Investigating of Mixture Ratio of 925 Sterling Silver Compound for the Metal Injection Molding Process

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Abstract

The objective of this study is to determine the mixture ratio of 925 sterling silver compound that was feasible to produce complete green part via a metal injection molding process. The mixture ratios of 925 sterling silver powder to the binder mixture were varied. The particle sizes of 925 sterling silver powders were 100 µm and less. The binder mixture consisted of high density polyethylene, polyvinyl alcohol, polyethylene glycol, paraffin wax as plastic flow ability promoting agent and stearic acid as lubricant. All mixtures were then mixed with an internal mixer. Metal injection molding was performed by using a ram injection machine under constant pressure and temperature of 190 °C and150 bars, respectively. The highest ratio of 925 sterling silver powder to the binder mixture that could inject the complete parts was required. The results exhibited that the favorable green parts were achieved by the formula with the mixture ratio of 90 percent of 925 sterling silver powder to10 percent of binders by weight. The components of the formula included 120 grams of 925 sterling silver powder and 13.33 grams of binders, containing 5.067 grams of high density polyethylene, 0.500 grams of polyvinyl alcohol, 0.167 grams of polyethylene glycol, 7.200 grams of paraffin wax and 0.400 grams of stearic acid. The green parts of the formula had average green density of 4.507 g/cm^3 and average green strength of 17.70 MPa. This mixture ratio can be utilized in the metal injection molding for producing the green parts.

Keywords: 925 sterling silver powder, Binder, Mixture ratio, Green density**,** Green strength

1. Introduction

925 sterling silver has been one of the materials most typically used in jewelry industries to produce silver jewelry items. In accordance with the international standard, sterling silver must contain silver at least 92.5 wt.% [1, 2]. Generally, the rest content is copper (7.5 wt.%) added to improve the strength and hardness of the alloy because pure silver is too malleable [1]. The investment casting or lost wax casting process has commonly been utilized in jewelry industries for producing jewelry parts. However, the parts produced by this process usually have quality problems from casting defects such as gas porosity, shrinkage porosity, interstitial inclusion and fire scale.

Recently, Metal Injection Molding (MIM) technology is employed in the mass production of parts made from steel and titanium. The MIM can produce high quality parts, complex and near net shape parts. The technique competes with traditional manufacturing techniques such as machining, pressing-stamping, and casting process [3]. German and Bose [4] applied an injection molding process for metal powder and found the metal powder was not able to inject like plastic injection molding. There must contain binders to keep the metal powder flowing along the mold cavity like fluid and to maintain its shape upon cooling. The MIM was developed from plastic injection molding technology. This process has been used for producing small metal parts with complex shape and having good mechanical properties. Since the complex shape parts producing by MIM can be more precisely controlled in mass production resulting in lower unit costs compared to traditional process [5]. The MIM process has four main steps consisting of the feedstock mixing, injection molding, debinding and sintering [6]. For the MIM process, binder selection and binder ingredients is one of the most important part. Since the water-soluble binder is environmentally benign, it grows interesting. The feedstock of silver containing water-soluble binder was successfully prepared using water-soluble polyethylene glycol (PEG) together with polyvinyl butyral (PVB). The molded green parts are able to retain their shapes during solvent debinding using water [7]. In mixing of feedstock, the control of mixing temperature and the weight for each mixing sequence were also important. Mixing machine with high shear rate can make the homogeneous feedstock. The higher torque was required when the viscosity of the mixture increased at higher proportion of the powder content. Increasing in the rotating speed and the temperature leading to its low viscosity can help lessen the torque. It is important that the feedstock is homogeneous and free of powder–binder separation or particle segregation [8]. In MIM process of the 316L stainless steel powder, part defects caused by the low specific heat of the powder resulting in the rapid cooling of material during the injection. Consequently, the viscosity increased which led to short shot problem. Appropriate injection pressure brought about less shrinkage. Low injection pressure caused sink mark. If excessive pressure was applied, it led to the crack. Mold design was also an important factor in injection molding [9]. The gate locations had effects on morphology in MIM of 316L stainless steel parts. A perpendicular gate injection caused a separation between outer skin and core of green parts. The homogeneous parts without black streak, crack and phase separation were successfully molded by the parallel gate injection with low pressure and speed [10]. The MIM has been utilized for fabrication stainless steel watch cases and bracelet [11] as well as used for the production of precious metal jewelry [12]. However, there is limited information available about the MIM process for precious metals and jewelry production, the manufacturing of MIM parts with the 925 sterling silver is not clear.

In this work, the mixture ratio of 925 sterling silver compound for a metal injection molding process possible for producing complete green parts was determined. The mixture ratios between 925 sterling silver powder and binder were varied to find the highest ratio of 925 sterling silver powder that could produce the favorable parts.

2. Experimental setup

2.1 Mixing process

The binder composition for fabricating feedstock comprised high density polyethylene as polymer backbone to hold the silver particles and pack the powder into desired shape. Soluble polymer, polyvinyl alcohol and polyethylene glycol were used because they can be debinded by distilled water. Muangwaeng [13] found that the specimens which were made of feedstock with high polyvinyl alcohol content could be debinded in a shorter time. Therefore, the binder ingredients referring to that study were primarily employed. The percentage of binder ingredients was fixed at 3 wt.% of stearic acid as a surfactant to reduce the agglomeration, 54 wt.% of paraffin wax as a plastic flow ability promoting agent, 38 wt.% of high density polyethylene, 3.75 wt.% of polyvinyl alcohol and 1.25 wt.% of polyethylene glycol. The sterling silver powder and binder were mixed together by an internal mixer. The mixing process is shown in Fig. 1. The sequence of material addition to the 925 sterling silver powder as follows, first, the machine temperature was set to 60 ℃, next the metal powder were transferred to the machine and heated at 60 ℃ for 15 minutes with inverter frequency of 10 Hz. Each binder material, stearic acid, paraffin wax and high density polyethylene was added, sequentially. Later, polyvinyl alcohol and polyethylene glycol were added to the mixture at the same time. The temperature, time and frequency as shown in Table 1 were employed while adding each component to the internal mixer. Finally, the heater was turned off while keeping the mixing process continue for 90 minutes. An example of the feed stocks that were obtained from the process is shown in Fig. 1(c). Table 2 lists all the eight different mixing ratio of the feed stocks that were prepared in this study.

Table 1 Mixing condition of the 925 sterling silver with each binder material.

Material	Temperature (℃)	Time (min)	Inverter frequency (Hz)
Stearic acid	100	10	10
Paraffin wax	100	10	10
High density polyethylene	100	10	15
Polyvinyl alcohol and polyethylene glycol	150	20	15

(a) Binder (b) Internal Mixer (c) Feed Stock

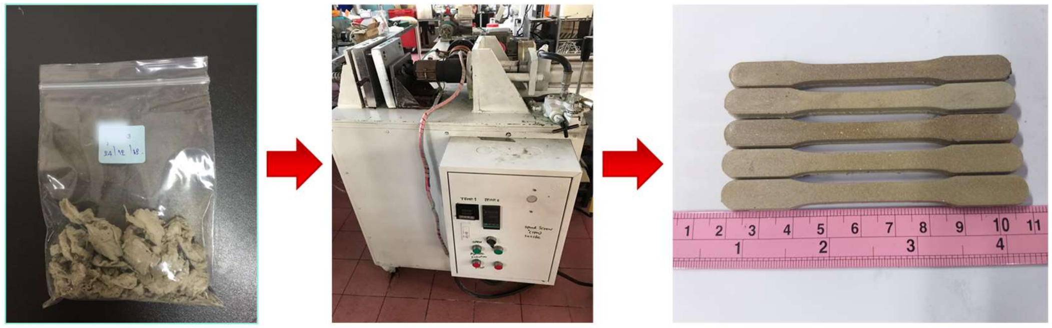
Figure 1 Mixing process.

Table 2 Mixture ratio (wt.%).

No.	Silver powder	Binder
1	98	2
2	94	6
3	90	10
4	86	14
5	82	18
6	78	22
7	74	26
8	70	30

2.2 Metal injection molding

Metal injection molding was performed by using a ram injection machine to prepare the green part samples as shown in Fig. 2. The metal injection molding condition is shown in Table 3. The barrel temperature at the extruder was set to 190 °C. The rotational speed of the screw was 40 rpm. The feed stock of 925 sterling silver compound was transferred to the extruder and melted for 15 seconds. The injection was conducted with the pressure of 150 bars, holding time of 30 seconds, and cooling time of 150 seconds. Finally, the mold was opened, and the samples were ejected out. The mold has two cavities; therefore, two samples were obtained per one injection. The injection was repeated at least three times for each mixture ratio and then five samples were taken for investigating physical and mechanical properties. The density and the strength of molded parts before sintering are green density and green strength, respectively. The powder molded parts must have enough green strength to withstand the handling load prior to sintering. Although, the shape of samples seems like the tensile test specimen, these samples were employed for three-point bending test for evaluating the green strength.



(a) Feed Stock (b) Ram Injection (c) Sample

Figure 2 Metal injection molding process.

Table 3 Metal injection molding condition.

Temperature (°C)	190
Pressure (bar)	150

For the physical property, green density of samples was evaluated. The volume of the green parts can be found by Archimedes' principle. The principle states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially, is equal to the weight of the fluid that the body displaces. Since the volume of the known fluid can be calculated from its weight, the volume of sample is determined. The samples were weighted by a four-digit weight scale. Therefore, the density ρ of the samples can be calculated as the equation (1):

$$\rho = \frac{m}{V} \tag{1}$$

Where m is mass of the sample, and V is volume of the sample which obtained from to the volume of the known fluid. For the mechanical property, the three-point bending test was performed to evaluate the green strength.

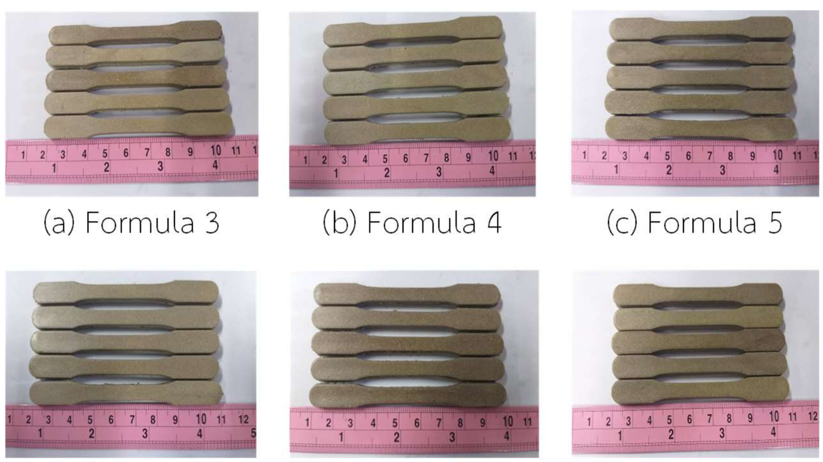
3. Results and discussion

3.1 Injection results

Variation in mixture ratio has an influence on viscosity. Sample obtained from mixture ratio of formula No.1 and No.2 with higher proportion of the silver powder content caused short shot. One of the causes of short shot in injection is high viscosity of the compound. Considering binder matrix, the viscosity of molten polymer depends on the temperature. Since the barrel temperature was fixed at 190 °C, the effect of temperature on viscosity is same for all mixture ratios of the 925 sterling silver compound. Therefore, the factor affecting viscosity of the compound was higher proportion of the powder content resulting in higher viscosity. The samples were incompletely filled due to high viscosity as shown in Fig. 3. To confirm the failed outcome, the injection with formula No.1 and No.2 was repeated two times.

Figure 3 Incomplete shape of green parts with mixture ratio of formula No. 1 and 2.

Increasing in binder ratio affects on the filling of compound into the mold during injection. The compound gets good flow ability with higher binder content assisting by paraffin wax, which is a plastic flow ability promoting agent. The green part samples made of the formula No.3 to No.8 feed stocks were favorable. The binder materials contained stearic acid functioning as the lubricant and surfactant, thus, increasing amount of stearic acid help reducing the viscosity of compound. Large amount of binder or lowering silver content led to completely fill resulting from its low viscosity as shown in Fig. 4. Next, debinding and sintering will be conducted in further work.



(a) Formula 3 (b) Formula 4 (c) Formula 5

(d) Formula 6 (e) Formula 7 (f) Formula 8

Figure 4 Green parts with different mixture ratio.

3.2 Physical property of green parts

Green density alters with changing in binder content. Average green density of five samples for each mixture ratio is shown in Fig. 5. The formula No.1 with the mixture ratio of 2 percent of binder or 98 percent of 925 sterling silver powder shows the highest green density of 4.693 g/cm^3 resulting from the highest silver powder content. The green density of sample decreased when the percentage of binder increased from 2 to

30 wt.%. Because the density of main contents of binder, paraffin wax (ρ_{PW} = 0.91 g/cm^3) and high density polyethylene (ρ_{HDPE} = 0.95 g/cm^3), are lower than that of 925 sterling silver (ρ_{925Ag} = 10.37 g/cm^3), consequently, the density decreased with increasing in binder ratio.

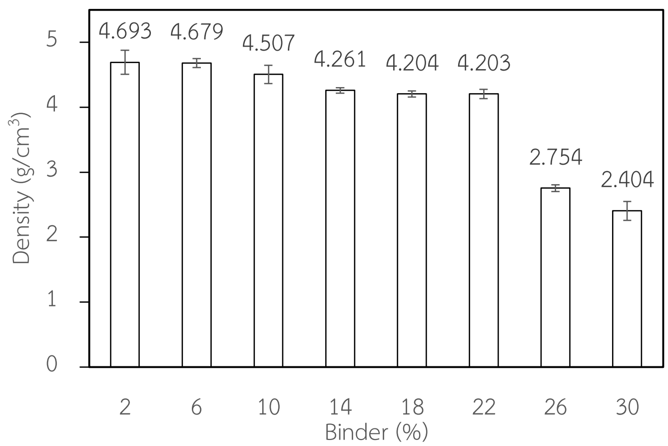


Figure 5 Green density of samples with different mixture ratios of binder.

3.3 Mechanical property of green parts

It is essential that the green parts have to withstand handling before they are fully fused in sintering. Green strength from three-point bending test is shown in Fig. 6. In the injection process, only a binder portion of compound was melt but the silver particles remained solid. They did not bind together with diffusion. Although higher powder content exhibited higher density in previous section, higher unbounded particles caused lower green strength. The green part maintained its shape with holding of binder matrix; therefore, the green strength depended on the amount of binder. The green strength increased with increasing in percentage of binder.

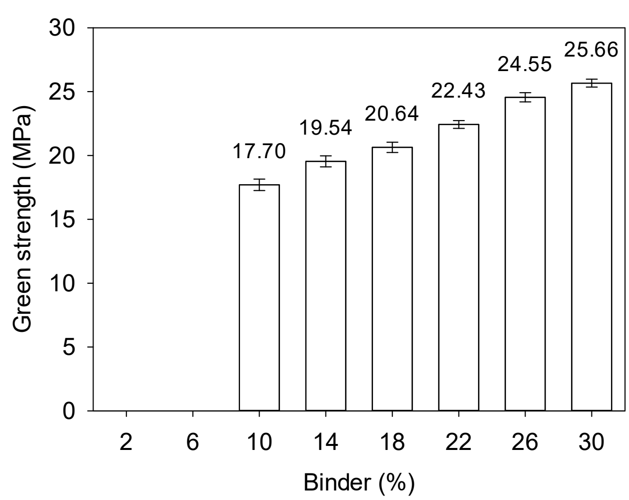


Figure 6 Green strength from three-point bending test.

4. Conclusions

This work aims to investigate the mixture ratio of 925 sterling silver compound that was feasible to produce complete green part via the metal injection molding process. Although there is the utilization of MIM for the fabrication of precious metals and jewelry components, there is limited information available. The mixture ratios of 925 sterling silver powder to the binder mixture were varied to find the highest ratio of 925 sterling silver powder that could produce the favorable parts. The following conclusions were drawn from the results obtained in this study.

1. Higher proportion of the silver powder content caused short shot. The optimal mixture ratio was the third formula which had the highest sterling silver powder content that could produce the complete parts.
2. The third formula mixture ratio contained 90 percent of 925 sterling silver powder and 10 percent of binders. The components of the third formula included 120 grams of 925 sterling silver powder and 13.33 grams of binders, containing 5.067 grams of high density polyethylene, 0.500 grams of polyvinyl alcohol, 0.167 grams of polyethylene glycol, 7.200 grams of paraffin wax and 0.400 grams of stearic acid.
3. The density decreased with increasing in binder ratio, whereas the green strength increased with increasing in percentage of binder. The green parts of the third formula have average green density of 4.507 g/cm^3 and average green strength of 17.70 MPa. This mixture ratio can be utilized in the metal injection molding for producing the green parts.

5. Acknowledgements

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6. References

[1] R.V. Carrano, “Sterling Silver Casting Problems,” *In Proceeding of the Santa Fe Symposium on Jewellery Manufacturing Technology,* pp. 91–103, 1990.

[2] A.M. Reti, “Understanding Sterling Silver,” *In Proceeding of the Santa Fe Symposium on Jewellery Manufacturing Technology,* pp. 339–356, 1997.

[3] K. Wiesner, “Metal Injection Moulding (MIM) Technology with 18ct Gold – A Feasability Study,” *In Proceeding of the Santa Fe Symposium on Jewellery Manufacturing Technology,* pp. 442–462, 2003.

[4] R. M. German and A. Bose, Injection molding of metals and ceramics. Princetion, NJ: Metal Powder Industries Federation, pp. 11–182, 1997.

[5] R.M. German, (2019, December 21). Overview: key criteria for selecting MIM technology [Online]. Available: http:/www.pim-international.com/designing_for_PIM/summary

[6] D. F. Heaney, Handbook of Metal Injection molding. Woodhead Publishing, Cambridge, 2012.

[7] C. Aumnate, N. Nawaukkaratharnant, and N. Chuankrerkkul, "Preparation of Feedstock Containing Water–Soluble Binder for Powder Injection Moulding of Silver," *Journal of Metals, Materials and Minerals,* vol. 32, no. 3, pp. 75–79, 2022.

[8] R. Supati, N. H. Loh, K. A. Khor, and S. B. Tor, "Mixing and Characterization of Feedstock for Powder Injection Molding," *Materials Letters,* vol. 46, no. 2–3, pp. 109–114, 2000.

[9] P. Setasuwon, A. Bunchavimonchet, and S. Danchaivijit, "The Effects of Binder Components in Wax/Oil Systems for Metal Injection Molding," *Journal of Materials Processing Technology,* vol. 196, no. 1–3, pp. 94–100, 2008.

[10] B. Muangwaeng, S. Rojananan, and S. Rojananan, "The Effect of Injection Parameters on Morphology in Metal Injection Moulding," *Advanced Materials Research,* vol. 802, pp. 174–178, 2013.

[11] B. Williams, "Watch Cases and Bracelet Parts: PIM Moves Upmarket," *Powder Injection Moulding International,* vol. 2, no. 2, pp. 31–32, 2008.

[12] J. Strauss, "The Potential of PIM For the Manufacture of Precious Metal Jewellery," Powder Injection Moulding International, vol. 2, no. 2, pp. 50-54, 2008.

[13] B. Muangwaeng, "Feedstock Fabrication for Metal Injection Moulding of Medical Devices," *M. Eng. Thesis (Polymer Processing Engineering), King Mongkut's University of Technology Thonburi, Bangkok, Thailand,* 2013.