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Effect of Sintering Temperature on Structure, Mechanical Properties and Permeability of Porous Coppers Using Sphere and Dendrite Powder Shapes

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ABSTRACT: *In this research, the porous copper samples were produced by loose sintering route at different sintering temperatures using sphere and dendrite powder shapes. The obtained porous samples were investigated the structure, porosity, compressive strength and permeability. The results show that the porosity and permeability of samples decreased of sintering temperature which resulted in the improvement of compressive strength. The permeability of sample using dendrite powders dropped quickly at high sintering temperature which is attributed to the lower porosity and the more close pores appeared in the structures. In this work, The increase of sintering temperature from 800 to 950^oC led to the reduction of the permeability from $3.68x10^{-13}m^2$ to $2.56x10^{-13}m^2$ and from $11.15x10^{-13}m^2$ to $6.29x10^{-13}m^2$ for the use of sphere and dendrite copper powders, respectively. Meanwhile, the porosity decreased from 41.0 to 34.2% for the use of the sphere Cu powders and from 64.8 to 51.6% for the use of the dendrite powders.*

KEYWORDS*: porous coppers; loose sintering; porosity; permeability*

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I. INTRODUCTION

Porous metals have been playing an important role in various fields such as functional structures, energy, biomaterials and chemical industries, etc. [1-5]. The high porosity and specific surface area as well as the interconnected pores lead to several unique properties of porous metals including good heat conductivity, electrical conductivity, high permeability and excellent acoustic properties, and so on [5-7]. Al, Ti, Cu, Ni and their alloys are widely used to produce porous metals [5, 8]. In which porous Cu-based has been attracted the attention in the fields of energy, thermal dissipation, catalysis, electrical devices, etc. [9-14]. There are several techniques to produce porous copper structure such as electro-deposition, powder metallurgy route, vapor deposition or free casting [15-19]. The powder metallurgy has been received much attention due to the potential to control the homogeneity distribution of pore, pore size and shape as well as porosity of porous coppers [20, 21]. In powder metallurgy route, the porous copper could be produced via the space holder method or loose sintering technique. The loose sintering produces the lower porosity but it can inhibit the contamination from the space holder materials in comparison with the space holder technique. In this work, the porous Cu samples were prepared by loose sintering at different sintered temperature using two kinds of powder shapes; sphere and dendrite powders. The porous samples were investigated the porosity, structure, compressive and permeability toward the increasing of sintering temperature.

II. EXPERIMENT

In this work, the two kinds of copper (Cu) powders (sphere and dendrite shapes with particle size in the range of 44-100μm by sieving, purity ~99.5%) were used as the starting materials. Porous copper samples were prepared by loose-powder sintering in the cylindrical stainless steel tubes to produce the pellets with diameter of 20 mm. The sintering was done in hydrogen gas flow using a tube furnace. The sintering temperature was verified at 800, 850, 900 and 950^oC for 1h. The heating rate was set up at 10 ^oC/min and after holding at sintering temperature, the samples were cooled with the furnace. The structure of porous copper samples was observed on a scanning electron microscopy (FE-SEM, Hitachi S4800). The phase analysis of selected samples was done on X-rays diffractometer (Cu-K_α: 1.5406 Å, XRD, D8 Advace Brucker). Compression test was carried out to determine the yield strength of sintered samples (Super L120, Tinius Olsen). The porosity was calculated from measured density (weigh/volume of sintered samples). The water permeability of all sintered samples was also measured to investigate the hydraulic conductivity of the obtained porous samples according to the Darcy's law [22].

III. RESULTS AND DISCUSSION

Figure 1 and 2 show the SEM images of the fracture surface of the porous coppers sintered at difference temperature. For samples using sphere Cu powders, the particle shape is not significant difference toward the sintered temperature, however, the necks grown among the particles was clearly observed. The increase of temperature led to the neck growth among the Cu particle. This observation is similar to the investigation of Jiang et al. in which they also reported that the neck growth increased with the sintering time and temperature [23]. For samples using dendrite powder shape, the Cu particles were also growing by the immigration of the dendrites to become the larger particles. Even, in one particles, the dendrites also immigrated together to reduce to surface energy and led to the larger dendites. So, the larger of dendrites was observed for the sample sintering at 950^{o}C as seen in Figure 2.

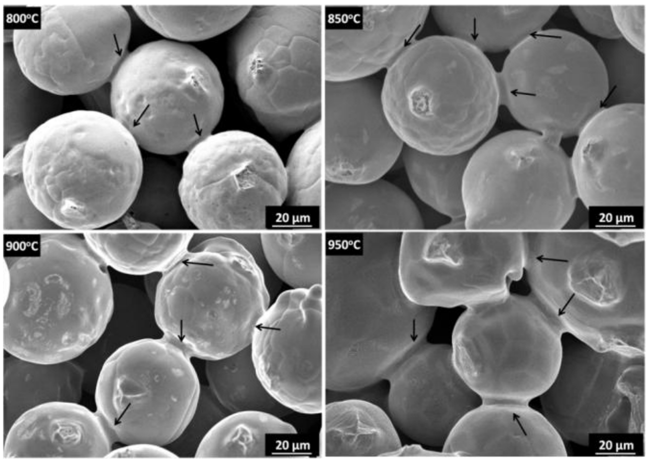

Fig. 1. SEM images of porous copper samples' fracture surfaces at difference sintering temperature using sphere Cu powders; the arrows showing the necks formed among particles

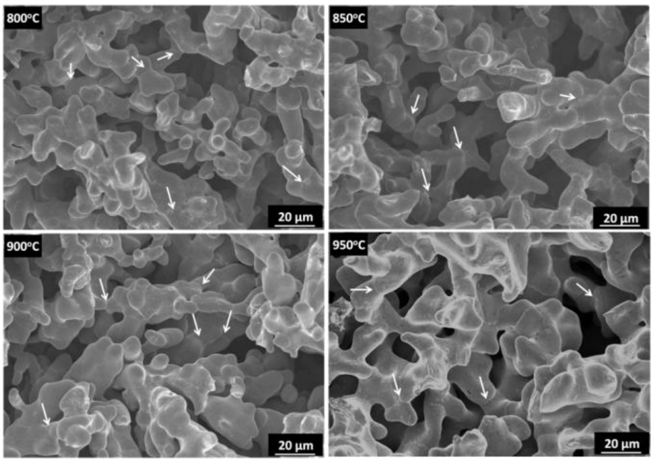

Fig. 2. SEM images of porous copper samples' fracture surfaces at difference sintering temperature using dendrite Cu powders; the arrows showing the necks formed among particles

The XRD pattern and SEM-EDX analysis of the two powder shapes sintered at 950^{o}C are shown in Figure 3 and Figure 4. The XRD patterns show that only diffraction peaks of Cu are detected without the appearance of copper oxide. Although the small amount of oxygen was detected for both kinds of powder shapes as seen in the SEM-EDX analysis (oxygen contents are less than 1 wt.%), the results show that hydrogen can be used as the good environment for porous copper sintering.

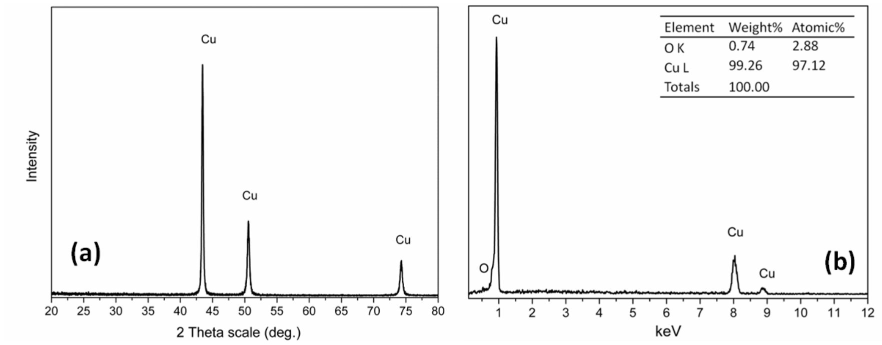

Fig. 3. a) XRD pattern and b) EDS spectrum of porous Cu sintered at 950°C using sphere powder shape

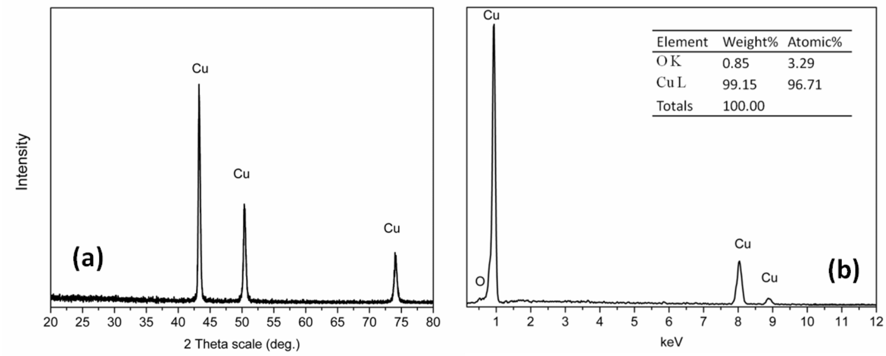

Fig. 4. a) XRD pattern and b) EDS spectrum of porous Cu sintered at 950°C using dendrite powder shape

The porosity of sintered samples was calculated and plotted as seen in Figure 5. As the sintering temperature increased, the rearrangement of the powder particles is enhanced which led to the higher shrinkage of the samples resulted in the reduction of porosity [24]. So, for both kinds of Cu powder, the porosity is reduced toward the sintering temperature, from 64.7 % to 51.6 % and from 41.0 % to 34.2% for the use of dendrite and sphere powder shape, respectively. It it is seen that the porosity of the samples using dendrite Cu powders is higher than that of the samples using the sphere Cu powders at the same sintering temperature. This is due to the fact that the dendrite powder, its self, has higher pores in the particle which also resulted in the more pores induced after sintering in comparison with sphere power shape. However, the reduction rate of porosity is higher for samples using the dendrite powder shape which is attributed to the more contact area among the Cu dendrite particles. The results are also in complement with the above SEM images for both kinds of powders with various sintering temperature.

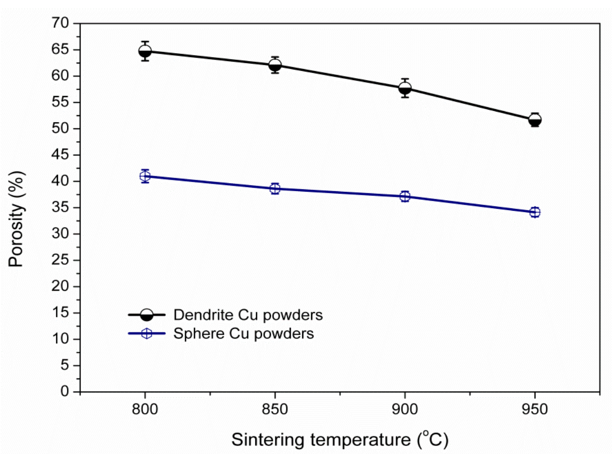

Fig. 5. The porosity of samples vs. the sintering temperature

The stress-strain curves of porous samples are plotted in Figure 6 and 7. For using of both kinds of powders, the increase of sintering temperature led to the improvement of compressive strength by the reduction of porosity and the enhancement of bonding among the Cu powders (evident by the development of the necks between the particles). Moreover, the higher porosity of the samples using dendrite powders resulted in the much lower compressive strength in comparison to the use of sphere Cu powders. Besides that the more irregular pores induced by the dendrite powders which promoted the stress concentration at the edges of the pores and led to the deterioration of the mechanical properties of porous samples using dendrite shape in comparison with the use of the sphere powders [19, 25].

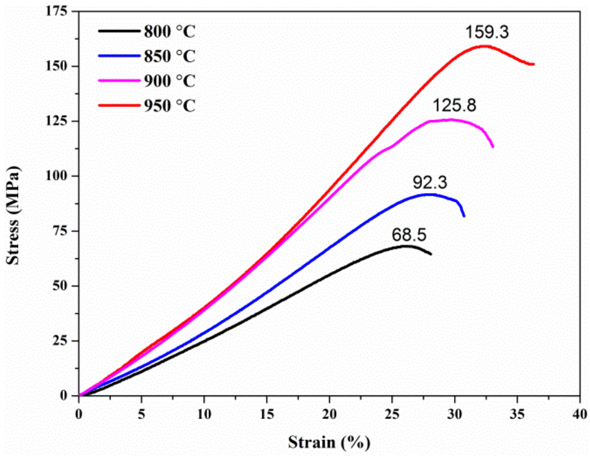

Fig. 6. The stress-strain curves of porous samples using sphere powders at different sintering temperature

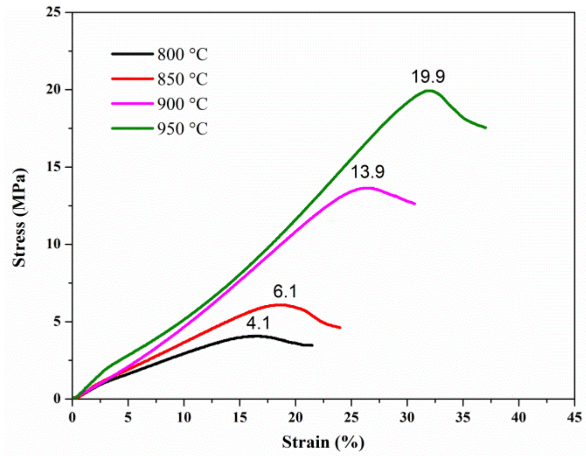

Fig. 7. The stress-strain curves of porous samples using dendrite powders at different sintering temperature

The permeability of porous copper samples is plotted in Figure 8. The porosity reduced by the increase of sintering temperature resulted in the reduction of permeability. As the sintering temperature increased from 800 to 950^{o}C, the permeability decreased from 3.68x10^{-13}m^2 to 2.56x10^{-13}m^2 and from 11.15x10^{-13}m^2 to 6.29x10^{-13}m^2 for the use of sphere and dendrite copper powders, respectively. As the obtained results, the porosity of porous dendrite powders decreased about 16.1% but the permeability quickly dropped about 43.6% as the sintering temperature increase from 800^{o}C to 950^{o}C. The permeability, indeed, depends on the open porosity and the pore size of the samples [26-28]. At high sintering temperature, 950^{o}C, the collapse of porous structure strongly happened in porous samples using the dendrite powders resulted in more close pores in the structure which led to the quick drop of permeability. It is obviously that the pores in porous samples using sphere copper powder are formed by the contacts among the sphere particles, so the pore size is smaller as the increase of sintering temperature but the close pores are very slow to form compared to the use of the dendrite powder. Therefore, the permeability of samples using the sphere powders decreased slowly.

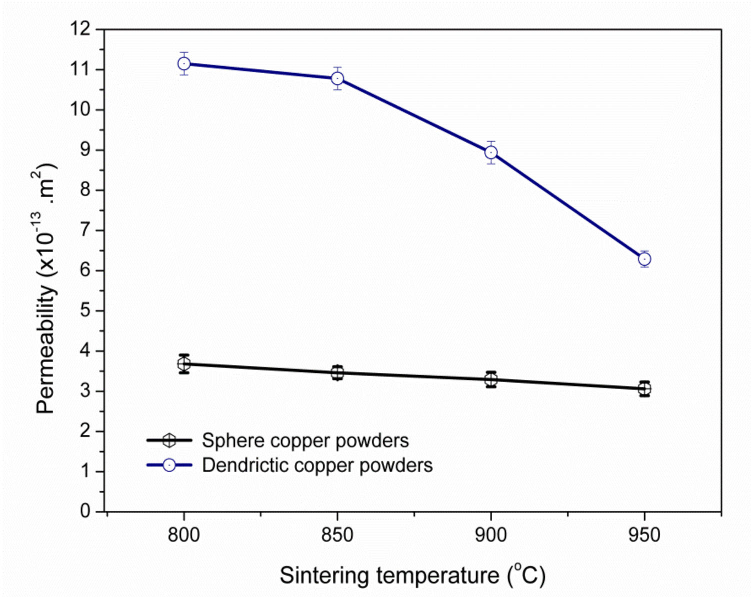

Fig. 8. The permeability of porous samples vs. sintering temperature

IV. CONCLUSION

The porous Cu samples have been produced via loose sintering technique using the dendrite and sphere powder shapes in this work. The porosity, structure, compressive strength and permeability of porous samples strongly depended on the sintering temperature. The necks formed between Cu particles were developed by increasing the sintering temperature. The porosity and permeability decreased with the increase of sintering temperature of using both kinds of powder shapes. But the using of the dendrite powders led to the quickly drop of permeability at high sintering temperature which could be attributed to the more close pores formed in the structure. The compressive strength was enhanced toward the increase of sintering temperature resulted from the stronger bonding between Cu particles and the lower porosity. In comparison, the use of sphere powders brought to higher compressive strength but lower permeability due to the lower porosity at all sintering temperature.

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