Powder Metallurgy of Copper Based Composite with Silica Sand

by

Sayidah Nafishah binti Mohd Sabri

A dissertation in partial fulfilment of

the requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____
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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

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.

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SAYIDAH NAFISHAH BINTI MOHD SABRI

ABSTRACT

The objective of this project was to study the powder metallurgy process and to determine the suitable sintering temperature for copper base composite with silica sand. The scope of study was on powder metallurgy and properties of copper matrix composite with silica sand reinforcement. One of the most important stages in powder metallurgy process was the compaction and sintering process which will determine the green and sintered density. Experiment with sintering temperature of 750^{o}C, 850^{o}C and 950^{o}C was conducted and the sintered products were observed through an optical microscope. Hardness test was carried out on each sample and the results were graphed. With higher sintering temperature, different hardness was obtained depending on the amount of silica added to each sample. From the results, it is concluded that the sintering temperature of 750^{o}C is most suitable to be used for copper composite with 5% to 20% micro silica sand.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of study

Powder metallurgy is a forming and fabrication technique consisting of three major processing stages. First, the primary material is physically powdered, divided into many small individual particles. Next, the powder is injected into a mold or passed through a die to produce a weakly cohesive structure (via cold welding) very near the dimensions of the object ultimately to be manufactured. Pressures of 10-50 tons per square inch are commonly used. Also, to attain the same compression ratio across more complex pieces, it is often necessary to use lower punches as well as an upper punch. Finally, the end part is formed by applying pressure, high temperature, long setting times (during which self-welding occurs), or any combination thereof. [7]

Two main techniques used to form and consolidate the powder are sintering and metal injection molding. Recent developments have made it possible to use rapid manufacturing techniques which use the metal powder for the products. With this technique, the powder is melted and not sintered where better mechanical strength can be accomplished.

1.2 Problem statement

Suitable heating rate, time, temperature and atmosphere are required for reproducible results. The sintering temperature is essential to attain high performance properties for powder metallurgy. A high temperature promotes densification, which is beneficial to both strength and ductility. However, a high sintering temperature also contributes to microstructural coarsening (enlarged austenite grain size and coarser pearlitic structure) that degrades the mechanical properties. For powder mixtures, the sintering temperature may be above the melting-point of the lower-melting constituent, e.g. copper/tin alloys, iron/copper structural parts, tungsten carbide/cobalt cemented carbides, so that sintering in all these cases takes place in the presence of a liquid phase, hence the term liquid phase sintering. It is, of course, essential to restrict the amount of liquid phase in order to avoid impairing the shape of the part.

1.3 Objective of the study

The objective of the study is to determine the suitable sintering temperature for powder metallurgy of copper based composite with silica sand.

1.4 Scope of work

1. Study on copper matrix composite, silica sand reinforcement.
2. Experiment on the sintering time and temperature
3. Hardness testing and examine through Optical Microscope on the complete product.

CHAPTER 2
LITERATURE REVIEW

2.1 Powder Metallurgy

Powder metallurgy (P/M) has become competitive with processes (such as casting, forging, and machining), particularly for relatively complex parts made of high-strength and hard alloys. It has been shown that P/M parts can be mass-produced economically in quantities as small as 5000 per year and as much as 100 million per year for vibrator weights for cell phones. [7]

The most commonly used metals in P/M are iron, copper, aluminium, tin, nickel, titanium, and the refractory metals. For parts made of brass, bronze, steels, and stainless steels, prealloyed powders are used, where each powder particle itself is an alloy. Metal sources are generally bulk metals and alloys, ores, salts, and other compounds.

The powder-metallurgy process consists of the following operations, in sequence:

1. Powder production
2. Blending must be carried out to obtain uniformity of mechanical properties throughout the part.
3. Compaction is where metal powder is compacted in a die through the application of high pressures.
4. Sintering is the process of taking compacted metal into the mold and to be placed under a high heat for a long period of time.
5. Finishing operations inevitable

2.2 Copper based alloy

The physical properties of pure copper in massive form are given in Table 2.1. Outstanding are the electrical and thermal conductivities which are markedly higher than those of any other base metal and are exceeded only by silver. A copper powder with a purity exceeding 99.95% is available, and, of course, the individual particles have the same properties as massive copper. However, it is impractical to achieve a density of 8.94 g/cm[1] by pressing and sintering alone, and, therefore, the properties of P/M parts are influenced by the density attained [11].

Table 2.1: Physical Properties of Massive (Fully Dense) Copper [11]

Properties	C.G.S Units
Melting Point	1083 ^{o}C
Density	8.94 g/cm^3 @20 ^{o}C
Coefficient of Thermal Expansion	17.0 x 10^6 /^{o}C (20 – 100 ^{o}C)
Electric Conductivity	0.586 megmho-cm @ 20^{o}C
Modulus of Elasticity (Tension)	117,000 MPa

The sintering temperature of the powder metallurgy will be adjusted in the region of the melting point of copper which is 1357.77 K, 1083°C since copper has lower melting temperature compared to silica sand.

The consolidation of a mass of powder is usually performed in a closed die, although other most granular copper powder is used in the production of P/M parts, and, generally, a closed die is used to form a specific shape. To achieve uniform densification it is necessary to select a particle-size distribution which will permit uniform packing in the die. It is also necessary to select suitable pressing conditions.

Outstanding are the electrical and thermal conductivities which are markedly higher than those of any other base metal and are exceeded only by silver. A copper powder with a purity exceeding 99.95% is available, and, of course, the individual particles have the same properties as massive copper. However, it is impractical to achieve a density of 8.94 g/cm by pressing and sintering alone, and, therefore, the properties of P/M parts are influenced by the density attained. Densification can be increased by additional operations such as double pressing-double sintering or forging, for example, and the properties of the P/M part approach those of the massive metal as a limit.

A pure copper P/M parts are produced with relatively low pressures. An initial compacting pressure of 34- 40 ksi (234-276 MPa) has been recommended for thin sections although higher pressures can be used for heavier sections. The objective is to permit the escape of gases and water vapor formed by the internal reduction of oxides during sintering. Compacting pressures that are too high will prevent proper sintering of the center of the compact and reduce the electrical conductivity and the strength. Recommended pressures and compression ratios for some copper and copper alloy compacts are given in the Table 2.2 below.

Table 2.2: Compaction Pressure for Copper and Copper Alloys [2]

Compacting Pressure			
Typical P/M Part	**tons/sq. in**	**MPa**	**Compression Ratio**
Brass Parts	30-50	414-690	2.4-2.6:1
Bronze Bearings	15-20	207-276	2.5-2.7:1
Copper-Graphite Brushes	25-30	345-414	2.0-3.0:1
Copper Parts	15-18	207-248	2.6-2.8:1

As pressed and sintered, the electrical conductivity of pure copper parts can range from 80% to 90% IACS and higher conductivities can be achieved by additional working of the parts. The effect of sintered density on the electrical conductivity and mechanical properties of sintered copper is indicated in Figure 2.1 below.

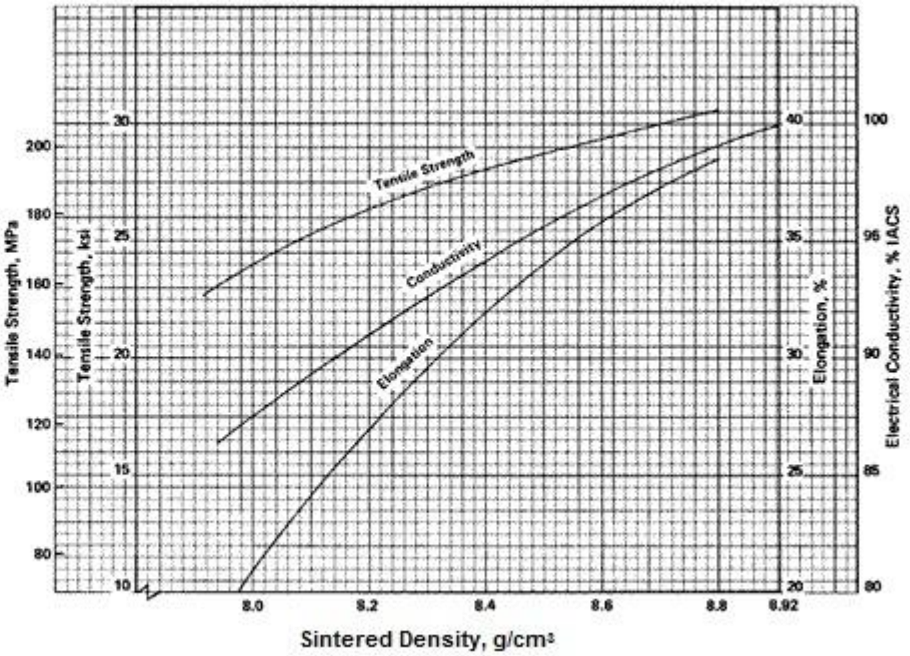


Figure 2.1: Effect of Density on the Properties of Sintered Copper [5]

The high electrical conductivity and excellent ductility that can be achieved in copper P/M compacts lead to the selection of pure copper powder for P/M parts for electronic and electrical applications where conductivity is essential. Such parts include commutator rings, contacts, shading coils, nose cones and twist type electrical plugs. A specific application is a diode used as the base of the silicon rectifier for the alternator charging systems in automobiles.

Copper powders are used in copper-graphite compositions, which have low contact resistance, high current-carrying capacity and high thermal conductivity for brushes in motors and generators and as moving parts of rheostats, switches and current-carrying washers. These powders are also used to produce electrode tools for electrical discharge machining of complex dies. Copper powder is selected for its high electrical and thermal conductivity.

Pure copper is also used in nonelectrical P/M applications. An interesting example is a copper blade shank which is impregnated with grease to increase the service life of a pocket knife.

An example of copper composite is brass (copper –tin). Most tin bronze parts are produced from premixes although some are made from pre-alloyed powder. Since prealloyed powders have higher yield strengths and work hardening rates than premixed powders, the pressing loads required to achieve a given green density are higher than those required when pressing elemental powders. The differences in pressing characteristics of premixed and prealloyed powders are indicated in Figure 2.2.

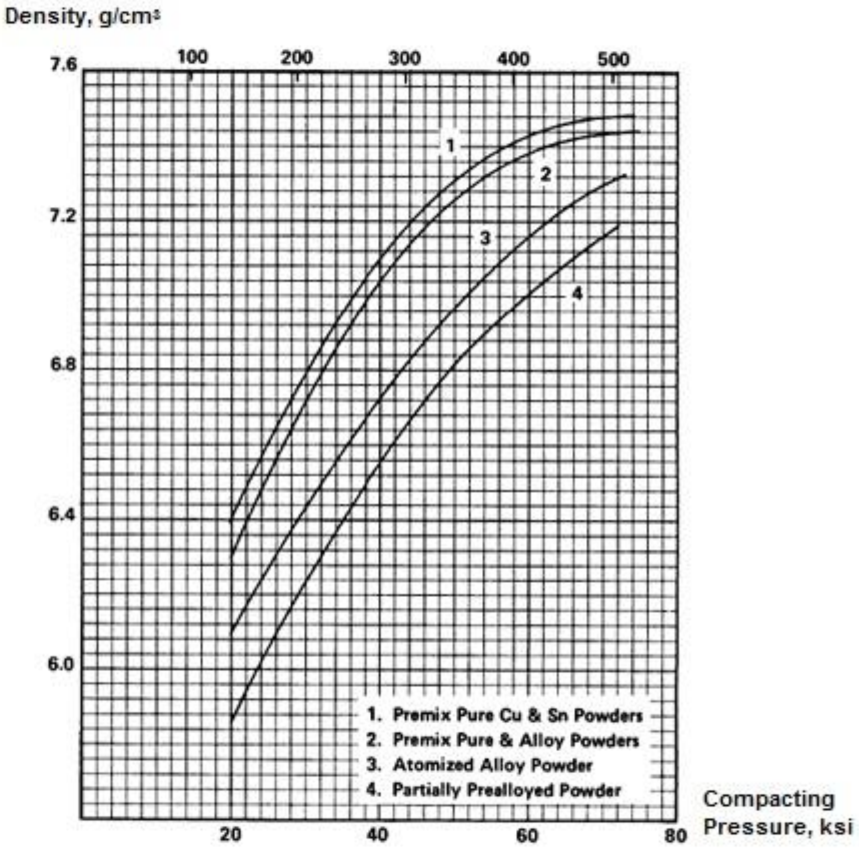


Figure 2.2 : Pressing Characteristics of Premixed and Prealloyes 9:1 Copper - Tin Powders [6]

Properties of tin bronze P/M parts are influenced also by such factors as heating rate and sintering time and temperature. Faster heating rates tend to produce greater growth than slow heating rates. Sintering temperature influences both growth and strength. Sintering time influences dimensional control and strength; rapid growth occurs at the beginning of sintering and is followed by a period of predictable slow shrinkage. By completing sintering in the shrinkage range, it is possible to maintain dimensional control over the bronze P/M product.

2.3 Natural Silica Sand

Silica is the most abundant mineral found in the crust of the earth. It forms an important constituent of practically all rock-forming minerals. It is found in a variety of forms, as quartz crystals, massive forming hills, quartz sand (silica sand), sandstone, quartzite, tripoli, diatomite, flint, opal, chalcedonic forms like agate, onyx etc., and in with numerous other forms depending upon colour such as purple quartz (amethyst), smoky quartz, yellow quartz or false topaz (citrine), rose quartz and milky quartz. Only pure quartz crystal or rock crystal, untwinned, clear, free from any inclusion, has an important property which is expands (mechanically) under the influence of electric current and conversely pressure induces a measurable electric current. This property is known as piezoelectricity. The current thus developed is called piezoelectric current.

Silica is used in various industries for its abrasion resistance, electrical insulation and high thermal stability. Silica (SiO_2) is a multi-functional ceramic material that is being used in various industries to improve surfaces and mechanical properties of diverse materials. It is used as a filler, performance additive, rheological modifier or processing aid in many product formulations, such as paints & coatings, plastics, synthetic rubber, adhesives, sealants, or insulation materials. In particular silica fume (amorphous silicon dioxide) or microsilica is being added to concrete in order to improve the concrete strength and durability. Silica fume is also being used in refractory concretes to reduce porosity and to enhance strength by improved particle packing. [10]

The properties of silica sand are shown in the Table 2.3 below.

Table 2.3 Properties of silica sand

Properties	Units
Melting Point	1650°C
Density	2.634 g/cm^3
Coefficient of Thermal Expansion	5.5×10^{-7}/°C (20–320 °C)
Compressive strength	2070 MPa
Modulus of elasticity	70 GPa
Resistivity	10^{12}-10^{16} Ωm

In this project, silica sand is sieved to size of less than 63µm. Particles which are smaller in diameter will have enough green strength in the compacted form and provide a reasonably smooth surface finish.[1] Green strength refers to the force needed to break a compacted part before it is sintered. If green strength is too low, parts may crack during ejection from the tools, or in handling, on the way to the sintering furnace.

2.4 Vickers Hardness Test

It is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond. The diagonal of the resulting indention is measured under a microscope and the Vickers Hardness value read from a conversion table.

Table 2.4: Conversion table for Vickers Hardness [15]

Vickers Hardness Number HV	Rockwell C Scale Hardness HRC	Vickers Hardness Number HV	Rockwell C Scale Hardness HRC	Vickers Hardness Number HV	Rockwell C Scale Hardness HRC	Vickers Hardness Number HV	Rockwell C Scale Hardness HRC
900	66.5	720	59.3	540	52.1	360	37.8
890	66.1	710	58.9	530	51.7	350	36.8
880	65.7	700	58.5	520	51.3	340	35.7
870	65.3	690	58.1	510	50.4	330	34.5
860	64.9	680	57.7	500	49.7	320	33.4
850	64.5	670	57.3	490	49.0	310	32.2
840	64.1	660	56.9	480	48.2	300	30.9
830	63.7	650	56.5	470	47.5	290	29.6
820	63.3	640	56.1	460	46.7	280	28.2
810	62.9	630	55.7	450	45.9	270	26.7
800	62.5	620	55.3	440	45.1	260	25.1
790	62.1	610	54.9	430	44.3	250	23.5
780	61.7	600	54.5	420	43.5	245	22.7
770	61.3	590	54.1	410	42.6	240	21.8
760	60.9	580	53.7	400	41.7	235	20.9
750	60.5	570	53.3	390	40.8	230	20.0
740	60.1	560	52.9	380	39.8	BACK	
730	59.7	550	52.5	370	38.8		

Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter. Devised in the 1920s by engineers at Vickers, Ltd., in the United Kingdom, the diamond pyramid hardness test, as it also became known, permitted the establishment of a continuous scale of comparable numbers that accurately reflected the wide range of hardness found in steels.

The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º. The diamond is pressed into the surface of the material at loads ranging up to approximately 120 kilograms-force, and the size of the impression (usually no more than 0.5 mm) is measured with the aid of a calibrated microscope. The Vickers number (HV) is calculated using the following formula

$$HV = 1.854(F/D_2),............................[Equation 1]$$

with F being the applied load (measured in kilograms-force) and D_2 the area of the indentation (measured in square millimetres). The applied load is usually specified when HV is cited. [13]

The Vickers test is reliable for measuring the hardness of metals, and also used on ceramic materials. The Vickers testing method is similar to the Brinell test. Rather than using the Brinell's steel ball type indenter, and have to calculate the hemispherical area of impression, the Vickers machine uses a penetrator that is square in shape, but tipped on one corner so it has the appearance of a playing card "diamond". The Vickers indenter is a 136 degrees square-based diamond cone, the diamond material of the indenter has an advantage over other indenters because it does not deform over time and use. The impression left by the Vickers penetrator is a dark square on a light background. The Vickers impression is more easily "read" for area size than the circular impression of the Brinell method. Like the Brinell test, the Vickers number is determined by dividing the load by the surface area of the indentation (H = P/A). The load varies from 1 to 120 kilograms. To perform the Vickers test, the specimen is placed on an anvil that has a screw threaded base. The anvil is turned raising it by the screw threads until it is close to the point of the indenter. With start lever activated, the load is slowly applied to the indenter. The load is released and the anvil with the specimen is lowered. The operation of applying and removing the load is controlled automatically.

Several loadings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness machines. A filar microscope is swung over the specimen to measure the square indentation to a tolerance of plus or minus 1/1000 of a millimeter. Measurements taken across the diagonals to determine the area, are averaged. The correct Vickers designation is the number followed "HV" (Hardness Vickers).

The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is rather more expensive than the Brinell or Rockwell machines.

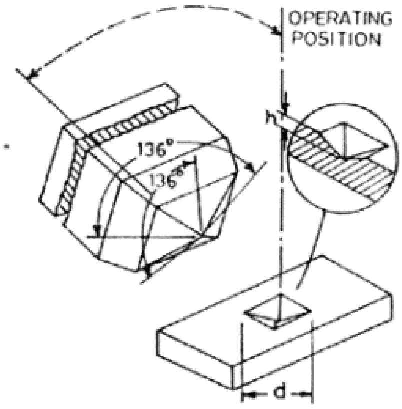


Figure 2.3: Visualization of measurement for Vickers hardness[13]

CHAPTER 3
METHODOLOGY

3.1 Procedure identification

Figure 3.1 shows the process flow of the whole project from when the project started until it finished.

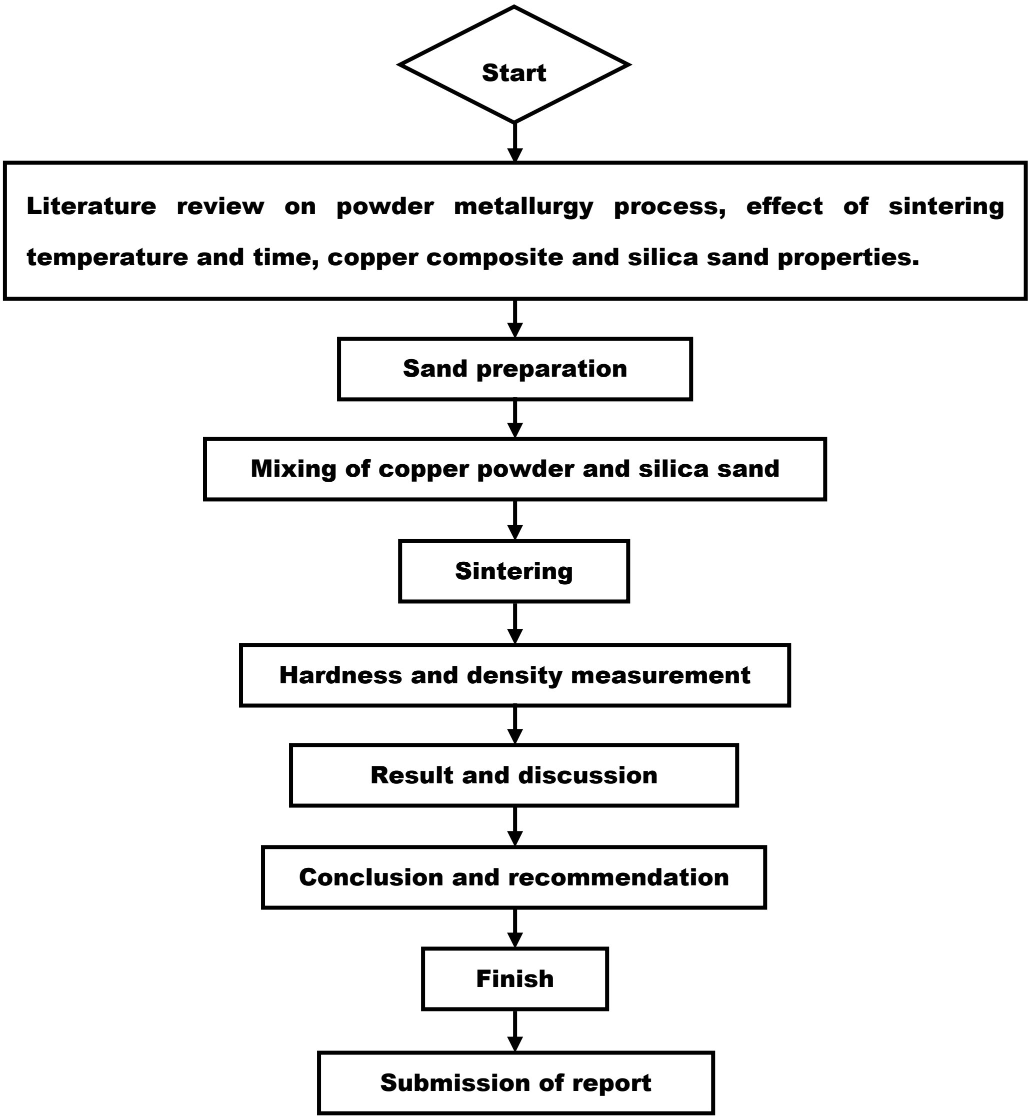


Figure 3.1 : Summary of activities of the study

3.2 Experimental methods

3.2.1 Purpose

The purpose of this experiment is to observe and inspect the powder metallurgy process and effects of different sintering temperature on different silica weight percentage in copper composite.

3.2.2 Sand preparation

The silica sand with 94% purity was originated from Tronoh, Perak, Malaysia and grounded to micro particles using ball mill and sieved using the mechanical sieve to size of 63 microns and lower. The copper powder with 99.7% purity is commercially available.

3.2.3 Mixing of Copper Powder and Silica

15 samples of pure copper and copper-silica mixture with added wax based binder were mixed using the ball mill for two hours. The samples produced were:

i. Three samples of pure copper of 2g each

ii. Three samples of mixture of copper and 5% silica (1.9g copper and 0.1g silica)

iii. Three samples of mixture of copper and 10% silica (1.8 g copper and 0.2g silica)

iv. Three samples of mixture of copper and 15% silica (1.7g copper and 0.3g silica)

v. Three samples of mixture of copper and 20% silica (1.6g copper and 0.4g silica)

3.2.4 Compaction

Each sample was put into a 13mm mould and compacted using the auto-palletizer at 100 pound weight for 3minutes. The density of each samples are measured using the density measurement device and the result is tabulated and a graph was produced.

3.2.5 Sintering

Figure 3.2: Sintering furnace

The green compacts were placed inside the sintering furnace with argon atmosphere. The heating rate is 5^oC/min and the cooling rate is 10^oC/min. The whole sintering process was conducted as follows:

i. Five samples with 0%, 5%, 10%, 15% and 20% weight percentage were sintered at 750^oC with heating time of 144 minutes, sintering time of 60 minutes and cooling time of 72 minutes, another

ii. Five samples with 0%, 5%, 10%, 15% and 20% weight percentage were sintered at 850^oC with heating time of 164 minutes, sintering time of 60 minutes and cooling time of 82 minutes, and

iii. Five samples with 0%, 5%, 10%, 15% and 20% weight percentage were sintered at 950^{o}C with heating time of 184 minutes, sintering time of 60 minutes and cooling time of 92 minutes respectively.

As mentioned earlier, the melting point for copper is 1085^{o}C. Thus, these three sintering temperature setting were chosen to observe the reaction copper in silica at the nearest to the copper melting point. It was decided that these three sintering temperature are the most appropriate temperature for this experiment. As high temperature promotes densification, which is beneficial to both strength and ductility, an extreme sintering temperature will contributes to microstructural coarsening that degrades the mechanical properties.

3.2.6 Density measurement

The density of each sintered samples were measured using the electronic balance with 0.1mg accuracy. The actual densities for each sample were calculated using Archimedes' principles. The samples were weighed in air, then suspended in distilled water and again weighed. The actual density was then calculated according to equation

$$\rho a = \left[\frac{Wa}{Wa - Ww}\right] x \rho w \ldots\ldots\ldots\ldots\ldots\text{[Equation 2]}$$

Where ρa is the actual density, Wa is the weight of the sample in air, ρw is the density of distilled water and Ww is the weight of the sample in distilled water. The results were tabulated and graphs were produced.

3.2.7 Optical Microscope Examination

Upon completion of the sintering activities, the samples were hot mounted and were later grind and polished to obtain a smooth surface in order to examine the microstructure and bonding between the copper and silica particles through the 100x magnification optical microscope. All samples were examined at three different spots for accuracy in results and pictures of each different spots were recorded accordingly.

3.2.8 Hardness Testing

Figure 3.3: Vickers Hardness tester

Testing of the hardness of each samples were conducted using the Vickers Hardness Tester. To perform the Vickers test, the specimen is placed on an anvil that has a screw threaded base. The anvil is turned raising it by the screw threads until it is close to the point of the indenter. With start lever activated, the load is slowly applied to the indenter. The load is released and the anvil with the specimen is lowered. The operation of applying and removing the load is controlled automatically by the machine. The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º (by defautlt). The diamond is pressed into the surface of the material at 30 kilograms load with 10 seconds dwell time, and the size of the impression was measured with the aid of a calibrated microscope.

3.3 Tools and equipment required

The main equipment and tool required for this research project are as follows;

a. Mechanical sieve was used to sieve the silica sand to desirable size (less than 63 microns)
b. Ball mill machine was utilized during the mixing of copper powder and silica sand
c. Auto pelletizer was used to compact the mixed powder
d. Sintering furnace is where the compacted particles were sintered at the allotted temperature
e. Electronic balance with accuracy of 0.1mg was used to measure green and sintered density
f. Vickers Hardness Tester
g. Optical microscope with 100x magnifying capability

3.4 Project planning

Gantt chart was prepared for the planning of the project from the proposal phase until completion of the project phases. The chart used to illustrate the progress and planning of the entire final year project. (Please refer to **Appendix 3-1** for the chart)

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Green Density

Green density is the density measured from a particle that has been compacted before being sintered. The graph as shown in Figure 4.1 was derived based on the density measured for each compacted copper with silica sand of different weight percentage. The *y*-axis which is the green density (g/cm^3) of the green product from the compaction of mixed copper and silica sand while the *x*-axis is the weight percentage of the samples.

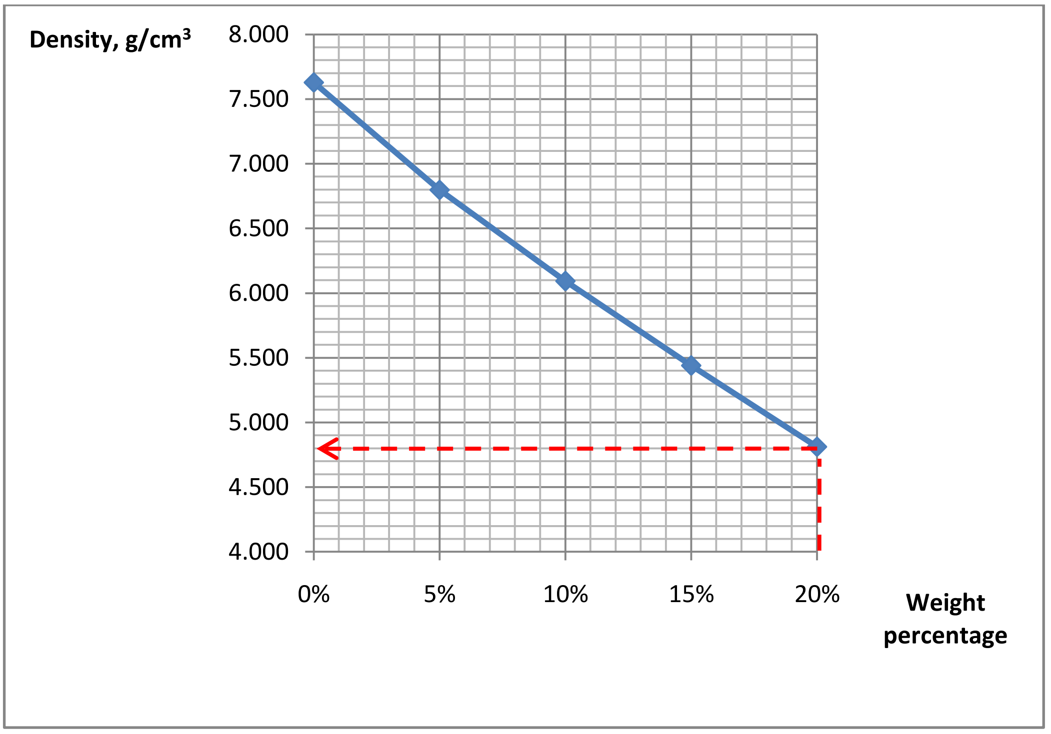


Figure 4.1: Green density achieved after compaction

The graph shows the trend of the green density in relation to weight percentage of the silica. It was observed that the green density gradually reduced from 7.629 g/cm^3 at 0% silica sand to 4.812g/cm^3 with 20% silica particles. This confirm that particles with higher silica reinforcement has higher porosity [16]. Silica sand particles has irregular shapes thus it raise the sample volume and making the particle density lower since:

$$\rho = \frac{m}{v} \text{ ....[Equation 3]}$$

where ρ is density (g/cm^3), m is the particle mass (g), and v is the particle volume (cm^3).

4.2 Sintered density

Sintered density is the density measured from a particle that has been sintered at different temperature. The graph as shown in Figure 4.2 was derived based on the density measured for each compacted copper with silica sand of different weight percentage. The *y*-axis which is the density (g/cm^3) of the sintered particle copper based composite with silica sand while the *x*-axis is the weight percentage of the samples.

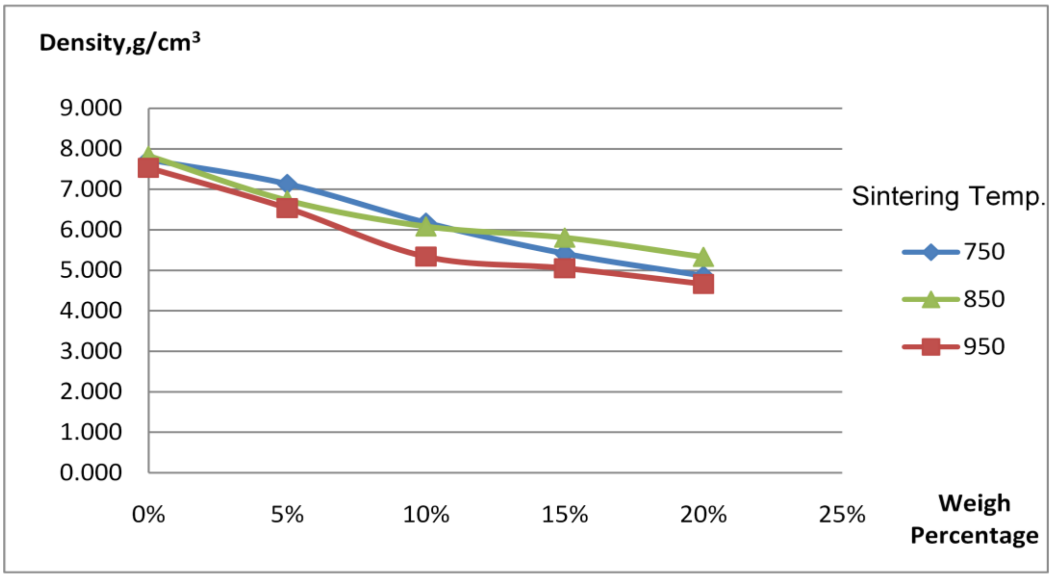


Figure 4.2: Sintered density of particles with different silica weight percentage at different sintering temperature.

After sintering, the density of all samples were found to be increasing. This is because during the sintering process, the silica sand particles occupied the porous area and mixed with copper to fill these porosities to reduce the densities and thus enhance the mechanical properties.

The graph in Figure 4.2 indicates that at temperature of 750^{o}C the sintered density decreases gradually with higher silica weight percentage. Similar trend was observed for higher temperature of 850^{o}C and 950^{o}C. However, the density of samples with 15% and 20% silica sintered at temperature of 850^{o}C tends to be higher than the density of similar weight percentage sintered at 750^{o}C and 950^{o}C. From the observation, it can be deduced that with higher silica weight percentage, the density decreased more and thus it is more favourable to use 850^{o}C for sintering temperature for copper composite with silica sand.

4.3 Hardness measurement

The graph in Figure 4.3 shows that with higher silica weight percentage, the hardness will increase. However at 850°C sintering temperature, the hardness started to saturate at 15% silica weight percentage. On the other hand, at sintering temperature of 950°C the hardness gradually decrease at 10% silica weight percentage. However, these phenomena was not observed at the sintering temperature 750°C wehere the hardness continue to increase with the increment of silica weight percentage.

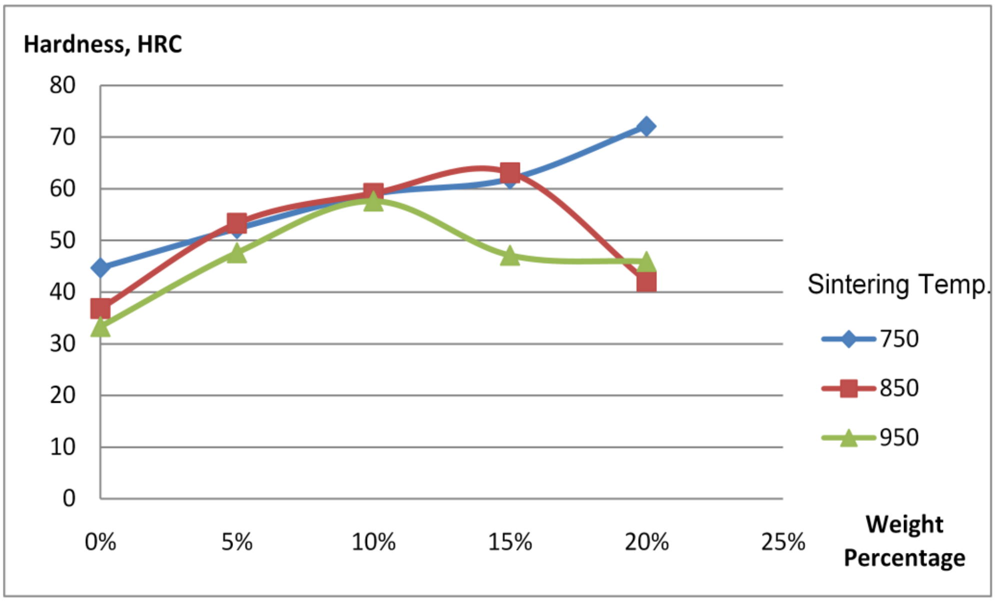


Figure 4.3: Hardness of particles with different silica weight percentage at different sintering temperature.

Therefore, it can be concluded that sintering temperature of 750°C is most suitable to be used for copper composite with silica sand.

4.4 Optical Microscope Examination

Figure 4.4 are the images from the optical microscope examination at 100x magnification for the 5% silica sand weight percentage sintered at different temperature.

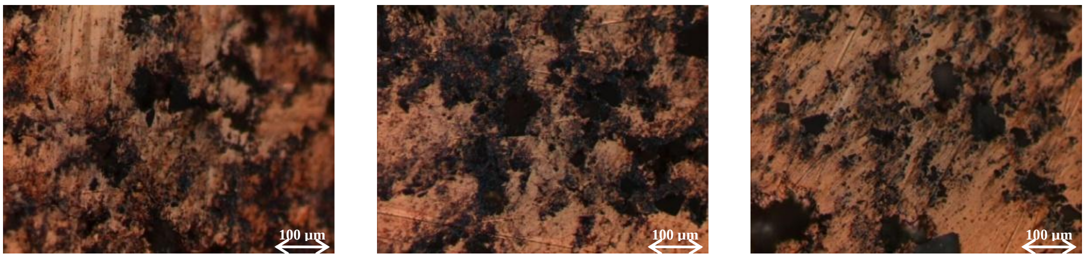
(a) 5% silica sintered at 750^{o}C

(b) 5% silica sintered at 850^{o}C

(c) 5% silica sintered at 950^{o}C

Figure 4.4: Pictorial images of copper composite with 5% silica sand weight percentage sintered at different temperature at 100x magnification

From the images, it can be recognized as indicated in the red circle, at 950^{o}C sintering temperature, more silica sand occupy the spaces within the copper composite compared to lower sintering temperature. This signify that at 950^{o}C sintering temperature silica is well bonded in the copper composite. Contrary to sintering temperature at 750^{o}C and 850^{o}C less silica sand occupy the copper material respectively. Similar observation can be seen in the Figure 4.5 below where different weight percentage of silica also gave a comparable result.



i. 20% silica sintered at 750^{o}C

ii. 20% silica sintered at 850^{o}C

iii. 20% silica sintered at 950^{o}C

Figure 4.5: Pictorial images of copper composite with 20% silica sand weight percentage sintered at different temperature at 100x magnification

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Powder metallurgy for copper based composite with micro silica sand that has been evaluated in this project is another viable composite that its usage can be expanded.

This project has been successful where it focuses mainly on determining the most suitable sintering temperature for copper based composite with different silica weight percentage. The objective of this project has been met where the appropriate temperature setting for the sintering process which is essential for the copper and silica to be properly bonded has been discovered.

From the test that has been conducted, it is concluded that the sintering temperature of 750^{o}C is most suitable to be used for copper composite with 5% to 20% micro silica sand. From the result of this test, the copper based composite with silica sand produces increment in hardness with more silica weight percentage. The whole process is reasonably simple to conduct at a low cost and the copper based composite with silica sand has a possibility to be further explored for more extensive usage.

5.2 Recommendation

In powder metallurgy, it is suitable to utilize silica as one of the reinforcement element in a composite with copper as the metal matrix. The advantages of using silica are that it is extensively available at a low cost. Thus, this type of composite has very high potential of being commercialized. It is therefore recommended that subsequent research to be further explored for the usage of this material to be applied in the commercial world.

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