# CHAPTER 1
# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

In the past few years, new technologies and devices are developing through the innovation of new engineering materials or improvement of the existing materials.

Metal Matrix Composites (MMCs) is one of the material technology that introduced results from the rapid growth in engineering material. MMCs are more expensive than the conventional materials processing they are replacing. As a result, they are found this process can improve properties and performance can justify the added cost. Today these applications are found most often in aircraft components, space systems and high-end or sports equipment.

The most popular method for fabrication MMCs is the infiltration of a preform by a liquid metal under pressure [1]. Since the project used powder form material, the Powder Metallurgy process is more suitable to produce the sample.

The process of P/M starts with homogeneous mixing of reinforcement with the powder matrix. The mixing is followed by compaction and compacted green samples are sintered in selected environments for densification of components [2].

Generally, Powder Metallurgy techniques have an advantage with respect to microstructure control, material use, product homogeneity and mass production [3].

## 1.2 PROBLEM STATEMENT

High demand on light weight materials which have good properties in electronics industry required a detail review and analysis into the ways to improve the hardness properties of Copper by reinforcing Carbon Nanotubes (CNTs) and also Copper reinforced by Carbon Fiber. The process involves mixing of CNTs and Carbon Fiber with copper in a suitable proportion followed by compacting and sintering at high temperature. Copper is highly conductive material and by the reinforcing CNTs or Carbon Fiber in copper, its hardness properties can be further enhanced since CNTs and Carbon Fiber has an excellent thermal conductivity which is up to 3000W/m.K. Therefore these composite is suitable in electronics industry for heating removal purpose.

## 1.3 OBJECTIVES

The main objectives of this project are to develop the samples of Carbon Nanotubes (CNTs) reinforced Copper matrix and Carbon Fiber reinforced Copper matrix and to study the microstructural of the sintered composites. The hardness properties of the composites will also be covered in this study.

## 1.4 SCOPE OF STUDY

The Carbon Nanotubes reinforced Copper matrix and Carbon Fiber reinforced Copper matrix samples will be developed using powder metallurgy process. The effect of sintering temperature in the powder metallurgy process will be studied in the hardness properties of composites using microhardness testing. While the microstructural examination will be carried out using optical microscopy and scanning electron microscopy (SEM) to investigate the dispersion of Carbon Nanotubes (CNTs) and Carbon Fiber in the copper matrix and the bonding between matrix and reinforced materials.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 CARBON NANOTUBES (CNTs)

The current stars of modern nanotechnology are the carbon nanotubes (CNTs), or simply “nanotubes”, which were discovered in 1991 by the Japanese physicist Sumio Iijima at the electronics concern NEC in Tsukuba, Japan [4].

Carbon nanotubes (CNTs) have been the subject of intensive study for applications of nanotechnologies in recent years due to their superior mechanical, electric, optical and electronics properties. Because of their exceptionally small diameters (≈ several nm) as well as their high Young’s Modulus (≈ 1 TPa), tensile strength (≈ 200GPa) and high elongation (10-30%) in addition to a high chemical stability, CNTs are attractive reinforcement materials for light weight and high strength metal matrix composite [5].

Carbon nanotubes (CNTs) are allotropes of carbon with a nanostructure that can have a length-to-diameter ratio greater than 1,000,000. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as extensive use in arcology and architectural fields. They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat [9].

Their name is derived from their size, since the diameter of a nanotube is in the order of a few nanometers (approximately 1/50,000th of the width of a human hair), while they can be up to several millimeters in length [8].

The chemical bonding of nanotubes is composed entirely of $sp^2$ bonds, similar to those of graphite. This bonding structure, which is stronger than the $sp^3$ bonds found in diamond, provides the molecules with their unique strength.

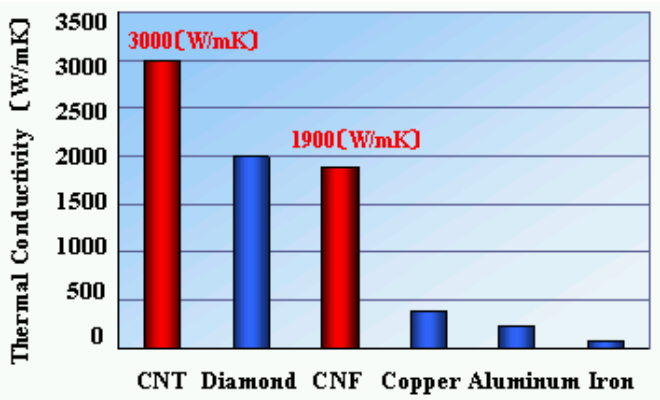


**Figure 2.1**: Comparative graph of thermal conductivity [10]

This material properties enhancement which is high in thermal conductivities as shown in comparative graph above introduce to heat sink material which use to overcome the overheating of micro electric components problem in electronic industry.

## 2.2 CARBON FIBER (CF)

Carbon fiber is a material consisting of extremely thin fibers about 0.005–0.010 mm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber very strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The density of carbon fiber is also considerably lower than the density of steel, making it ideal for applications requiring low weight [11].

The properties of carbon fiber vary widely depending on the structure of the fibers. In general, attractive properties of carbon fibers include the following:

- Low density
- High tensile modulus and strength
- Low thermal expansion coefficient
- Excellent creep resistance
- Chemical stability
- Biocompatibility
- High thermal conductivity
- Low electrical resistivity

Due to the above good properties of carbon fiber, make it very useful in aerospace, military, and motorsports, along with sporting goods and other applications. As the price of this carbon fiber decreases, their application have even become wider for civil engineering applications which they used carbon fiber in constructions to reinforced concrete.

## 2.3 COPPER (Cu)

Copper is typically produced by a pyrometallurgical (high temperature) process. Other methods for copper extraction include leaching copper from low sulfur ores with a weak acid, then electrolytically extracting the copper from solution [6].

Copper was one of the first metals to be worked into implements and the first metal to be smelted from ores. Its excellent ductility and high conductivity assure its use in modern society.

Like gold and silver, copper is malleable. It can be bent and shaped without cracking, when either hot or cold. It can be rolled into sheets as thin as 1/500 of an inch. Copper also is ductile, it can be drawn out into thin wire. [12]

Industry valued copper for these properties. Copper is second material after silver in its ability to conduct electricity, but silver is too expensive for this sort of use. Bronze and brass, however, do not conduct electricity as well as pure copper [13].

Besides electricity, copper also is an excellent conductor of heat, making it an important metal in cookware, refrigerators, and radiators. Copper is resistant to corrosion, that is, it will not rust. If the air around it often is damp, it will change from its usual reddish orange color to reddish-brown [12].

## 2.4 METAL-MATRIX COMPOSITES (MMC)

**Composite materials** are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure [14].

There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties [14].

The wide variety of matrix and strengthening materials allows the designer of the product to choose an optimum combination. The matrix material can be introduced to the reinforcement before or after the reinforcement material is placed into the mold cavity or onto the mold surface. The matrix material experiences a melding event, after which the part shape is essentially set. Depending upon the nature of the matrix material, this melding event can occur in various ways such as chemical polymerization or solidification from the melted state.

The physical properties of composite materials are generally not isotropic (independent of direction of applied force) in nature, but rather are typically orthotropic (different depending on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces or moments. Panel stiffness is also dependent on the design of the panel. For instance, the fiber reinforcement and matrix used the method of panel build, thermoset versus thermoplastic, type of weave, and orientation of fiber axis to the primary force [14].

Recently, the composite material using carbon fiber is applied in the broad field. When carbon fiber is used as Filler, it is known generally that the characteristic of it being lightweight and becoming high intensity and high elasticity is shown. In this research area, composite materials is Carbon Fiber Rein-forced Metals; CFRM which used metal for Matrix [10].

Application of a composite material, aerospace field and sporting goods, such as a tennis racket, golf club, engineering-works construction, etc. reach far and wide applications.

## 2.5 POWDER METALLURGY (PM)

Three processing methods have been primarily used to develop MMCs: high-pressure diffusion bonding, casting, and powder-metallurgy techniques. More specifically, the diffusion-bonding and casting methods have been used for continuous- fiber reinforced MMCs. Discontinuously reinforced MMCs have been produced by powder metallurgy and pressure-assist casting processes.

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. Finally, the end part is formed by applying pressure, high temperature, long setting times (during which self-welding occurs), or any combination thereof [15].

Under high pressure, nanotubes can merge together, trading some $sp^2$ bonds for $sp^3$ bonds, giving the possibility of producing strong, unlimited-length wires through high-pressure nanotube linking [9].

Although the process has existed for more than 100 years, over the past quarter century it has become widely recognized as a superior way of producing high-quality parts for a variety of important applications. This success is due to the advantages the process offers over other metal forming technologies such as forging and metal casting, advantages in material utilization, shape complexity, near-net-shape dimensional control, among others. These, in turn, yield benefits in lower costs and greater versatility [15].

In reality, PM comprises several different technologies for fabricating semi-dense and fully dense components. The conventional PM process, referred to as press-and-sinter, was used to produce the planetary carrier. The surgical scissor parts were formed through the metal injection molding (MIM) process, the manifold was manufactured through hot isostatic pressing (HIP), while the connecting rod was produced using powder forging (PF).

In PM process, custom-blended metal powders are fed into a die, compacted into the desired shape, ejected from the die, and then sintered in a controlled atmosphere furnace. Sintering is the process by which metal powder compacts (or loose metal powders) are transformed into coherent solids at temperatures below their melting point.

During sintering, the powder particles are bonded together by diffusion and other atomic transport mechanisms and the resulting somewhat porous body acquires a certain mechanical strength [7]. The sintering step creates metallurgical bonds between the powder particles, imparting the necessary mechanical and physical properties to the part.

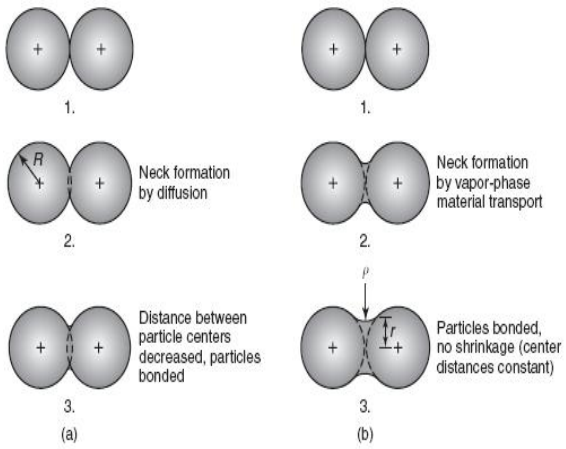


**Figure 2.2**: Sintering Process [7]

Parts produced through the press-and-sinter process are subject to certain limitations as well. Tooling and the maximum press tonnage capabilities impose size and shape constraints on parts that can be fabricated. Finally, the presence of residual porosity in the parts will cause certain physical and mechanical properties to be lower than those of the shaped material.

## 2.6 RULE OF MOXTURE (ROM)

'Rules of Mixtures' are mathematical expressions which give some property of the composite in terms of the properties, quantity and arrangement of its constituents [16].

The properties of the composites, usually density can be predicted by the ‘Rule of Mixtures’ can be denoted as weight fraction or volume fractions. These expressions are derived for a two-phase material and then generalized to a multiphase material.

The volume fractions and weight fractions are given by the equation below.

$$v_c = v_f + v_m \tag{2.5.1a}$$

$$V_f = \frac{v_f}{v_c}, \qquad V_m = \frac{v_m}{v_c} \tag{2.5.1b}$$

and

$$w_c = w_f + w_m \tag{2.5.1c}$$

$$W_f = \frac{w_f}{w_c}, \qquad W_m = \frac{w_m}{w_c} \tag{2.5.1d}$$

The density of the composites material can be obtained in order to establish conversion relations between the weight fractions and the volume fractions. From the basic equation of density, the mass divided by the volume.

$$\rho = \frac{m}{v}$$

The weight in equation Eq. (2.5.1c) can be replaced by the density and volume and equation written as:

$$\rho_c v_c = \rho_f v_f + \rho_m v_m \qquad (2.5.2)$$

Dividing both sides in Eq. (2.5.2) by $v_c$ and substituting Eq. (2.5.1b), the Eq. (2.5.2) can be rewritten as:

$$\rho_c = \rho_f V_f + \rho_m V_m \qquad (2.5.3)$$

For the case of fiber-matrix composites, the equation Eq. (2.5.3) can be written as:

$$\begin{aligned} \rho_c &= \rho_f V_f + \rho_m V_m \\ &= \rho_f V_f + \rho_m (1 - V_f) \\ &= V_f (\rho_f - \rho_m) + \rho_m \end{aligned} \qquad (2.5.4)$$

Since $V_f + V_m = 1$

where $v_c, v_f, v_m$ represent the volume of composite, fiber and matrix material.

$V_f$ And $V_m$ represent volume fraction of fiber and matrix material.

$w_c, w_f, w_m$ Denoted as weight of composite, fiber and matrix material.

$W_f, W_m$ represent weight fraction of fiber and matrix material.

# CHAPTER 3
# METHODOLOGY

## 3.1 PROJECT FLOW

This project begins with researching and understanding on the fundamentals of metal matrix composites, powder metallurgy process and sample preparation for testing. All information about the materials, equipment and experimental procedure were gathered in the first semester of the final year project. The flow of the research processes is illustrated in **Figure 3.1**.

Next stages of this project are the samples preparation using powder metallurgy process and analysis of the microstructure. The last part was the hardness testing of the samples using micro hardness indentation test.

All the experimental work is done in Block 17 of Mechanical Engineering Building with the assistance of mechanical technicians.

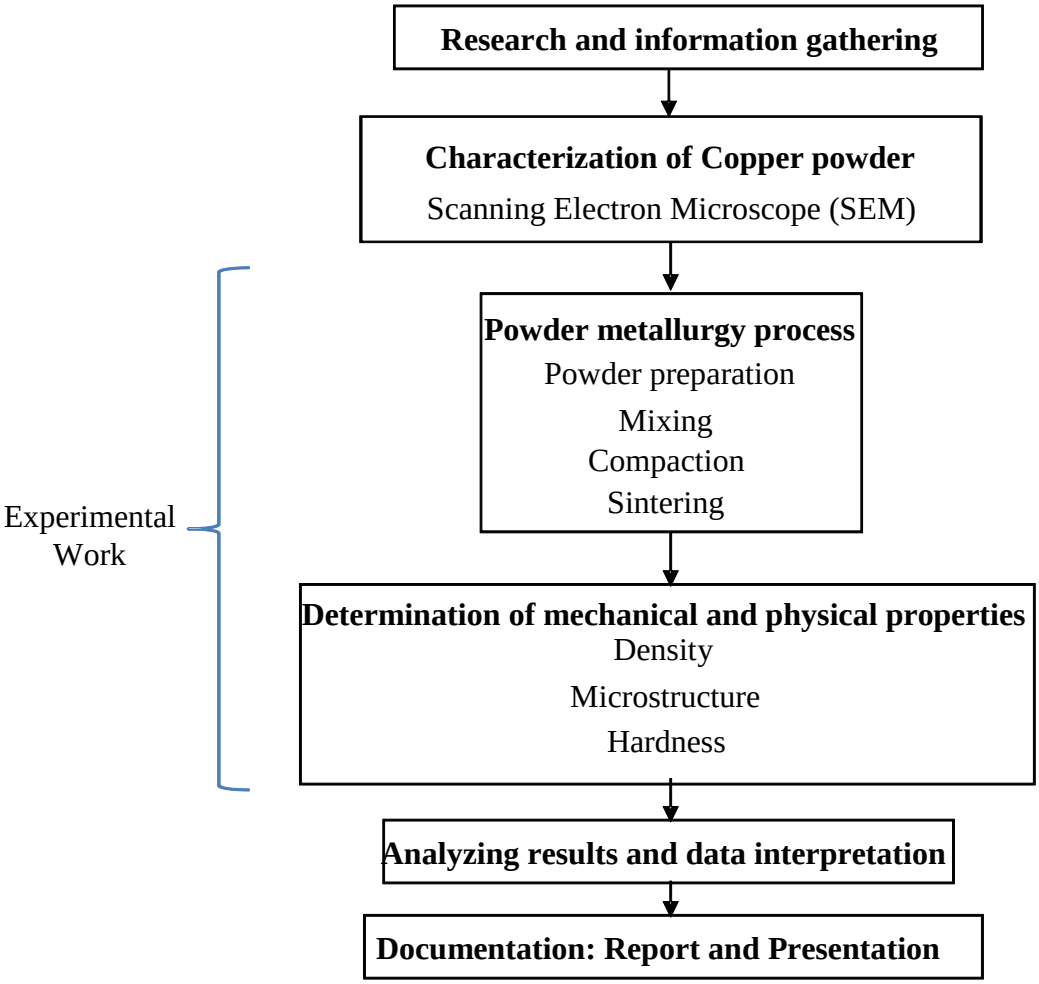


**Figure 3.1:** Flow chart of Project.

## 3.2 SAMPLE PREPARATION

### 3.2.1 Materials and preparation of CNTs, carbon fiber and copper powder.

Matrix and reinforcement material are prepared accordingly by varies sample volume fraction of fiber from 0 to 10% increase by 2.5% (0%, 2.5%, 5.0%, 7.5 % and 10.0%). The mass and theoretical density of the composites samples were calculated using Rule of Mixture (ROM). Refer **Appendix II** for detail calculation.

### 3.2.2 Pre Blending

The accurately weighted matrix and reinforced material is stirred manually to mix them uniformly. This process was done manually using spatula and 400ml beaker for three (3) to five (5) minutes.

Note: Carbon Fiber are chopped (1mm to 2mm length) while mixing with the copper powder until finish. This is to ensure the homogeneity of the mixture and to avoid agglomeration of the carbon fiber in the composites samples.

### 3.2.3 Compaction of mixture

The mixture of the CNTs and copper powder and the chopped Carbon fiber and copper powder are compacted using auto pellet press machine at ambient temperature in a circular die to produce a disc shape of solid green sample with 2mm thickness and 13mm diameter. The samples were pressed under compacted load of 17 tonne or approximately about 490MPa pressure.

The dimension of the compacted samples are measured and recorded to analyze the sample size and volume before and after sintering process.


**Figure 3.2**: Auto pallet Press Machine used for compaction

### 3.2.4 Sintering

The compacted samples or known as ‘green samples’ are sintered in furnace tube for densification of powder particle below the matrix’s melting point of the matrix (70-80% melting temperature) which is 900°C. These process take one and half hour for furnace to heat from room temperature up to 900°C with heating rate of 5°C per minute and another one and half hour heating at constant 900°C temperature. The argon gas in the furnace is control by flow rate of 1100$cm^{3.}$

After the heating process is completed, the samples were cooled down under standard room temperature. All samples were sintered in the argon gas environment to avoid the surface contamination [2].

The dimension of the sample are measured again and recorded to analyze the sample size and volume before and after sintering process.

Note: The furnace need to be purge for 15 minutes before start the heating process. All sintered samples are mounted using hot mount technique for testing preparation.

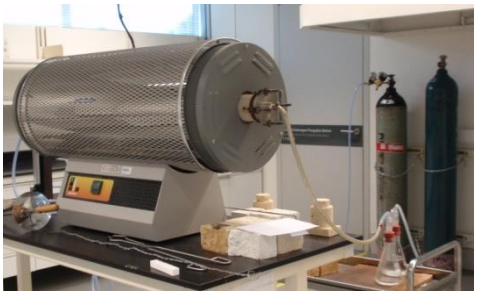

**Figure 3.3**: Tube Furnace used for sintering

### 3.2.5 Hot Mounting

After sintering process the samples is then mounted by Buehler, Simpliment 1000 mounting machine. Thermosetting polymeric powder used is phenolic powder. The phenolic powder is placed in the mould with sample then is heated for 2min and cooled for 5min under the pressure of 3500psi

**Figure 3.4**: Auto Mounting Pressing Machine used for mounting

### 3.2.6 Polishing and Grinding

Grinding and polishing is performed using Grinder and Polisher machine model Metaserv 2000. The sample is ground with SiC paper and water. The SiC paper used raging from 800 grits to 1200 grits.

The samples are polished with the rough polish started with 6micron and then with the 1 micron diamond compound. The speed for both processes is 150 to 200 rpm.

**Figure 3.5:** Grinder and Polisher Machine used for grinding and polishing samples

## 3.3 SAMPLE TESTING

### 3.3.1 Microscopic Examination

In order to analyze microstructure of the sample, metallurgy optical microscope and scanning electron microscope (SEM) are used.

The model for metallurgy optical microscope is Zeiss and the magnification employed in this experiment is 20X. For scanning electron microscope the magnification employed is 500X.

**Figure 3.6**: SEM used to get the microscope image of the samples surface

### 3.3.2 Hardness Test

Hardness of composites samples are measured by conducted Micro hardness testing using Leco LM 247 AT, microhardness machine. The unit of hardness used is Vickers Pyramid Number. The loads used are 50gf and 100gf with the magnification of 50X.

The hardness reading for each sample is taken at ten (10) different locations of the sample's surface to get the most accurate average hardness of the composites. These hardness values provided the data to estimate the yield strength properties of the nanocomposite.

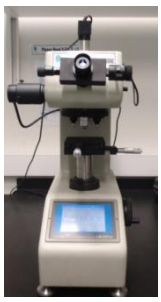

**Figure 3.7**: Microhardness Testing Machine used for indention test

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 PARTICLE SHAPE AND SIZE DISTRIBUTION

Copper powder was characterized using Scanning Electron Microscope to determine particle shape and size distribution of the used copper.

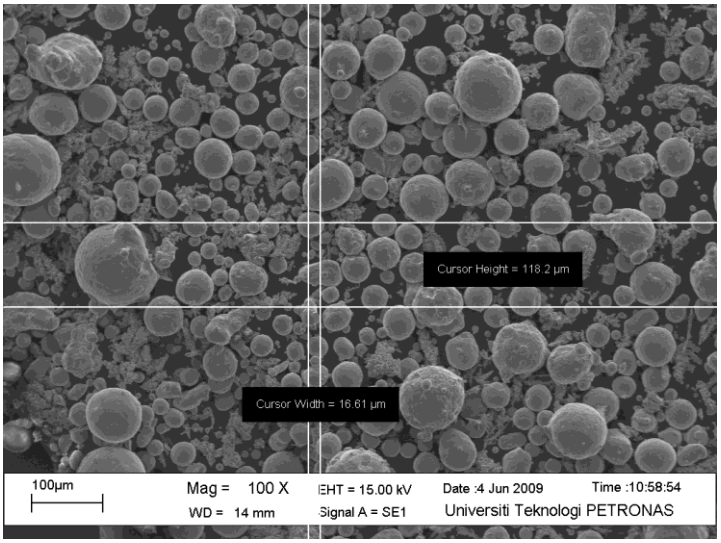


**Figure 4.1:** Particle shape of copper powder

**Figure 4.1** show a scanning electron micrograph of spherical shape copper powder used for this experimental research with 100x magnifications. The particles size ranges approximately from 10µm to 120 µm.

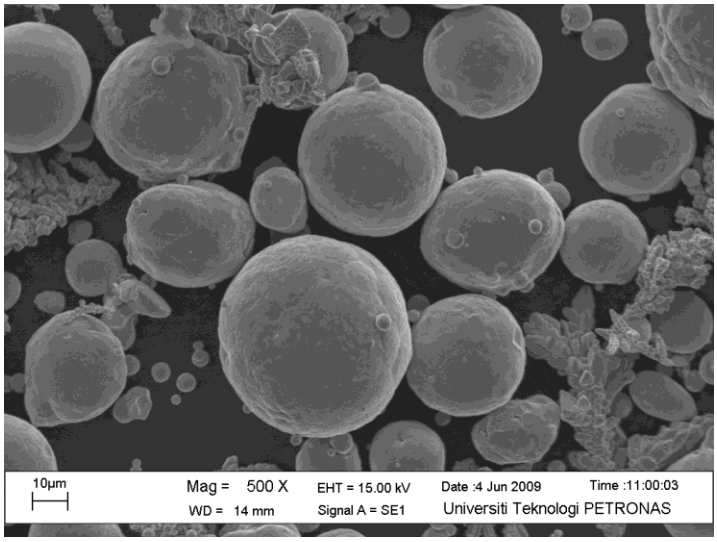


**Figure 4.2:** Particle shape of copper powder

SEM image **Figure 4.2** also showed that most of this copper powder particle is in spherical shape. This shows that this copper powder was produced by gas atomization process. However, there are some of the particles are not in spherical shape with rough and irregular surface. Particle size and shape are the important criteria in producing green product with better packing and improved density during final compaction [8].

## 4.2 PHYSICAL CHARECTERIZATION

### 4.2.1 Dimensional changes

**Figure 4.3**: Green sample

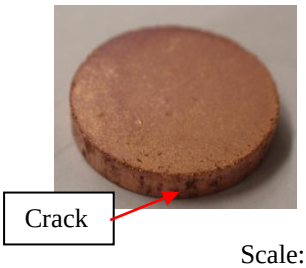


**Figure 4.4**: Sintered sample

Dimensions of the samples differ from green sample and sintered sample. Diameter and thickness of the disc shape samples increased or expand after sintering process. The percentage expansion in thickness is up to 5% .This is due to grain growth of the copper molecules during the sintering process.

From the sample observation, some cracks appear at the wall surface of the disc shape sample as shown above (Refer **Figure 4.4**). This crack produced during the sintering process due to the solid carbon which inside the pores of the parts precipitates from the carbon monoxide in the endogas. This process happened due to inhomogeneous of the composites material between Copper and reinforcement which are CNTs and carbon fiber. Carbon fiber and also CNTs tend to stick each other during the mixing process.

The existence of the cracks on the sintered samples is due to the thermal different coefficient of the copper and reinforced materials.

### 4.2.2 Density

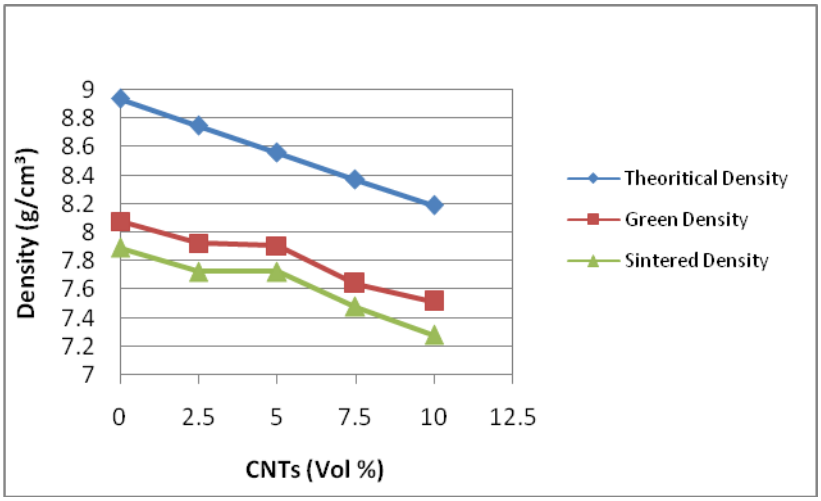


**Figure 4.5**: Density of green and sintered Cu-CNTs composites for various volume fractions

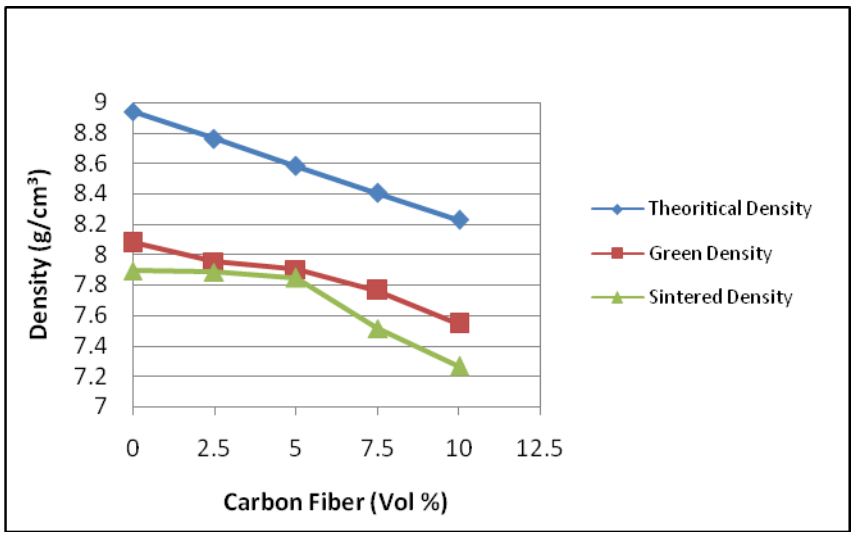


**Figure 4.6**: Density of green and sintered Cu-CF composites for various volume fractions

The previous two figures (Refer **Figure 4.1** and **Figure 4.2**), shows that density of the composites decreased by increasing the volume fraction of fibers and there are slightly differences between theoretical, green and sintered density.

The green density is lower than the theoretical density because theoretical density is calculated using rule of mixture base on the exact density of copper and reinforcement (CNTs or CF) materials properties. The production route of the materials and sample preparation also affects the actual density.

The sintered density of Cu-CNTs was found in the range of 7.28 g/cm³ to 7.893 g/cm³ while for Cu-CF is 7.264 g/cm³ to 7.893 g/cm³. The sintered density is lower than the green density of the composites because densification takes places during compaction and sintering process.

The green and sintered density is calculated from the mass of samples divide by measured volume of the composites samples.

$$\rho = \frac{m}{v} \qquad \text{where} \qquad \begin{aligned} \rho &= density \\ m &= mass \\ v &= volume \end{aligned}$$

Since volume of the samples increase, the density decreased.

## 4.3 MICROSTRUCTUCTURE OF SINTERED SAMPLES

### 4.3.1 Optical Microscopy (Bright field)

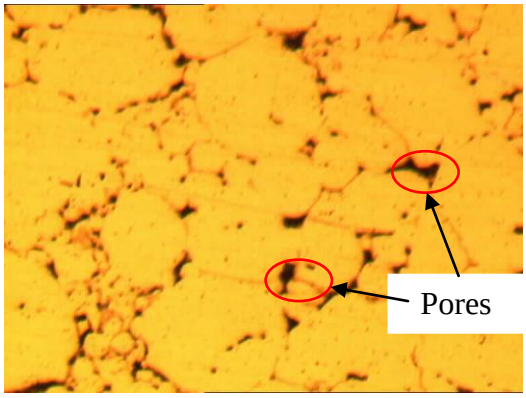


**Figure 4.7**: Optical micrograph of sintered Cu-CNTs

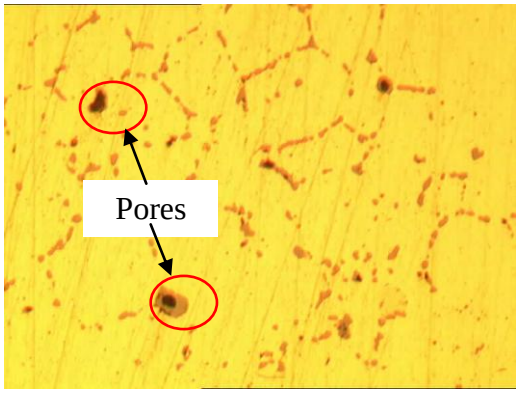


**Figure 4.8:** Optical micrograph of sintered Cu-CF

An optical micrograph (bright field) surface of the composites samples with 200 magnifications are shown above in **Figure 4.3 and Figure 4.4**. The micrograph indicate that the grain growth of copper powder as a result of the sintering. The twin boundaries occur between crystallites. This indicates that recrystallization also takes place. However, there are some pores lying near the boundary.

### 4.3.2 Optical Microscopy (Dark field)

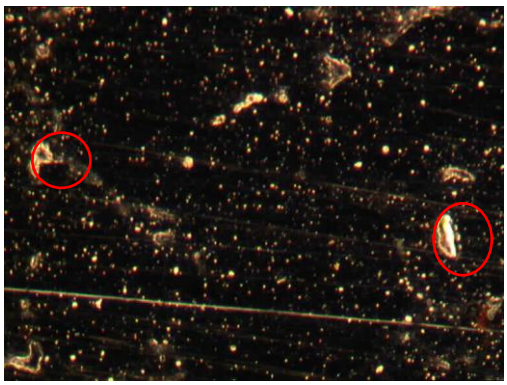

**Figure 4.9**: optical micrograph of sintered Cu-CNTs

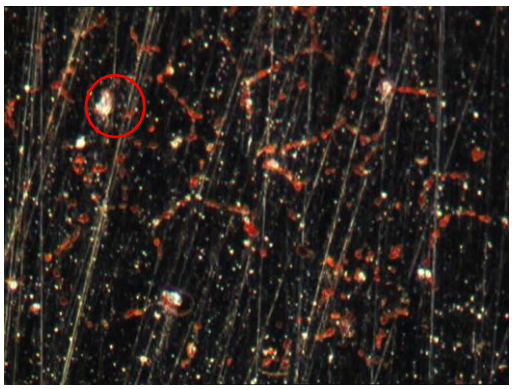

**Figure 4.10**: optical micrograph of sintered Cu-CF

An optical micrograph (dark field) surface of the composites samples with 200 magnifications are shown above in **Figure 4.5 and Figure 4.6.** Bright or white colors in the above figures indicate the presences of pores in the sintered surfaces of the composites. Sintered Copper and CNTS composites samples tend to produce more pores compare to the sintered Copper and CF. This behavior will lead to ductility properties of the material.

### 4.3.3 Scanning Electron Microscopy

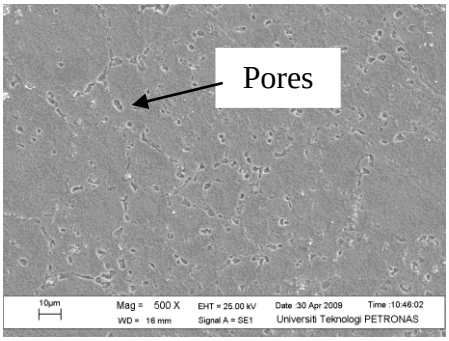


**Figure 4.11**: SEM image of sintered Cu-CNTs

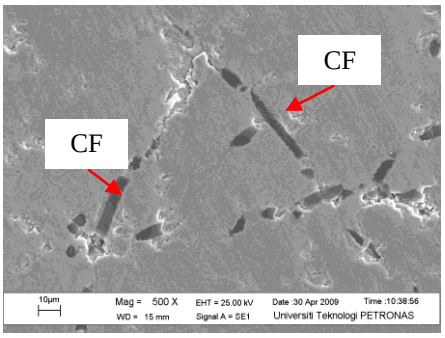


**Figure 4.12**: SEM image of sintered Cu-CF

CNTs particle cannot be seen in the SEM images with 500x magnification (**Figure 4.11**) since the particle size is too small which is about 5 to 20 µm lengths and 1 to 1.2nm diameter. However, the porosity is visible on the microstructure surface. SEM images of the composites surface (**Figure 4.12**) shows that short Carbon Fiber diffuse in the copper particle. The grain size for Cu-CNTs is approximately about 15µm up to 40µm.

## 4.4 HARDNESS OF SINTERED SAMPLES

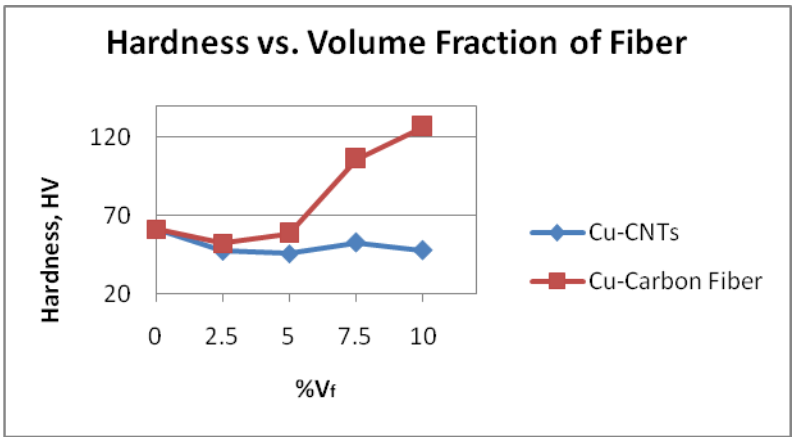


**Figure 4.13:** Relationship between the hardness and volume fraction of reinforcement material

The hardness curves indicated how strong the intermolecular bond between particles. The hardness value obtained from the microhardness testing usually use to estimate the yield strength of the composites. To convert HV to MPa is multiply by 9.807 [14].

### 4.4.1 Cu-CNTs composites

Figure 4.10 shows that the hardness values for copper and CNTs composites are varies and lower from the expected values. The existences pores and void on the microstructure surface lower the composites samples even though the grain sizes was increased.

### 4.4.2 Cu-CF composites

From the above (**Figure 4.13**) hardness curves, the hardness values are increased as the Carbon fiber volume fraction increased. The hardness of the composites decrease from 0%$V_f$ to 2.5% $V_f$ which is from 61.32 to 52.29HV. However, it increased back started from 5.0% $V_f$ to 10%$V_f$ and the increasing value is between 52.29 up to 126.7HV. It shows that low density of sintered part can result in low hardness value.

## 4.5 SIGNIFICANCE OF THE STUDY

The significance of this study is mainly about the need to develop low cost, light weight and high performance Copper metal matrix composites using Carbon nanotubes and carbon fiber particle as reinforcement.

Nanotechnology such as nanocomposites can make a contribution to the following areas:

- Optimizing of existing product
- Damage protection
- Reduction in weight and/or volume
- A more efficient use of materials
- Reduced need for maintenance and/or operational upkeep

And as a direct result:

- Reduction in the consumption of raw materials and energy
- Conservations of resources
- Greater economy

# CHAPTER 5
# CONCLUSION AND RECOMMENDATIONS

## 5.1 CONCLUSION

Development samples of Carbon Nanotubes (CNTs) reinforced Copper matrix and Carbon Fiber reinforced Copper matrix composites were successfully using powder metallurgy process with 17 tonne or approximately about 490MPa load and sintered at 900°C.

Reinforced materials help to provide lightweight material by reducing the density of materials. The sintering behavior of the composites were investigated and explained by analyzed the microstructure of the composites surface. The microstructure behaviors reflect the hardness of the composite. Sintered Copper and CNTS composite show the low hardness values since there are a lot of pores on the composites surface. This pores increase the ductility of composites. Improvement of properties in metal matrix composites (MMC) system are rare possibly because of the low interfacial bonding strength between the matrix and CNTs reinforcements [7].While the hardness value of the sintered Copper and carbon fiber improved by increasing the volume of the carbon fiber.

## 5.2 RECOMMENDATION

Copper powder need to be coated with the reinforcement using electroless copper coating to improve the diffusion bonding between the copper powder and reinforced (CNTs and CF) materials.

For further improvement, use short carbon fiber that readymade by manufacturer with the same length. This is to produce better result and use proper assumption for the project.

Extended effort on the testing methods such as TEM or FESEM on the Copper and CNTs to see the clearer images and bonding between the composites material will be give more valuable information for this project.

# REFERANCES/BIBLIOGRAPHY


[1] Deborah D.L Chung, 2005, *Composite Materials: Science and Applications*, Springer

[2] F. Ahmad, G.Goudah, O. Mamat, N.Muti, R.M. German, *Development of Carbon Nanotubes-reinforced Copper composites for heat sinking applications.*

[3] Randall M. German (1998), *Powder Metallurgy of Iron and Steel*.

[4] Sylvia Leydecker, 2008, *Nano Materials in Architecture, Interior Architecture and Design*, The Deutsche Nationalbibliothek.

[5] Hoganas PM-school, *Sintering*.

[6] Donald R. Askeland and Pradeep Phule, 2003, *The Science and Engineering of Materials*, Fourth Edition.

[7] P.Quang, Y. Gi Jeong, S.C. Yoon, S.I. Hong, S.H. Hong and H.S. Kim, *Carbon Nanotube Reinforced Metal Matrix Nanocomposites Via Equal Channel Anngular Pressing*.

[8] Jenkin and J.V. Wood, in Powder Metallurgy-an overview, The Institute of Metals Series on Powder Metallurgy , USA.

[9] CNTs. 27 July 2008 <http://en.wikipedia.org/wiki/Carbon_nanotube>

[10] Composites. 22 August 2008 <http://www.endomoribu.shinshu-u.ac.jp/.../cnt/index.html>

[11] Carbon Fiber. 22 August 2008 <http://en.wikipedia.org/wiki/Carbon_fiber>

[12] Copper Ore. 22 August 2008 < www.beyondsky.com/mineral/**copper**.html>

[13] Properties of Copper. 22 August 2008
<www.unr.edu/sb204/geology/props.html>

[14] Composites. 27 July 2008 <http://en.wikipedia.org/wiki/Composites>

[15] PM. 5 August 2008 <http://en.wikipedia.org/wiki/Powder_metallurgy>

[16] ROM. 14 August 2008
<www.tech.plym.ac.uk/sme/mats216/powerpoint/**rules**%20of%20**mixture**.ppt>

[17] Vickers Hardness Test, 27 July 2008< http:// Vickers Hardness Test. html>

APPENDIX I
Properties of research materials

Properties of research material

| Material / Properties | SWCNTs (f) | Carbon Fiber | Copper, Cu (m) |
|---|---|---|---|
| **Density, $\rho$ (g/cm$^3$)** | 1.4 | 1.8 | 8.94 |
| **Melting temperature, $T_m$ (°C)** | ≈ 3400 | ≈ 3000 | 1083.4 |
| **Young's Modulus** | ≈ 1.5TPa | 228 GPa | 110 - 128 GPa |
| **Yield Strenght** | 62000MPa | 3200 MPa | 70 MPa |
| **Thermal Conductivity** | ≈ 3000W/m.K | 7.2 | 401 W/m.K |

APPENDIX II

Sample calculation of Volume, Mass, and the theoretical density of the composites

**Calculation**

Composite volume is calculated from the sample volume such below dimension:

Thickness, t: 2mm
Diameter, D: 13mm

Composite Volume, $v_c$

$$= \pi \times \mathrm{r}^2 \times \mathrm{t}$$

$$= \frac{\pi D^2}{4} t$$

$$= \frac{\pi \times 13^2 \times 2}{4}$$

$$= 265.465 mm^3$$

$$= 2.655 \times 10^{-7} m^3$$

<u>At $V_f$ = 2.5% $V_m$=97.5%</u>

$$V_f = \frac{v_f}{v_c}$$

$$v_f = V_f v_c$$

Volume of fiber (CNTs), $v_f$

$$= 0.025 \times (2.6547 \times 10^{-7})$$

$$= 6.6366 \times 10^{-9} m^3$$

$$V_m = \frac{v_m}{v_c}$$

$$v_m = V_m v_c$$

Volume of matrix (Copper), $v_m$

$$= 0.975 \times (2.6547 \times 10^{-7})$$

$$= 2.5883 \times 10^{-7} m^3$$

From the density-mass relation, we can find the mass portion of the reinforcement and matrix material in the composites.

$$\rho = \frac{m}{v}$$
$$m = \rho v$$

$$m_f = \rho_f v_f$$
$$= (1.4 \times 10^6) \times (6.6366 \times 10^{-9})$$
$$= 0.0093 \text{ g}$$

$$m_m = \rho_m v_m$$
$$= (8.94 \times 10^6) \times (2.5883 \times 10^{-7})$$
$$= 2.3139 \text{ g}$$

The theoretical density of the composite can be calculating using equation (2.5.3);

$$\rho_c = \rho_f V_f + \rho_m V_m$$
$$= (1.4 \times 10^6)(0.025) + (8.94 \times 10^6)(0.975)$$
$$= 8.7515 \times 10^6 \text{ g/m}^3$$
$$= 8.7515 \text{ g/cm}^3$$

Volume, Mass, and the theoretical density of the Cu-CNTs composites

| $V_f$ (%) | $V_m$ (%) | $v_f$ | $v_m$ | $m_f$ (g) | $m_m$ (g) | $\rho_c$ (g/m$^3$) |
|---|---|---|---|---|---|---|
| 0 | 100 | 0 | $2.6547 \times 10^{-07}$ | 0 | 2.3733 | 8940000 |
| 2.5 | 97.5 | $6.6366 \times 10^{-09}$ | $2.5883 \times 10^{-07}$ | 0.0093 | 2.3139 | 8751500 |
| 5.0 | 95.0 | $1.3273 \times 10^{-08}$ | $2.5219 \times 10^{-07}$ | 0.0186 | 2.2546 | 8563000 |
| 7.5 | 92.5 | $1.9910 \times 10^{-08}$ | $2.4556 \times 10^{-07}$ | 0.0279 | 2.1953 | 8374500 |
| 10.0 | 90.0 | $2.6546 \times 10^{-08}$ | $2.3892 \times 10^{-07}$ | 0.0372 | 2.1359 | 8186000 |

Volume, Mass, and the theoretical density of the Cu-Carbon Fiber composites

| $V_f$ (%) | $V_m$ (%) | $v_f$ | $v_m$ | $m_f$ (g) | $m_m$ (g) | $\rho_c$ (g/m$^3$) |
|---|---|---|---|---|---|---|
| 0 | 1 | 0 | $2.65 \times 10^{-07}$ | 0 | 2.3733 | 8940000 |
| 2.5 | 0.975 | $6.64 \times 10^{-09}$ | $2.59 \times 10^{-07}$ | 0.0119 | 2.3139 | 8761500 |
| 5.0 | 0.95 | $1.33 \times 10^{-08}$ | $2.52 \times 10^{-07}$ | 0.0239 | 2.2546 | 8583000 |
| 7.5 | 0.925 | $1.99 \times 10^{-08}$ | $2.46 \times 10^{-07}$ | 0.0358 | 2.1953 | 8404500 |
| 10.0 | 0.9 | $2.65 \times 10^{-08}$ | $2.39 \times 10^{-07}$ | 0.0478 | 2.1359 | 8226000 |

APPENDIX III
Density variations of composites samples

Density variations of the Cu-CNTs composites samples

| Samples No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Volume Fraction of CNTs, $V_f$ (%) | 0 | 2.5 | 5 | 7.5 | 10 |
| Theoritical Density, $\rho_c$ (g/cm³) | 8.94 | 8.75 | 8.56 | 8.37 | 8.19 |
| Green Density, $\rho_g$ (g/cm³) | 8.078 | 7.924 | 7.909 | 7.643 | 7.515 |
| Sintered Density, $\rho_s$ (g/cm³) | 7.893 | 7.725 | 7.725 | 7.48 | 7.28 |

Density variations of the Cu-Carbon Fiber composites samples

| Samples No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Volume Fraction of CNTs, $V_f$ (%) | 0 | 2.5 | 5 | 7.5 | 10 |
| Theoretical Density, $\rho_c$ (g/cm³) | 8.94 | 8.7615 | 8.583 | 8.4046 | 8.226 |
| Green Density, $\rho_g$ (g/cm³) | 8.078 | 7.954 | 7.901 | 7.761 | 7.544 |
| Sintered Density, $\rho_s$ (g/cm³) | 7.893 | 7.886 | 7.849 | 7.514 | 7.264 |

APPENDIX IV
Hardness value of the composites

Hardness of the Cu-CNTs composites

| $\%V_f$ | 0 | 2.5 | 5 | 7.5 | 10 |
|---|---|---|---|---|---|
| Hardness (HV) | 61.32 | 47.45 | 45.53 | 52.54 | 47.8 |

Hardness of the Cu-CF composites

| $\%V_f$ | 0 | 2.5 | 5 | 7.5 | 10 |
|---|---|---|---|---|---|
| Hardness (HV) | 61.32 | 52.29 | 58.19 | 105.9 | 126.7 |