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Effects of Aluminium on Sintered Properties of Cu-10wt%Sn Bearing

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Abstract

Self-lubricating bearings are one of the oldest industrial applications of porous powder metallurgy parts, dating back to the mid-1920s. They remain the highest part produced by the P/M industry. The objective of this research was to study the effects of sintering time, sintering temperature and ratio of adding aluminium on sintered properties of Cu-10wt%Sn bearing that was produced from powder metallurgy processing. Various physical and mechanical properties such as density, percentage of porosity and hardness were tested to elucidate the effect of processing parameters. Phase identification and microstructure were analyzed by X-Ray Diffractometer and optical microscope, respectively. Sintering times in the experiment were 5, 30, 45, 60 and 90 minutes; sintering temperatures were 830°C and 900°C and ratios of adding aluminium were 0wt%Al (no adding), 5wt%Al and 10wt%Al. It was found that the larger the addition of aluminium, the greater was the reduction in density and hardness under all sintering conditions. However, additional heat treatment after sintering, by isothermal annealing at 750°C for 1 hour and quenching in water, increased the hardness of all specimens. The best processing condition to obtain a high hardness was sintering at 900°C for 30 to 60 minutes followed by isothermal annealing at 750°C and quenching in water.

Key words: Self-lubricating Bearing, Cu-10wt%Sn, Powder metallurgy

Introduction

Porous parts are divided into two groups, filters and self-lubricating bearing. Glass, ceramics and metallic materials can be used as the starting materials.(1) Nevertheless, sintered metal powders have the best performance as starting materials, as they possess high strength, high thermal resistance, high corrosion resistance, durability and ease to control porosity and permeability. Self-lubricating bearings are one of the oldest industrial applications of porous P/M parts, dating back to the mid-1920. They remain the highest part produced by the P/M industry. The kind of metal powders used for porous parts is selected according to the application. The most commonly used powders include bronze, stainless steel, nickel and nickel-base alloys, titanium and aluminium. While operating self-lubricating bearing, the bearing material carries the load while the pores act as lubrication channels. Consequently, improving self-lubricating bearing by dispersion hardening in order to reduce wear and acquire a lower friction coefficient will increase its service life. The objective of this research is to study the effects of sintering time, sintering temperature and ratio of adding aluminium on sintered properties of Cu-10wt%Sn bearing that was produced from powder metallurgy processing.

Materials and Experimental Procedures

Premixed Cu-10wt%Sn powders and 99.9% pure aluminium powders were mixed and blended together in various ratios of added aluminium: 0wt%Al (no adding), 5wt% and 10wt%Al. The mixture was compacted into cylindrical shape (1.1 mm. diameter and 1-1.3 mm. height) under a fixed pressure of 180 MPa. Weight and size of the sample were measured to calculate density before sintering. Sintering took place in a batch type alumina tube furnace maintained at 830°C and 900°C for 5, 30, 45, 60 and 90 minutes under argon atmosphere. After sintering samples weight and size were measured. Density and porosity were measured by Archimedes' method. Hardness of samples was measured by Vickers microhardness tester using 1 kg load. The samples were phase identified by using X-ray Diffractometer. The microstructure was investigated by using optical microscope and scanning electron microscope.

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Results and Discussion

Results will be discussed in two parts: result from sample sintered at 900°C and after heat treatment.

Sintering Temperature at 900°C

It was found that microstructures of samples at different sintering times look similar. Figure 1 shows the microstructure of 0wt%Al, 5wt% and 10wt%Al sample sintered at 900°C for 30 minutes (a) – (c) at the center of the sample, (d) –(f) at the edge of the sample. Pores at the center of the sample are quite round, but pores at the edge of the sample are irregular, and with added aluminium the pores become more irregular. This indicates that sintering at the center was more complete. Possible causes of pores at edges were friction at die wall during compaction, and evaporation of aluminum from the sample surface.

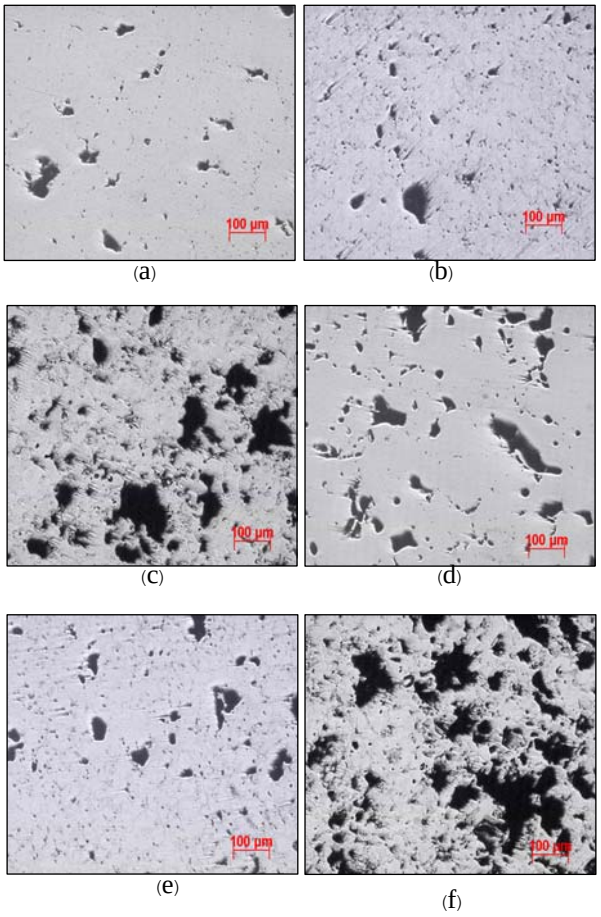

Figure 1. Microstructure of 0wt%Al, 5wt% and 10wt%Al sample sintered at 900°C for 30 minutes (a)–(c) at the center of the sample; (d) – (f) at the edge of the sample.

Figures 2 and 3 demonstrate the density and hardness of 0wt%Al (no adding), 5wt%Al and 10wt%Al samples sintered at 900°C.

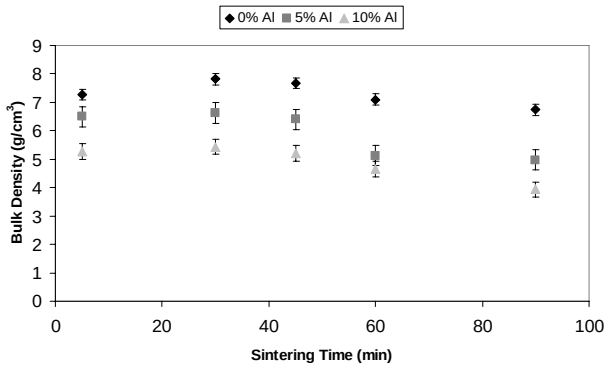

Figure 2. Effect of sintering time and amount of aluminium on the density of Cu-10wt%Sn samples sintered at 900°C.

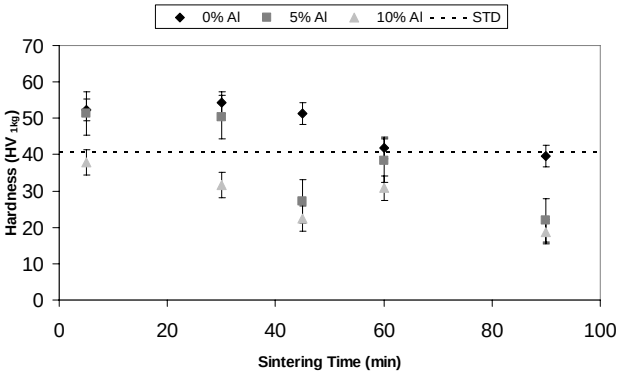

Figure 3. Effect of sintering time and amount of aluminium on the hardness of Cu-10wt%Sn samples sintered at 900 °C.

The density of non-added aluminium samples sintered at 900°C for 30 minutes was the greatest and amounted to 7.81 g·cm^{-3}, with a minimum porosity of 9.53% and the maximum hardness of 54.4 HV. Densities of 5wt%Al and 10wt%Al adding samples sintered at 900°C for 30 minutes were greatest and equaled 6.63 and 5.44 g·cm^{-3}, respectively. The porosity was 15.53% and 27.96%, respectively. However, the hardness was maximum at 51.30 and 37.90 HV when sintered at 900°C for 5 minutes. For all sintering times, samples without addition of aluminium have higher hardness than the ones with aluminium. The effect of aluminium on the density of the samples is as follows: the larger the addition of aluminium, the greater is the reduction in density at all sintering times. It is lower than that of the reference samples from the K.Powder factory, indicated by the dash line in Figure 3. Therefore,

porosity increases and hardness decreases when adding a larger amount of aluminium at all sintering times. The same correlation is found in samples sintered at 830°C. When the samples have less density and more porosity, this can cause stress concentration at the edge of the pores. Stress concentration is one of the causes that set off lower sample hardness. Two possible causes of pore occurrence are vaporization of aluminium and Kirkendall void. Vaporization of aluminium occurs because aluminium has higher vapor pressure at high temperature. Vapor pressure of pure aluminium obeys equation 1.[2]

$$\log(P) = 10.917 - \frac{16211}{T} \qquad \text{Eq.1}$$

P is a vapor pressure in Pascal and T is an absolute temperature. Vapor pressure at 900°C is 0.17×10^{-3} Pa. Atmospheric pressure is much larger than vapor pressure of pure aluminium at 900°C; therefore, the vapor pressure effect can be neglected. Weight loss after sintering of samples sintered at 900°C for different sintering times is shown in Table 1.

Table 1. Weight loss after sintering at 900°C for different sintering times.

Sintering time (min)	0 wt%Al (g)	5 wt%Al (g)	10 wt%Al (g)
5	0.040	0.030	0.030
30	0.015	0.055	0.035
45	0.040	0.035	0.045
60	0.025	0.065	0.035
90	0.025	0.050	0.035

Lubricant weight plus aluminium weight for 0wt%Al, 5wt%Al and 10wt%Al samples are 0.045 g, 0.375 g and 0.715 g, respectively. It can be seen that weight loss of all samples is less than lubricant weight plus aluminium weight. Therefore, the main cause of pore occurrence in samples is from Kirkendall effect which is diffusion phenomenon of two species with different diffusion coefficient. This causes void in the samples. In this case, the void is caused from tin and aluminium diffusing into copper faster than the reverse. A long sintering time allows tin and aluminium more time to diffuse into copper; hence, a larger amount of pores was created. Figures 4 – 6 show XRD patterns of samples sintered at 900°C for 30, 60 and 90 minutes.

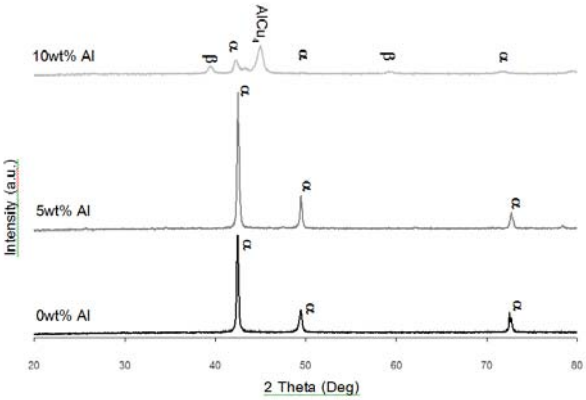

Figure 4. XRD Pattern of samples sintered at 900°C for 30 minutes.

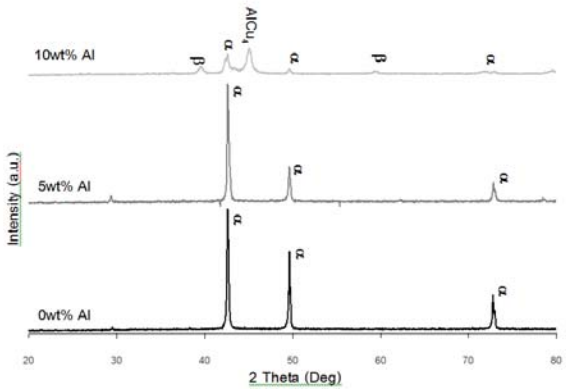

Figure 5. XRD Pattern of samples sintered at 900°C for 60 minutes.

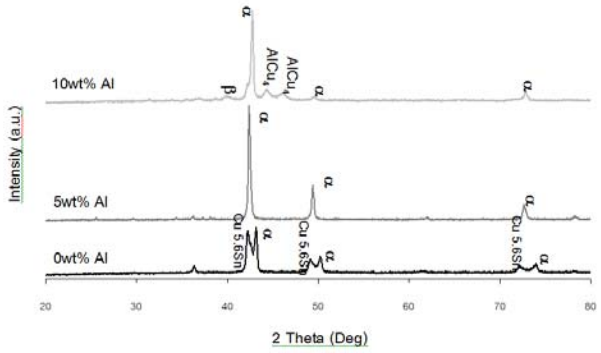

Figure 6. XRD Pattern of samples sintered at 900°C for 90 minutes.

The XRD pattern gives evidence that the main phase found in samples is solid solution of 10wt% tin in copper (α phase, JCPDS #44-1477), which can be found in all samples. Furthermore, β phase (JCPDS #06-0621), which is solid solution of high tin content in copper (25 – 26.5wt%tin), and the intermetallic compound $AlCu_4$ (JCPDS #28-0006) are still present in 10wt%Al samples. Split peaks also occur in the samples sintered at 900°C for 90 minutes. These split peaks are matched

with Cu-5.6Sn JCPDS files (JCPDS #31-0487). The relative amount of phases is as follows: the amount of α phase in 10wt%Al samples sintered at 900°C increases with sintering time, and amount of β phase in 10wt%Al samples sintered at 900°C decreases with increasing sintering time. While the amount of α phase increases with progressing sintering time, so are the vacancies occurring from diffusion of tin into copper. Therefore, the trends of density and porosity are as aforementioned.

Results from Heat Treatment

Figure 7 shows the microstructures of samples sintered at 900°C for 30 minutes and heat-treated at 750°C for 60 minutes of 0wt%Al, 5wt% and 10wt%Al sample, (a) - (c) at the center of the sample, (d) - (f) at the edge of the sample.

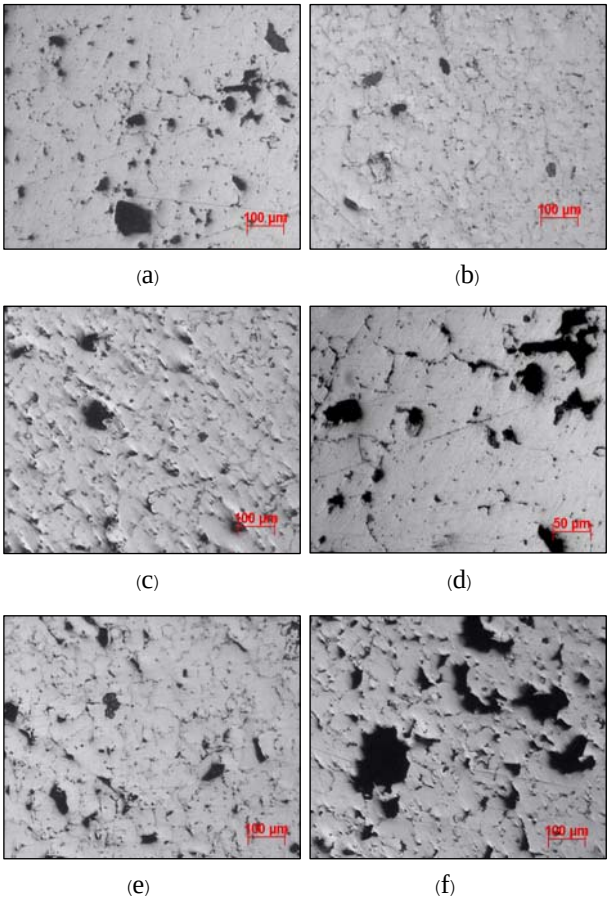

Figure 7. Microstructures of samples sintered at 900°C for 30 minutes and heat-treated at 750°C for 60 minutes of 0wt%Al, 5wt% and 10wt%Al sample; (a) – (c) at the center of the sample; (d) – (f) at the edge of the sample.

The microstructures confirm that pores at center and edge of the samples slightly increase when compared to the ones before heat treatment. Table 2 shows the density, porosity and hardness of 0wt%Al (no adding), 5wt%Al and 10wt%Al samples sintered at 900°C, and heat treatment at 750°C.

Table 2. Density, porosity and hardness of 0wt%Al (no adding), 5wt%Al and 10wt%Al samples sintered at 900°C, and heat treatment at 750°C.

Al amount (wt%)	Bulk Density (g/cm^3)	% Porosity	Hardness (HV_{1kg})
0	7.38	15.70	51.00
5	6.43	19.66	69.20
10	5.26	29.97	39.60

Comparing density and porosity before and after heat treatment, it was found that density after heat treatment is slightly lower than before heat treatment; porosity after heat treatment is slightly higher than before heat treatment. Hardness after heat treatment of 0wt%Al is slightly lower than before heat treatment. However, hardness of the samples with added aluminium, 5wt%Al and 10wt%Al increases by 37% and 25%, respectively. Figure 8 shows the XRD pattern of samples sintered at 900°C for 30 minutes, and heat-treated at 750°C for 60 minutes.

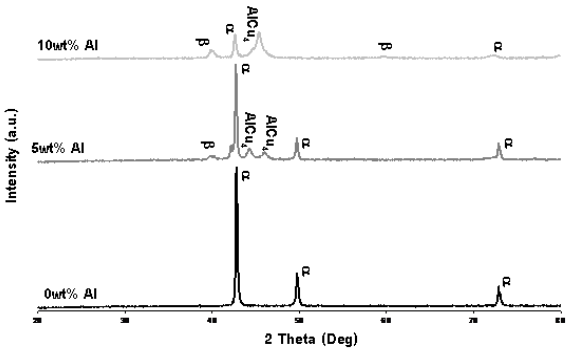

Figure 8. XRD Pattern of samples sintered at 900°C for 30 minutes and heat-treated at 750°C for 60 minutes.

According to the XRD pattern of heat-treated samples, it was found that the main phase existing in samples is solid solution of tin in copper (α phase), which is the same as in samples before heat treatment, and α phase can be found in all samples. Five weight percent samples contain both α phase, a slight amount of β phase and $AlCu_4$.

Ten weight percent samples contain α, β phase and $AlCu_4$. Considering the relative amount of phases in heat-treated samples, it was found that the aluminium sample without adding contains only α phase. For added aluminum sample, 5wt%Al contains β phase as a new phase which had not been found in the sample before heat treatment. The ten weight percent aluminum sample has no new phase after heat treatment. Therefore, the cause of hardness reduction of the aluminum sample (0wt%Al) without adding is pores formation and coalescence. Although the density of 5wt%Al sample is slightly reduced, the hard new phase, $AlCu_4$, which exists in the sample, increases its hardness.

Conclusions

1. The larger the addition of aluminium is, the greater is the reduction in density and hardness in as-sintered tin-bronze bearing material.
2. Porosity increases and hardness is reduced when adding larger amount of aluminium at all sintering times.
3. The main cause of pore occurrence in samples is from Kirkendall effect.
4. Additional heat treatment at 750°C for 60 min can increase hardness of tin-bronze bearing material with addition of 5wt%Al and 10wt%Al samples by 37% and 25%, respectively.

Acknowledgements

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