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STUDY ON THE INFLUENCE OF SINTERING CYCLE TO THE PROPERTIES OF COPPER FOAM

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ABSTRACT
Poor thermal management leads to high LED junction temperature and give negative impacts to its life and performance. High temperature of LED junction has proven to produce less light and accelerate chip degeneration. Open pore cell copper foam provide good solution to the poor thermal management problem since it has higher surface area, thus increase surface emissivity and enhance thermal conductivity. In this study, copper foams were fabricated using metal injection moulding by using potassium carbonate as space holder. The effect of sintering cycle on physical and mechanical properties were studied using two different sintering cycle which are 450-850°C and 450-850-950°C. It is found that sintered copper foams using 450°C-850-950°C sintering cycle has better mechanical properties in term of hardness and transverse rupture strength. It also exhibit higher porosity which is up to 33.9% compared to 33.1%, thus has higher surface area. This is proven by higher thermal conductivity exhibit by the specimen sintered using 450°C-850-950°C.

General Terms
Sintering.

Keywords
Copper foam, open pore cell, sintering-dissolution, potassium carbonate

1. INTRODUCTION
Light emitting diodes (LEDs) has become one of the main focus areas for general illumination in lighting industry due to its energy efficiency and long lasting light sources. Although LEDs commonly advertised to last between 50,000 to 100,000 hours, its life could be reduce to only few thousand hours when using in fixtures due to poor thermal management [1]. It is a major problem since poor thermal management will leads to high junction temperature which negatively affects the performance of the LED. Elevated junction temperatures have proven to cause an LED to produce less light (lumen output), less forward voltage and significantly accelerate chip degeneration by as much as 75% with an increase from about 100-135°C during regular use [2]. For regular LED fixtures using passive cooling, heat generated LED junction is conducted through heat sink and then dissipated to surrounding by natural convection and radiation. In general, aluminium is widely used as LED heat sink. Wrought copper, Cu is an alternative material to replace aluminium since it has higher thermal conductivity hence effectively dissipated heat better. However, the disadvantage of using wrought copper is that it has higher density than aluminium. Therefore, lightweight copper is needed for LED application. This problem can be solves using foaming technique.

Metallic foams or cellular materials are unique materials with controlled pore structure. Metallic foams have excellent physical and mechanical properties as well as thermal, acoustic, electric and impact absorbance properties [3, 4]. It is a porous metal with high strength to weight ratio with good foam mechanical energy absorption during compression contributed by the ductility of copper [5, 6]. It also offers several interesting features such as low density, high stiffness, high gas permeability and high thermal conductivity. Cu foam has attracted extensive research because of its great market potential in various fields such as catalyst, chemical engineering, energy and environmental protection. The excellent thermal and electrical conductivities of the copper foam are ideally suited for wide range of application such as heat exchanger and catalyst support.

Cu foam conventionally made by investment casting and powder metallurgy but these processes cannot produce near net shape product. For powder metallurgy process, space holder is used to produce open and close cell metal foam made by any sinterable materials. Lost carbonates sintering (LCS) process is one of the solid route technologies to produce open cell porous metals with controlled pore structures. LCS is a simple, low cost process and enables control over pore size and porosity. Porous metal parts are obtained by removing the carbonate particles from the sintered compact either by decomposition or dissolution. Sintering-dissolution process (SDP) is used when there are two phase precursors with one phase is water soluble. Manufacturing of Cu foam using powder metallurgy and dissolution process is considered as part of the development of eco-materials.

Other than limitation in producing near net shape product, another disadvantages of powder metallurgy is that the pore size and its distribution does not affect much on the mechanical properties due to the anisotropic nature of the foam produced by conventional powder metallurgy. This is because space holder particles were rearranged during compaction process leading to non-homogeneous distribution of Cu particles across the thickness [5]. Metal injection moulding (MIM) is one of powder metallurgy process used to produce complicated and near net shape parts. MIM combines the advantages of plastic injection moulding and versatility of conventional powder metallurgy process. MIM enable complex parts to be easily formed to form near net shape product. It is process with high design freedom and tolerance without the needs of secondary machining. For MIM process, polymer binder is added into the metal powder particles as the vehicle of flowability during the injection of green body prior to sintering. The binder is removed by debinding process.

In this study, open pore cell Cu foam is produced using MIM technique and SDP process to obtain the final specimen. Since SDP process was used, addition of carbonates is necessary to act as space holder for pore preform. Space holder selection is critical to ensure the formation of open cell and interconnected pores. NaCl is common salt/carbonate meanwhile Na_2CO_3 is an alternative to increase the interconnectivity of the pores. However, these carbonate especially Na_2CO_3, laminations were observed and lose its integrity after dissolution process [7]. As replacement for NaCl and Na_2CO_3, potassium carbonates (K_2CO_3) is suitable carbonates used as space holder as reported in several literature [3-5, 8]. It is because K_2CO_3 has melting point above the normal sintering temperature of copper and soluble in water. Thus, uniform and homogeneous open cell can be achieved.

2. METHODS AND MATERIALS

In this study, 60% Cu and 40% K_2CO_3 powders were premix using turbula mixer for 3 minutes for homogeneous distribution of the particles. Based on Table 1, the particle size of the Cu and K_2CO_3 at D50 are 16.61 µm and 245.84 µm respectively. The microstructure of the powder particles analysed using Scanning Electron Microscope (SEM) show that both copper and K_2CO_3 powders have polygonal shape such as shown in Fig. 1. The premix blends were added with paraffin wax, polyethylene and stearic acid prior to mixing process. The powders were mixed using z-blade mixer at the speed of 50 rpm for 1.5 hours. The mixing process is conducted at temperature of 160°C to produce the feedstock before it is cooled to room temperature for granulation.

Table 1. Particle size analysis for Cu and K2CO3 powders using Particle Size Analyzer

Reading	Copper, Cu	K2CO3
D20, µm	6.06	201.36
D50, µm	16.61	245.84
D80, µm	24.47	299.57

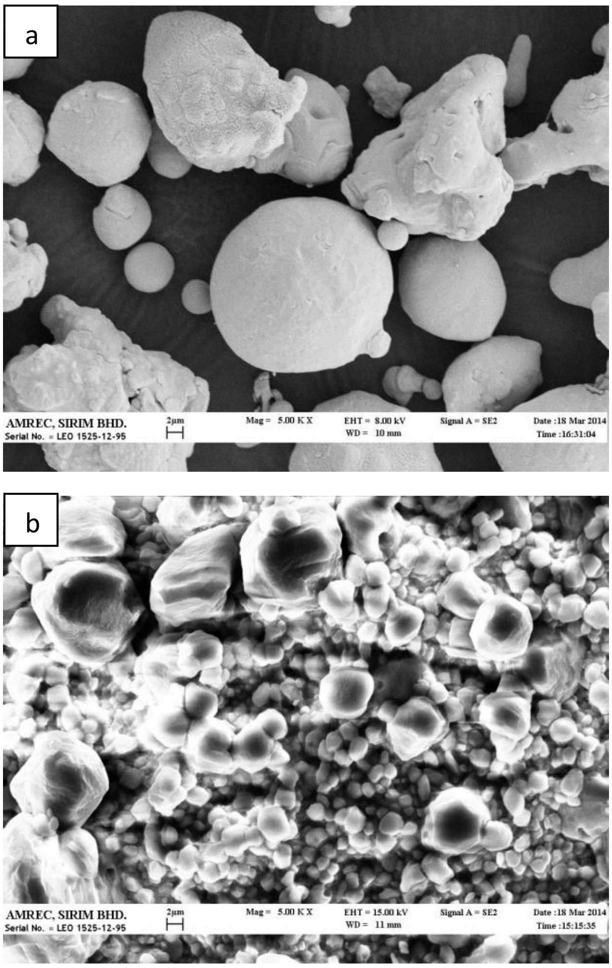

Fig. 1. Morphology of (a) copper and (b) potassium carbonate powders

The granulated feedstock is injected using vertical injection moulding machine at with pressure between 0.6 – 0.9 MPa to produce the green body. The temperature during injection is between 180-200°C. The Cu green body is subjected to solvent extraction by immersing it in heptane at 60°C for 5 hours to remove paraffin wax and stearic acid. Sintering process took place in tube furnace under nitrogen atmosphere. The sintering schedule used is as shown in Figure 2. The sintering process includes thermal debinding process at 450°C. Thermal debinding is critical in order to remove all the organic binders as well as to eliminate residual gases trapped in the specimen meanwhile 850°C is the sintering temperature of the Cu. For 450-850-950°C sintering schedule, 950°C is the temperature for carbonate removal since the melting point of K_2CO_3 is 891°C which it starts to decompose [9]. The sintered Cu foam undergoes dissolution process using 70°C warm water to remove the carbonates completely from the parts to formed interconnected pores.

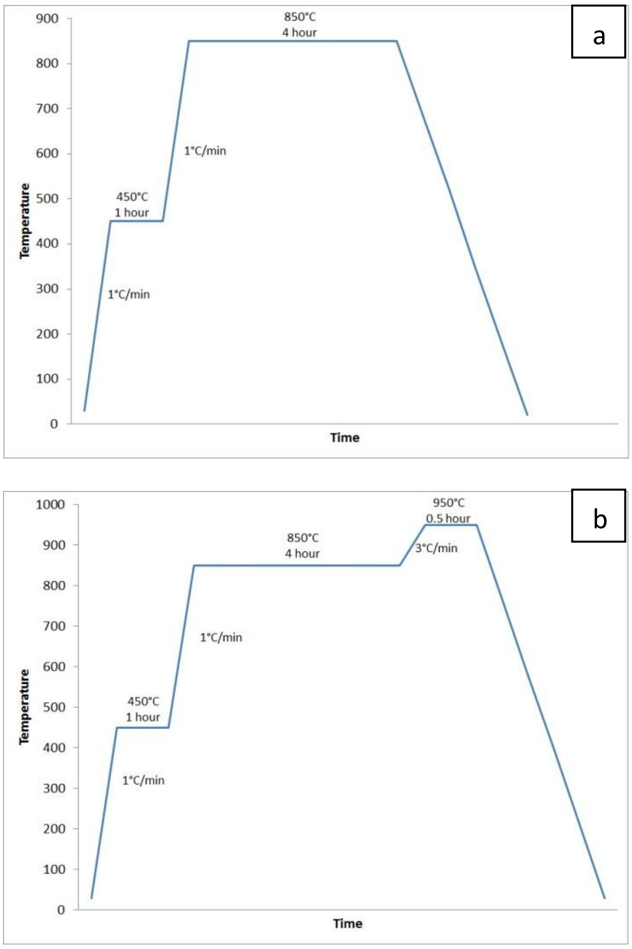

Fig. 2. Two types of sintering schedules to fabricate Cu foam which are (a) 450-850°C and (b) 450-850-950°C.

3. RESULTS AND DISCUSSION

The density of copper foam using 40% K_2CO_3 is such as shown in Table 2. It is found that Cu foam using 450-850-950°C (specimen A) has lower density compared Cu foam using 450-850°C (specimen B). Both Cu foams has lower density compared to bulk density of copper, which is 8.96 g/cm^3, which proved the existence of pore formation in the sintered specimen. Specimen A exhibits higher porosity compared to specimen B which is up to 33.9% compared to 33.1%. Higher porosity in specimen A shows that the 450-850-950°C sintering schedule enhance the removal of carbonates. The combination of decomposition and dissolution of carbonates may be able to solve the problem of time consuming due to long dissolving period such as reported by Yavuz *et. al.* [7]. Based on the results obtained, it is also found that both specimen A and B exhibit higher porosity compared to Cu foam reported by *Harjanto et. al*., which is 27.4% [3].

Table 2. Density and porosity of Cu foam using different sintering schedule.

Specimen	Density, g/cm3	Porosity, %
A	5.93	33.9
B	5.99	33.1

Table 3 shows the mechanical properties of Cu foams in term of its hardness, transverse rupture strength (TRS) and thermal conductivity. It is found that there is slight difference in term of hardness for both of the Cu foams. However, TRS values reveal that specimen A has lower strength compared to be B. TRS values of specimen A and B are 66.01 MPa and 110.93 MPa respectively. It is believed that the strength of the Cu foams in strongly influenced by the percent of porosity exhibited by the specimens. Since specimen A has higher porosity and lower density compared to specimen B, TRS value of specimen A is slightly lower compared to B. This is similar as reported in several literatures in which flexural strength is proportional to the relative density [4, 5].

Table 3. Mechanical properties of Cu foams.

Specimen	Hardness, HV	TRS, MPa	Thermal conductivity, W m-1 K-1
A	54.60	66.01	403.74
B	61.27	110.93	329.63

Thermal conductivity of specimen A is higher compared to specimen B. It is suggested that higher porosity in specimen A enhance its thermal conductivity. This is because specimen A has higher percent of porosity compared to B, which leads to higher thermal conductivity. Although specimen A has higher thermal conductivity compared to B, it is found that there is not much difference with the thermal conductivity of pure copper, which is ~ 390 W/m.K [10, 11] This is maybe due to other factors such as distribution and orientation of pores or existence of impurities. Further investigation is needed to confirm these matters.

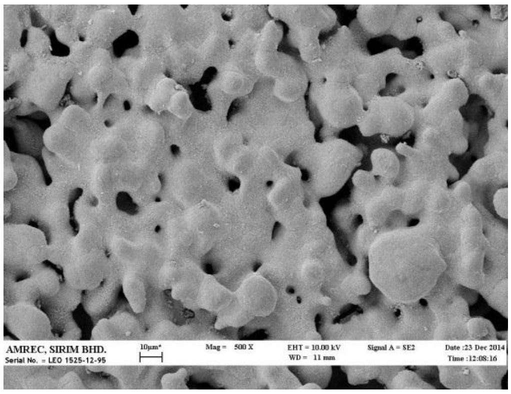

Fig. 3. Porosities exhibited by the Cu foam.

Fig. 3 shows the porosity exhibited by Cu foam after sintering and dissolution process. This shows that the SDP process successfully contributes to the formation of pores in the sintered copper. However, it is found that the formation of pores in the Cu foams as results of combination between interconnected pores and isolated pores. Although interconnected pores improved thermal conductivity of the foams, isolated pores tends to decrease its thermal conductivity. Similar finding suggested that the formation of isolated pores may occur during dissolution process due to equaxed space holder [7].

4. CONCLUSION

Cu foams are fabricated using MIM technique and employs SDP process to form interconnected pores. Cu foam specimens were divided based on the sintering schedules which are 450-850-950°C (specimen A) and 450-850°C (specimen B). Specimen A has lower density and higher porosity than specimen B which indicates that sintering at 950°C enhances the removal of K_2CO_3. Higher porosity in specimen A leads to decrease in strength, which is only 66.01 MPa compared to 110.93 MPa in specimen B. Higher porosity in Cu foams is proven to enhance thermal conductivity since specimen A has higher thermal conductivity compared to B. Although specimen A has higher thermal conductivity, there is no significant difference compared to pure copper. This is probably due to formation of isolated pores apart from interconnected pores exhibited by the specimens.

5. ACKNOWLEDGEMENTS

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