contains pearlite and proeutectoid cementite. Pearlitic structure of the grain formed after the carbon diffusion by substitution by the means of filling in the interparticle voids of irons. Only coarse pearlite preset because the samples did not go through heat treatment. They only go through annealing when cooling down in the furnace. At the grain boundaries, proeutectoid cementite formed. This happens because of the composition of samples are all having carbon content between 0.76 and 2.14 wt%. Free copper can also be seen in the SEM images. Having higher copper content results in more area of free copper in the SEM image.

4.3 Mechanical Properties

4.3.1 Hardness Testing

Table 10: Hardness result of each samples.

Copper Content	1st notch	2nd notch	3rd notch	Average
5%	39.9	40.4	39.9	40.07
10%	63.1	67.2	60.1	56.80
15%	69.1	70.1	69.1	69.43
20%	69.6	75.8	77.0	74.13

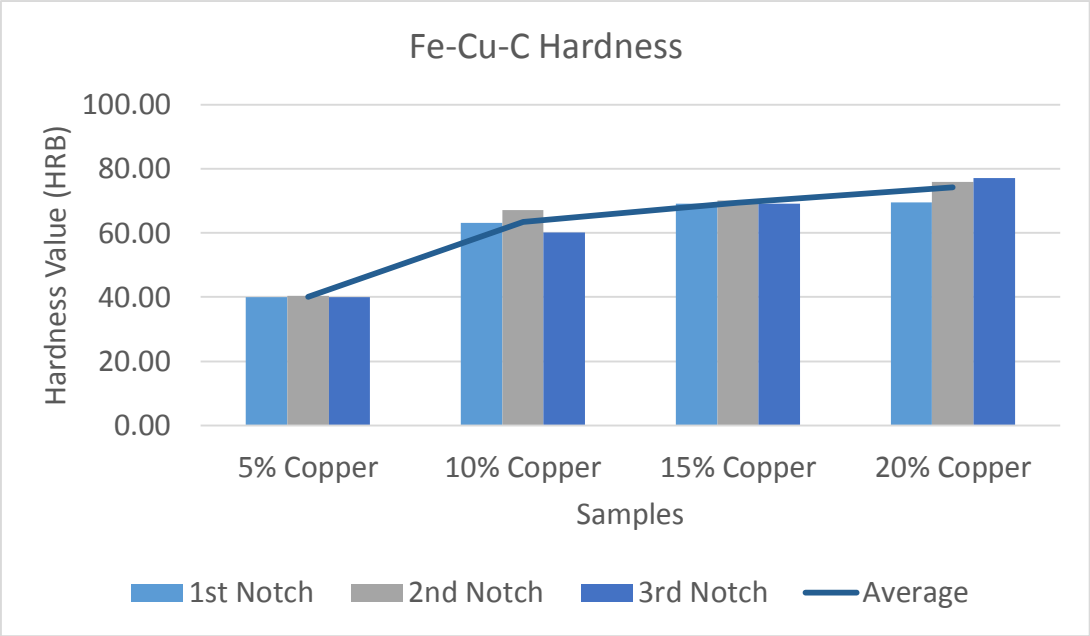

Figure 17: Hardness value for each samples.

Hardness testing was done to all of the samples using Rockwell HRB standard. The result in the table above shows that by increasing the copper content, the hardness increase. This is caused by the properties of copper assimilating with the properties of other materials. Based on the scope of study, 20% of copper provides the best hardness value compared to others. However, based on the chart plotted off of the hardness value of the samples, the trend indicates that with further increase in copper content

to the system will result in less increase in hardness. Therefore, it can be deduced that at one point, the increase in hardness will be negligible as it will be too small compared with the previous addition of copper content. By then, the increase in copper content will be unnecessary.

By using the hardness conversion table, and a correlation equation between Brinell hardness and tensile strength, we can estimate the tensile strength of the samples.

Table 11: Estimated tensile strength.

Copper Content	Rockwell B (HRB)	Brinell hardness (HB)	Tensile strength (MPa)
5%	40.07	74	255.30
10%	56.80	91	313.95
15%	69.43	109	376.05
20%	74.13	118	407.10

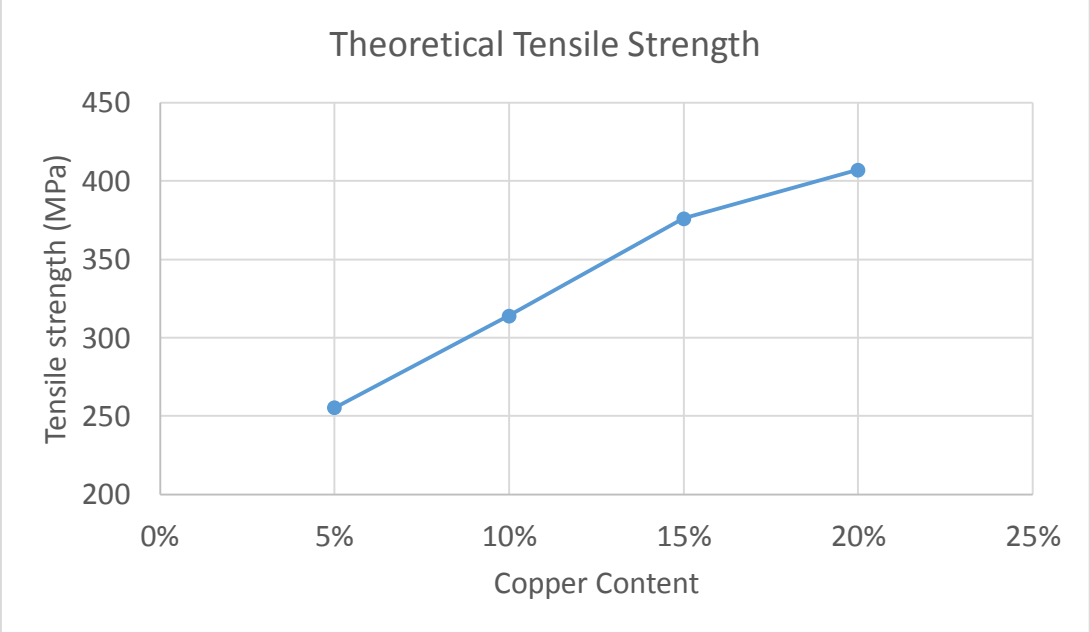

Figure 18: Theoretical Tensile strength.

It is shown from the chart above that by increasing the copper content, the theoretical tensile strength also increase. Nonetheless, the trend shows that further increase in copper content will result in lower increase in theoretical tensile strength value. This is because the theoretical tensile strength is closely related by the hardness of the sample.

4.3.2 Wear Testing

Figure 19: Scratch result of 5% copper with progressive force.

Figure 20: Scratch result of 10% copper with progressive force.

Figure 21: Scratch result of 15% copper with progressive force.

Figure 22: Scratch result of 20% copper with progressive force.

The grooves that was made with progressive force are shown in the figures above. There are two factors affecting the groove beaviour during the scratch test. They are the friction due to deformation and friction due to adhesion. With a closer look, the edges of the groove indicates that with higher copper content, the samples are more aligned and adhesive. This is shown by the structure of the groove's edge, which showed more alignment and uniformity at higher copper content. Although fracture did not happen in all samples, plastic deformation occurs in all four samples. However, the highest plastic deformation was analysed to be when the copper content is the lowest. Therefore, with higher copper content, the particles are more aligned and adhesive, and the sample has less plastic deformation due to scratching. Aside from that, we can see that the system with 5% copper produces the biggest groove, and the system with 20%.

CHAPTER 5

CONCLUSION & RECOMMENDATION

Powder metallurgy is one of the most used technique for manufacturing metal products for its cost effectiveness, high machinability and other reasons. Fe-Cu-C is widely used alloy in the industry as the system promotes the properties of iron, making it suitable for many numbers of usage e.g. pinion gear. Based on that, this study will be useful to many people as the system will be more understandable by others. In this case, how it behaves when the copper content in the system is varied.

From the microstructure point of view, the microstructure contains pearlite and proeutectoid cementite. Carbon with 1 wt% formed a proeutectoid cementite grain boundaries while the phase of iron in the samples are pearlite as carbon occupied the interparticle voids between iron particles. With increasing copper content, more area of free copper can be seen at the photomicrograph of all the samples.

For the physical properties of the system, Shrinkage and densification occurs to the green bodies after going through sintering process. This information is crucial in order to near-net shape products by means of press and sinter powder metallurgy. Further studies will have to be done by focusing on the shrinkage and the densification ratio as it will prove beneficial to the industry. Shrinkage will have to be factored in when producing die of desired products as the products will be smaller than the compacting die. Densification ratio will also must be calculated as to avoid any unnecessary increase in density for the desired products.

For the mechanical properties of the system, the increase in copper also lead to the increase in hardness. The highest copper content has the highest hardness value. This can be seen in Figure 17. However, based on the trend, with each increase in copper content, it will result in lower increase in hardness. At one point, the increase in copper content will not be needed as the increase in hardness will be negligible. After that, based on the scratch test, highest copper content proved to be the best composition as it has the least plastic deformation.

In conclusion, this study focuses on different amount of copper content in Fe-Cu-C system with the copper content being 5%, 10%, 15%, and 20% of weight percentage. Based on this scope of study, it is found that Fe-Cu-C system with 20 wt% copper is the best composition. This is based on the microstructure, physical and mechanical properties of the system. Be that as it may, further studies must be done with different composition of Fe-Cu-C to facilitate deeper understanding of the behaviour of Fe-Cu-C with different composition.

Reference

Jonnalagadda, K. P. (2012). Influence of graphite type on copper diffusion in P/M Copper Steels.

Langford, J. I., Louër, D., & Scardi, P. (2000). Effect of a crystallite size distribution on X-ray diffraction line profiles and whole-powder-pattern fitting. Journal of applied crystallography, 33(3), 964-974.

Marucci, M. L., & Hanejko, F. G. (2010). Effect of copper alloy addition method on the dimensional response of sintered Fe-Cu-C steels. Advances in Powder Metallurgy & Particulate Materials, 11-21.

Mohd Ishak, M. (2015). Microstructural evolution and physical properties changes during liquid phase sintering of fe-cu-c compacts.

Mustapha, M., Ak, M., Mohammad, M., Meh, B., & Harun, Z. (2002). Changes of Fe Matrix's Lattice Constant during Liquid Phase Sintering of Fe-Cu-C Compacts by X-ray Diffraction Techniques. Malaysian Journal of Science, 21(0).

Narasimhan, K. S., & Semel, F. J. (2007). Sintering of powder premixes – a brief overview. Advances in powder metallurgy and particulate materials, 1, 05.

Tsutsui, T. (2012). Recent Technology of Powder Metallurgy and Applications. Hitachi Chemical Technical Report No. 54.