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Study of Process Parameters in Conventional Powder Metallurgy of Silver

Suttha AMARANAN and Anchalee MANONUKUL*

National Metal and Materials Technology Center,
114 Thailand Science Park Phaholyothin Rd.,
Klong Nueng, Klong Luang, Pathumthani. 12120

Abstract

Compaction, sintering and physical properties of silver powder were investigated. The silver powder was uniaxially compacted into a cylindrical specimen using compaction pressures of 13.79, 27.58, 41.37 and 55.16 MPa. Compacted parts were sintered at 700, 800 and 900°C in argon atmospheres. In addition, compacted parts were also sintered in vacuum at 900°C. For the sintering temperatures of 700 and 800°C, it was found that the sintered density increased as the compaction pressure increased below 40 MPa, while the sintered density decreased at a compaction pressure above 40 MPa. At the sintering temperature of 900°C, the sintered density decreased with increasing compaction pressure. The highest sintered density of 10.22 $g \cdot cm^{-3}$ (67.41 % relative density) was obtained at a temperature of 900°C under argon atmosphere for compaction pressure of 13.79 MPa. At this sintering temperature, vacuum sintering gave a slightly higher sintered density than argon atmosphere. Moreover, the difference in shrinkage of thickness and diameter of the sintered parts was observed. The diameter has higher shrinkage than the thickness. The weight of the specimen did not affect the sintered density, whereas the compaction pressure, sintering temperature and atmosphere influenced the sintered density.

Key words: Silver, Powder metallurgy, Compaction and sintering

Introduction

Silver is a soft, ductile and malleable metal. It has high electrical and thermal conductivity. Silver products are traditionally fabricated by investment casting, which consists of many processing steps. Investment casting has low yield in mass production. Conventional powder metallurgy (compaction and sinter) is a process which can fabricate the loosed powder into a near-net-shape product in large quantity with less processing steps and higher yield in production. Silver powder is used in various applications, such as electronic parts, water purification, dental amalgams, jewellery and souvenirs.[1] Moreover, there are many parameters that can affect the sintering of silvers, for example the sintering rate (Hirschhorn and Berglund 1968), heating rate (Oliber, *et al.* 2003) and atmospheres, which were air, oxygen and argon.[2,5,7,9] In this work, the conventional powder metallurgy process was thus applied for processing silver. Four process parameters, which are compaction pressure, specimen weight, sintering temperature and sintering atmosphere, were investigated. Their effects on sintering were studied.

Materials and Experimental Procedures

The silver powder was supplied by Beauty Gems Co., Ltd., Thailand. The theoretical and tap densities of the powder were 10.49 and 3.04 $g \cdot cm^{-3}$, respectively. Figure 1 shows the SEM micrograph of silver powder. This silver powder was irregular. There was some agglomeration of small silver powders. The average agglomerated size of the silver powder was 5.0 µm. The silver powder was uniaxially compacted into a cylindrical specimen. The compaction pressures were varied as follows; 13.79, 27.58, 41.37 and 55.16 MPa. Subsequently, compacted parts were sintered at 700, 800 and 900°C for 4 hours in argon. In addition, samples were also sintered in vacuum at 900°C. The influence of the weight of the specimens was investigated. Three different weights of silver powder, which were 10, 15 and 18 g, were compacted using the compaction pressure of 55.16 MPa, and sintered at 700°C under argon atmosphere for 4 hours. The physical properties, such as, density and dimensions and linear shrinkage, were measured for both green and sintered parts. It is discerned that the linear shrinkage reported in this work was calculated from the comparison between the sintered parts with respect to the green parts.

Corresponding author Tel.:+66 2564 6500 ext. 4707; Fax. : +66 2564 6403;
E-mail : anchalm@mtec.or.th

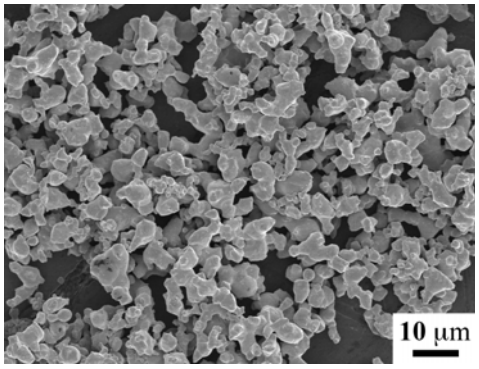


Figure 1. SEM micrograph of the silver powder

Results and Dissustion

Green Density

The effect of compaction was investigated on the sintering of silver. Different compaction pressures in the range 13.79-55.16 MPa were applied. The green density, which is the density of specimen after compaction (the left vertical axis), and the corresponding relative green density (the right vertical axis) were plotted on the same graph as shown in Figure 2 as a function of compaction pressure. It is discerned that the relative green density was calculated from the green density, and the theoretical density for silver in this work was 10.49 g·cm^{-3}. The green density and relative green density increased as the compaction pressure increased. Furthermore, the rate of increase in green density with respect to the compaction pressure was lower at higher compaction pressure. In addition, the highest green density of 7.25 g·cm^{-3} (69.11 % relative green density) was obtained at a compaction pressure of 55.16 MPa. When the compaction pressure of 13.79 MPa was applied, this gave the lowest green density of 5.31 g·cm^{-3} (50.64 % relative green density). Silver powder was elastically and plastically deformed during compaction. Compaction with low compaction pressure caused powder rearrangement, elastic deformation and initial plastic deformation of powders. Further compaction caused the powder to become better packed and more plastically deformed.[3] The compact which was pressed with higher pressure had less porosity, a higher number of contacts and a larger contact area. This resulted in work hardening and hence higher compaction pressure was required. It became more difficult to obtain higher density using the same increment in compaction at the higher-pressure range. Figure 3 shows the green and relative green density plotted against the specimen weight. It can be seen that the green densities were similar due to usage of the same compaction pressure.

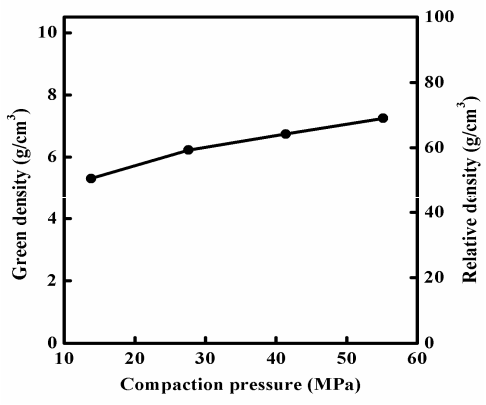


Figure 2. Green density and relative green density as a function of compaction pressure

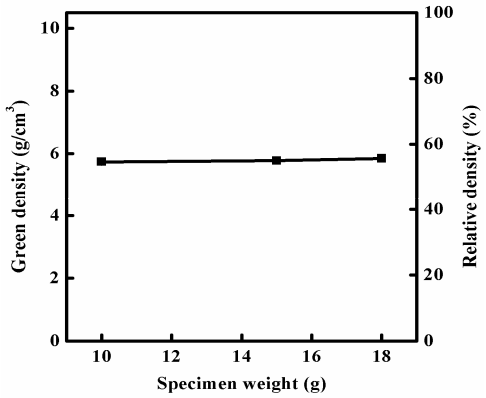


Figure 3. Green density and relative green density as a function of specimen weight

Sintered Density

The green specimens were sintered at 700, 800 and 900°C for 4 hours in argon atmosphere. For the sintering temperature of 900°C, the green parts were sintered in both argon atmosphere and vacuum. The sintered density (the left vertical axis) and the relative sintered density (the right vertical axis) were plotted against the compaction pressure as shown in Figure 4. For sintering in argon atmosphere at temperatures of 700 and 800°C, the sintered density increased as the compaction pressure increased up to compaction pressures of 40 MPa, while the sintered density slightly decreased at compaction pressures above 40 MPa. The sintering temperature of 900°C demonstrates that the specimens which were sintered in the argon atmosphere had a slightly lower density than the specimen sintered in vacuum due to the trapped gas inside the pores which opposed densification.[6,8] In addition, the sintered density of those specimens sintered at 900°C in both vacuum and argon atmospheres decreased as the compaction pressure increased.

At the compaction pressure of 13.79 MPa in argon atmosphere it is observed that the sintered density at 700, 800 and 900°C increased accordingly. The density increased due to the higher densification at the higher temperature. [6,8,10] Sintering is thermally activated process with diffusion is the main mechanisum. Consequently, the motion of atoms and vacancies is faster when the temperature is raised.[3] The highest sintered density of 10.2 g·cm^{-3} (98.94 % relative sintered density) was obtained by sintering at 900°C in vacuum. On the other hand, the lowest sintered density of 9.65 g·cm^{-3} (92.02 % relative sintered density) was sintered at 700°C in the argon atmosphere.

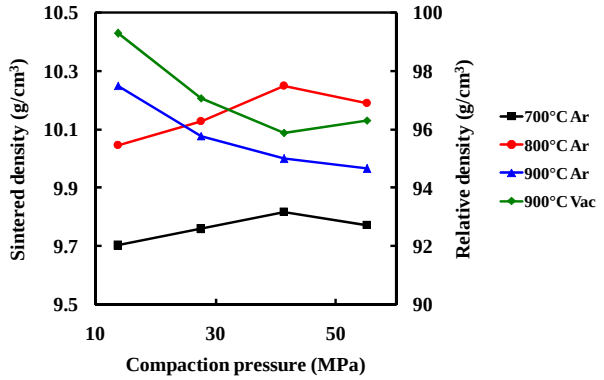


Figure 4. Sintered density and relative sintered density as a function of compaction pressure

The effect of specimen weight was investigated by pressing three different weighted silver powders. The silver powders were weighted 10, 15 and 18 g, and compacted using the constant pressure of 55.16 MPa. Compacted parts were sintered at 700°C in an argon atmosphere. Sintered density was plotted against the weight of specimen and is shown in Figure 5. It can be seen that the sintered density for all specimen weights was nearly the same.

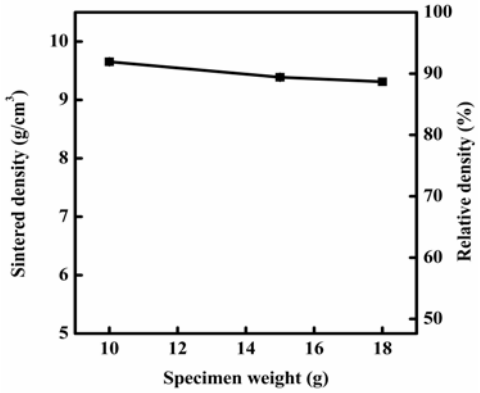
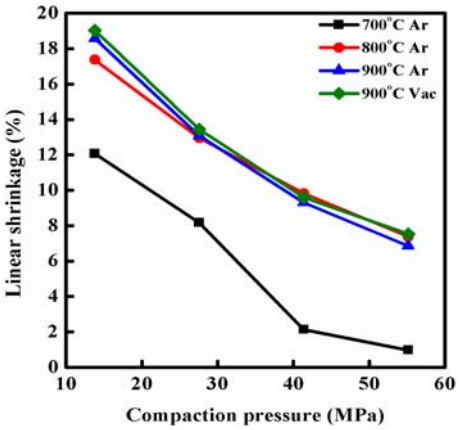


Figure 5. Sintered and relative sintered density as a function of specimen weight

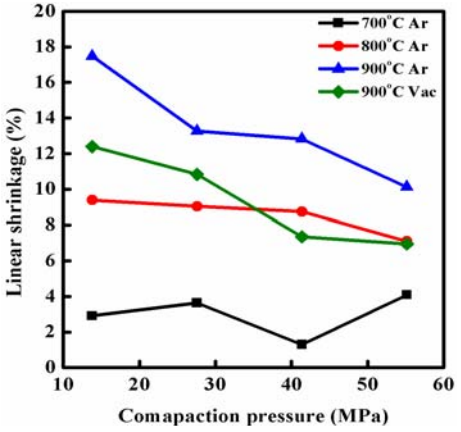
Shrinkage

The dimensions were measured for both green and sintered parts to depict shrinkage behaviour. The dimension changes were caused by densification during sintering, gravitational force and friction between sintered parts and supports.[4] Figure 6 shows the linear shrinkage of (a) diameter and (b) thickness as a function of compaction pressure. It can be seen that the shrinkage revealed the tendency to decrease as the compaction pressure increased. During sintering, shrinkage varied inversely with the green density shown in Figure 2. In addition, as can be distinguished from Figure 6 (a) and (b), the shrinkage for both diameter and thickness for all compaction pressures was lower at 700°C than at other sintering temperatures. The shrinkage is dependent on diffusion rate during sintering. At lower temperature, the diffusion rate of atoms and vacancies was lower than at higher temperature.

The comparison of the linear shrinkage of diameter and thickness illustrates that the diameter shrinkage was higher than thickness shrinkage for the compaction pressures of 13.79 and 27.58 MPa. For the compaction pressures of 41.37 and 55.16 MPa, the shrinkage of diameter and thickness were similar. After uniaxial compaction, the pores were flattened along the pressing direction and elongated in the direction perpendicular to the pressing direction. During sintering the pores tended to spheroidise. Hence on heating, the pores enlarged along the pressing direction while the pores shrank in the direction perpendicular to the pressing direction, leading to a different dimensional change for both directions.[4] For the high compaction pressures, which were 41.37 and 55.16 MPa, the compacted powder had higher plastic deformation than for the low compaction pressures. This meant that the pore shape of the compacted powder was flatter at high pressure, and thus resisted more to thickness shrinkages than at the low compaction pressures. Figure 7 shows the difference of diameter and thickness shrinkages versus compaction pressures. It is noticed that the difference of shrinkage was calculated from the diameter shrinkage minus the thickness shrinkage. The difference of diameter and thickness shrinkages was getting smaller as the compaction pressure increased. For the sintering temperature of 900°C in an argon atmosphere, the thickness shrinkage was higher than the diameter shrinkage for the compaction pressure above 27.58 MPa, which is similar to the sintering temperature of 700°C in the same atmosphere for the compaction pressure above 41.37 MPa.



(a)



(b)

Figure 6. Linear shrinkage of (a) diameter and (b) thickness with respect to the green part

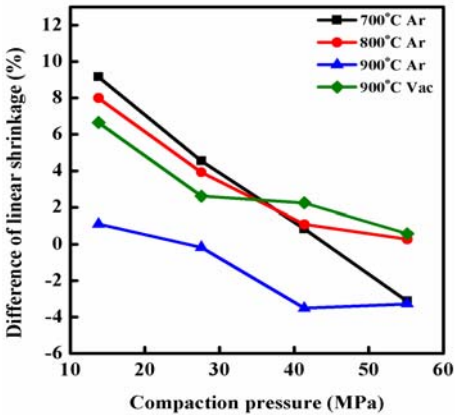


Figure 7. Difference of width shrinkage and thickness shrinkage

Conclusions

The investigation of the effects of compaction pressure, specimen weight, sintering temperature and sintering atmosphere for compacted silver powder was carried out. The silver powder was uniaxially compacted into cylindrical shape using four different compaction pressures, which were 13.79, 27.58, 41.37 and 55.16 MPa, and sintered at 700, 800 and 900°C for 4 hours in an argon atmosphere. In addition, specimens were also sintered in vacuum for 900°C sintering temperature. The results suggested that a higher compaction pressure enhanced green density. For the sintering temperatures of 700 and 800°C, the sintered density increased as the compaction pressure increased below 40 MPa, while the sintered density decreased at the compaction pressure above 40 MPa. At the sintering temperature of 900°C, the sintered density decreased with increasing compaction pressure. Although shrinkage was anisotropic, diameter and thickness shrinkages tended to decrease as the compaction pressure increased. A higher sintering temperature enhanced densification and shrinkage. In addition, the green and sintered densities were independent of specimen weight.

Acknowlegements

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