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MORPHOLOGY OF 925 SILVER POWDER PARTICLES PRODUCED FROM GAS ATOMIZATION

Montri Kawsuk[1], Surat Wannasrib[2], Sirichai Torsakula[3]*
Faculty of Engineering, Rajamangala University of Technology Thanyaburi Patumtani, Khlong Luang Pathum Thani, Thailand[13]
Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand[2]
sirichai.to@en.rmutt.ac.th

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**Corresponding Author*

ABSTRACT
In order to examine the impact of metal water temperature and gas flow rate on the production of 925 silver alloy powder via closed-coupled nozzle and gas atomization process with nitrogen gas as the production medium, and since the morphology of the powder particles could not account for the influence of these variables, the aim was to comprehend and propose a new approach for a general framework for studying the influence of such factors. As a consequence, an investigation was conducted into the impact of these two variables on the morphology, which was characterized by roundness values. Particle size and distribution information can be conveyed to facilitate interpretation. According to the results of the experiment, the gas flow rate and metal water temperature influence the particle morphology in terms of particle size and distribution with respect to roundness. The particle size distribution of metal powders is more restricted and the particle roundness increases. This is due to the fact that the particle morphology plays a critical role in determining which metal powder particles are suitable for forming metal powder workpieces via various production methods. The gas flow rate and metal water temperature influence the particle size distribution, roundness value, and significant size of 925 silver alloy powder.
Keywords: *Gas Atomization, Close Coupling, 925 Silver, Particle Morphology, SEM*

1. Introduction

The success of additive manufacturing (AM) has captured the world's attention over the past few decades. This is because it is a production process that can customise the shape of the workpiece. The production model meets your needs and overcomes various limitations. that other production methods cannot be overcome and can quickly produce workpieces with a specific shape for a group or individual, such as medical devices for prosthetic surgery that are unique to an individual (Giganto et al., 2020) and demonstrate other advantages. There are many other things that are useful for product development to meet human needs. At present, Additive Manufacturing technology,It was developed quickly to keep up with the needs of users. This causes a variety of materials or process steps for creating pieces as follows: SLA (Stereolithography), forming liquid resin with a laser, used in Prototype, Concept Modeling, or Casting Patterns. It is similar to DLPC (Digital Light Processing), but changes from Laser light is the use of a projector camera to shine liquid resin instead. The main material is Photopolymer. Advantages: There are many materials to choose from Good accuracy.

Build size is large. The surface of the workpiece is smooth. AM for forming and producing metal workpieces has not yet been widely used for the production of actual workpieces in the manufacturing industry (Zhu et al., 2018) (Zhu et al., 2024) (Ruinan et al., 2020). One reason is the lack of AM-specific, standardised methods for determining the properties or characteristics of metal powder particles. which is an upstream raw material that is fed into the production process, and it is still not possible to accurately predict or predict the mechanical properties of the parts produced (Li et al., 2024)(Both et al., 2020). For confident powder metallurgy to be used and parts with consistent and predictable properties to be made, the properties of the metal powder particles used in AM must be known. causing various research and development activities. It focuses on studying and analyzing the properties and characteristics of metal powders (Lu et al., 2018). The characteristics of good metal powders must include uniformity in the size and shape of the particles. It is important to ensure repeatability of parts with consistent quality, for example, metal powder must have a uniform, spherical shape. The particle size distribution is in a narrow range and has good packing behavior. This will make the final product of the production process have good mechanical properties (Mellin et al., 2021) and have the highest density, which is similar to the traditional production method. There are also other features. Several other things to consider include morphology and metal powder flow.

When the morphology of metal powder particles was mentioned, it was found that there are many factors affecting the morphology. Consisting of the metal powder production process. metal water temperature type of medium that breaks metal water into particles (water or gas) form of water or gas spray nozzle the collision angle of the medium with the metal stream, etc., where the morphology of the metal powder particles affects the density of the metal powder flow properties formability properties of the workpiece obtained from the final forming process according to (Wu et al., 2023). Various atomization parameters linked to atomizing gas, liquid metal, and atomizer, among others, may alter the surface morphology (e.g. particle shape and porosity at the surface) of generated powder (Msetra et al., 2021). The flow and apparent density of particles are affected by the surface morphology and others. (Macri et al., 2020) (Beckers et al., 2020) Analyze the morphology of 925 silver alloy powder particles in the production of jewelry and consumer products as a precious metal due to its high reflectivity and beautiful appearance. Changing the size and morphology of metal powder particles (Mitterlehner et al., 2021), Ag is usually mixed with other elements to improve material performance, (Yang et al., 2019), (HU et al., 2019), several studies It has been shown that high cooling rates can be used to effectively prevent segregation. Increases the solubility of alloying elements. (Bao et al., 2021) as a result, supersaturated Ag alloys have higher strength. However, Ag alloys still have relatively low hardness and low yield strength and low wear resistance. Therefore, it further limits its use. Current studies on Ag alloy production technology focus on traditional processing methods such as casting. However, it is difficult for this casting to effectively enhance the mechanical properties of Ag alloys (Guzman et al., 2021), furthermore, most of the defects result from the highly soluble nature of oxygen at high temperatures. And the solubility is noticeably low at low temperatures when the Ag alloy solidifies, causing the release of oxygen, causing gas pores. To increase the hardness of Ag allos metallurgy (Jargalsaikhan et al., 2024), post-casting treatments (such as age hardening, cold work (such as squeezing, bending, pulling, and cutting) and surface treatments are required. etc., which makes the production process complicated and expensive

This study focuses on examining and analyzing the morphology of 925 silver alloy powder particles that the research team's prototype gas atomizer experimentally produced. To support the needs of the jewellery manufacturing industry in the country. It considers influences and factors related to the metal powder production process, which consists of metal stream size. metal water temperature The flow rate of the gas from the belly hits the metal stream so that the metal water breaks down into liquid droplets. The information obtained from the research is useful for selecting appropriate conditions for controlling the production of metal powders to ensure consistent quality in terms of shape, size, and particle size distribution, and has a positive effect on confidence and consideration for selection for the production of jewellery pieces by entrepreneurs in this industry who follow guidelines that have been researched for other types of metal powders.

2. Materials and Methods

The material used in the study is alloy 925 according to TIS 21-2515 standard, obtained by mixing 99.99% pure silver with 99.9% pure copper with a silver to copper ratio of 92.5 : 7.5. The Ag alloy powder has a spherical shape perfect and significantly different particle sizes this not only improves the bulk density,But it also improves the dispersion of highly reflective metal powders many times thus increasing the absorption rate. (Spierings et al., 2018),The part of the graphite crucible with the induction melting unit as the heat source. These devices are one component of the prototype gas atomizer for powder production at Rajamangala University of Technology Isan, with various components of the machine and working principles as shown in the diagram in Figure 1. Nitrogen gas is used as a medium for atomizing metal water, and the spray head used for the experiment is a spray head. a close-coupled nozzle with a 3 mm-diameter melted metal stream conveying pipe and a gas release channel along the circumference of the metal stream. The angle of collision of the gas with the metal stream is 22 degrees, as shown in Figure 2.

The production of metal powder involves fusing silver and copper, 1 kilogram at a time, in a graphite crucible heated by induction heating. Under the closed melting chamber, which is covered with nitrogen gas, by melting the metal to a uniform temperature of 1300 degrees Celsius for 5 minutes, then reducing the temperature to 1,060, 1,160, and 1,260 degrees Celsius, respectively. For atomization at temperature to allow the metal water to flow down the bypass pipe, and atomization occurs from collision with high-speed gas with flow rates of 400, 500, and 600 litres per minute, respectively. Then the metal water droplets change from liquid droplets to solid particles and fall into the container below. In the atomization tank, the obtained metal powder particles were sieved and separated with a Haver & Boceker model Haver EML 20 Digital Plus sieve for 6 minutes in order to meet the ASTM E11 analytical technique standards by sieving with sieve sizes of 75 µm, 50 µm, and 20 µm, respectively, to prepare for analysis, inspection, and testing of various properties. The metal powder samples were kept at room temperature under a blanket of nitrogen gas to prevent the metal powder from being exposed to the atmosphere (Kawsuk et al., 2024).

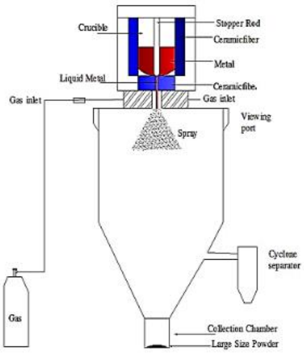


Fig. 1. Vertical gas atomizer

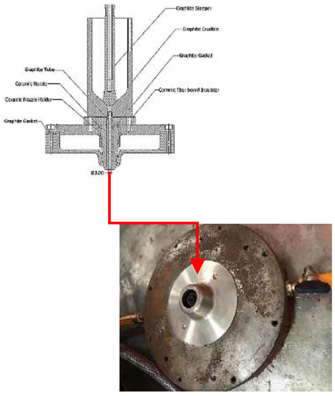


Fig. 2. Close-coupled nozzle with a gas release channel along the circumference of the metal stream.

2.2. Various analysis, inspection and testing

1) Particle morphology analysis was performed with an OM light microscope, Olympus model BX60M and a scanning electron microscope, SEM, Thermo Scientific, Apreo 2. Prepared SEM analysis examples commonly used metal powder sampling procedures. This is done to provide a clear background in the image. Makes it easier to separate particles the metal powder will be evenly distributed. together in a small amount to prevent overlapping.
particles in the picture.

2) Analysis and verification of particle roundness values Analyzed by taking photos from the camera. OM was used to analyze roundness using ImageJ version 2019 software. It was measured by dividing the circumference length of the circle by the circumference of the projected image of the particle. The shape parameter reported here is High Sensitivity Circularity (HSC), which is a normalized value that describes how close the particles are together, as in Equation 1.

$$\text{HS Circularity} = 4 \times \pi \times \text{area} / \text{perimeter} \quad \text{(Fu et al., 2012)} \qquad (1)$$

3) Analysis of particle size and distribution We used a Laser Scattering Particle Size Distribution Analyses machine (Horiba, model LA 950) to do the tests. We compared the width of the particle distribution that wasn't affected by the median (D50), which can be found using equation 2.

$$\text{Span} = \frac{D90 - D10}{D50} \quad (2)$$

3. **Experimental results**

From the study of the shape of the metal powder particles using scanning electron microscopy (SEM), it was found that all conditions of the metal powder formation experiment in the gas atomization process were this involves the separation of liquid metal water from rapid gas expansion. The suction force that occurs in the area of gas expansion causes the liquid metal to form a thin hollow sheet, turning into an elliptical ligament, and the resulting metal powder particles have a spherical shape. As shown in the figure 3, with some satellite particles slightly attached to the main particles. As pointed out by the arrow in Figure 3, there are also some particles that look like long lines (ligament) and slightly mixed flat pellets, like all conditions of the experiment. The particle surface has a dendrite structure. As shown in Figure 4.

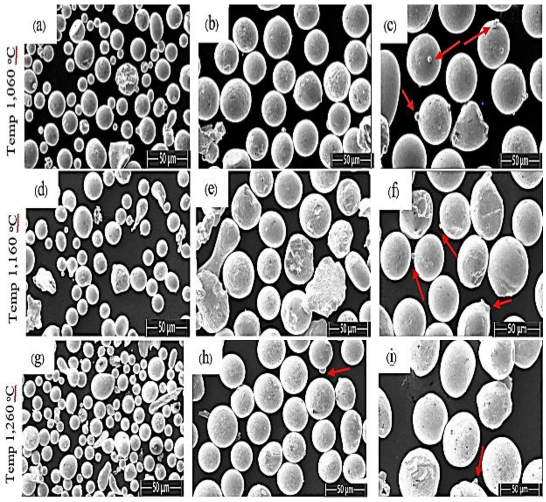


Fig. 3. Characteristics of metal powder particles from scanning electron microscopy (SEM) from a production experiment under a temperature of 1,060 oC (a) – (c) Metal powder particles sieved from 20 µm, 50 µm sieves. 75 µm, respectively, temperature 1,160 oC (d) – (f) metal powder particles that have been sieved from sieves size 20 µm, 50 µm 75 µm, respectively, temperature 1,260 oC (g) – (i) metal powder particles that have been sieved from sieve size 20 µm, 50 µm, 75 µm respectively

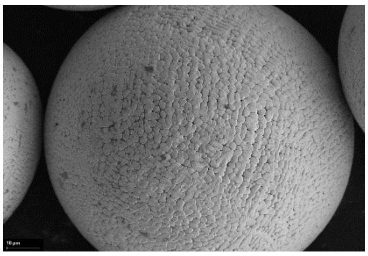


Fig. 4. Characteristics of metal powder particles from scanning electron microscopy (SEM) from a production experiment under a temperature of 1,060 oC (a) – (c) Metal powder particles sieved from 20 µm, 50 µm sieves. 75 µm, respectively, temperature 1,160 oC (d) – (f) metal powder particles that have been sieved from sieves size 20 µm, 50 µm 75 µm, respectively, temperature 1,260 oC (g) – (i) metal powder particles that have been sieved from sieve size 20 µm, 50 µm, 75 µm respectively

3.2 Circularity of particles

From measuring the roundness of the particles by taking OM images and measuring them with ImageJ version 2019 software, as shown in the example analysis shown in Figure 5, it was found that all conditions of the experiment The resulting metal powder particles have different roundness values as the results of the analysis are shown in Table 1.

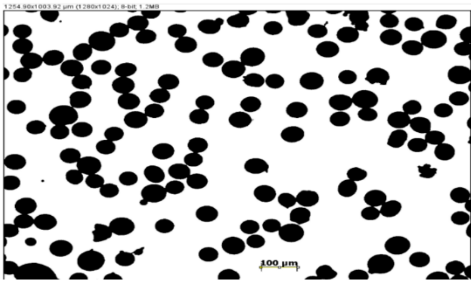


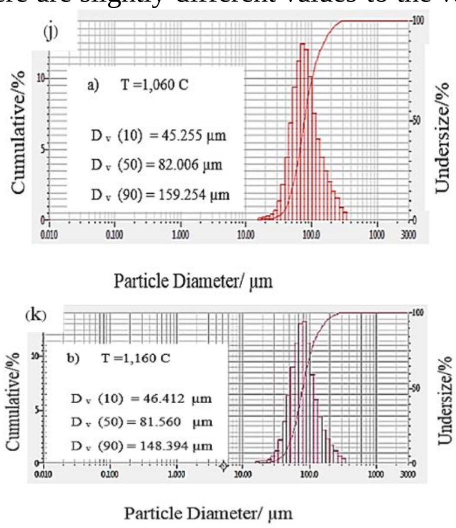
Fig. 5. Measurement of particle roundness from photographs using ImageJ version 2019 software.

Table 1 - Influence of metal water temperature and gas flow rate on the roundness value size and particle size distribution of metal powders

Melt metal Temperature (°C)	Gas flow rate (l/min)	Circularity	Particle Mean Size (µm)	D_{10} (µm)	D_{50} (µm)	D_{90} (µm)	span
1,060	400	0.825	94.111	45.255	78.032	159.254	1.460
	500	0.820	93.204	46.130	82.300	169.768	1.502
	600	0.812	91.694	45.785	82.006	161.682	1.413
1.160	400	0.905	93.592	46.412	78.950	148.394	1.291
	500	0.900	92.526	46.745	81.138	159.212	1.386
	600	0.887	90.005	46.400	81.560	158.938	1.379
1,260	400	0.910	92.776	46.219	77.938	148.315	1.309
	500	0.907	91.765	46.596	79.031	150.715	1.317
	600	0.894	89.544	47.301	80.232	151.477	1.296

3.3 Size and particle size distribution

From the study of the size and distribution of particle sizes the experimental conditions of the particle size determination (Hu et al., 2020) method described above were found to achieve a particle size distribution dependent on the random orientation of the particles during measurement in all methods (Guo et al., 2020; Fan et al., 2020) . Except using images (such as microscopy and automated image analysis), this means that if the value of Ag 925, which is a spherical particle Some parts resemble an oval shape. Uniform anisotropicity must be determined using one of these techniques. These techniques range in size from secondary (S) to primary (L) dimensions because the orientation of the particles is random. (or not controlled) during measurement as shown in Figure 6, therefore, in principle It can therefore be concluded that only automatic image analysis methods are able to form physically meaningful particles. As for the size distribution in the case of anisotropic particles, Spherical material only if the particles have good distribution (Abbireddy et al., 2009). The difference affects particle size and particle size distribution. There are slightly different values to the values shown in Table 1.



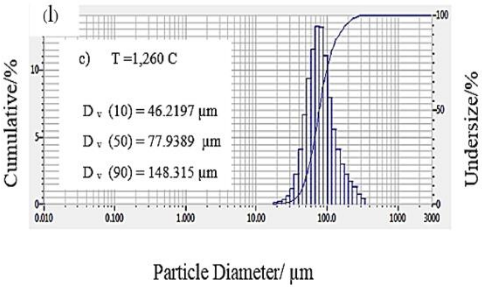


Fig. 6. shows particle size distribution analysis.

4. Discuss the experimental results.

Influence of factors related to the metal powder production process that affect the shape of metal powder particles.

A study analyzing the influence of related factors affecting the shape of metal powder particles using SEM images found that the temperature of the metal water has no effect on the shape of the particles being different (Williams et al., 2021) because most particles have the same The shape is quite similar to a sphere (Motas et al., 2021). There are satellite particles attached to the surface of the main particle and some particles have the appearance of long lines (ligament) and slightly mixed flat pellets, like all temperatures of the experiment (Malý et al., 2019) As shown in the SEM image in Figure 3, the particle surface has the appearance of dendrites. As shown in Figure 4, it is consistent with the research results of (Nasr et al., 2010) (Zheng et al., 2009) who studied the shape of aluminum metal powder produced by the atomization process. sun Microstructural properties of dendrites ranging in size from atomized Al 2024 powder. Micro-sized dendrites have well-defined primary arms and some secondary arms. The fine microstructure which may be This was due to the high rapid solidification rate resulting from the highly unbalanced conditions that occurred during GA as for the gas flow rate, it was found that the gas flow rate had no effect on the particle morphology. The difference is clearly the same as the temperature of the metal water. This is because the shape of the particles observed from the SEM images shown in Figures 3 and 4 are similar, with a similar spherical shape. There are satellite particles attached to the surface of the main particle. The same as mentioned above (DebRoy et al., 2018).

Influence of factors related to the metal powder production process on particle circularity

From the appearance of the metal powder particles shown in the SEM images in Figures 3 and 4, they have very similar shapes. It is difficult to explain the difference in shape. The researcher therefore chose to analyze the roundness of the particles in the images to help explain the differences in shape. Increasing the temperature of the metal water increases the roundness of the particles. Varies as the temperature of the metal water increases. This is consistent with the findings of A. (Hejdukc et al., 2021). For example, circularity was identified as the most important morphological parameter. In the case of the metal powder production experiment with a constant gas flow rate of 400 l/min and a metal water temperature of 1060°C, the metal powder particles produced had a roundness value of 0.811, but when the metal water temperature increased to 1160 °C. C and 1260°C, the roundness of the particles increased to 0.905 and 0.910, respectively, as shown in the comparison graph shown in Fig. 7, as the temperature of the metal water increased. This results in metallic water droplets. Caused by atomization, there is an increased time to form spheres in the air. for increased gas flow rate The roundness of the particles tends to decrease. is inversely proportional to the increase in gas flow rate. For example, in the case of a metal powder production experiment where the temperature of the metal water is set at a constant temperature of 1,160°C and the gas flow rate is 400 l/min, the particles The metal powder produced had a roundness of 0.905, but when the gas flow rate increased to 500 l/min and 600 l/min, the roundness of the particles decreased to 0.900 and 0.887, respectively (Grace et al., 2021). It was evaluated. Effect of particle aspect ratio on sphericity (Esteban et al., 2019) Particle sphericity is less than circularity for most particle shapes. Circularity should not be used as a substitute for sphericity for many particle shapes

(Kalman et al., 2022). A reference figure was used to approximate sphericity based on circularity (Nagahashi et al., 2023) because the increased gas flow rate results in metal droplets formed by atomization that transfer heat faster. There is little time to form a spherical shape in the air. which is consistent with the research results of (Urionabarrenetxea et al., 2020) who conducted detailed research on making copper powder particles more spherical in shape. By heating the powder particles obtained from the atomization process until they melt again and then allowing them to cool slowly. in a normal atmosphere without exposure to the high flow rate gases involved in the process

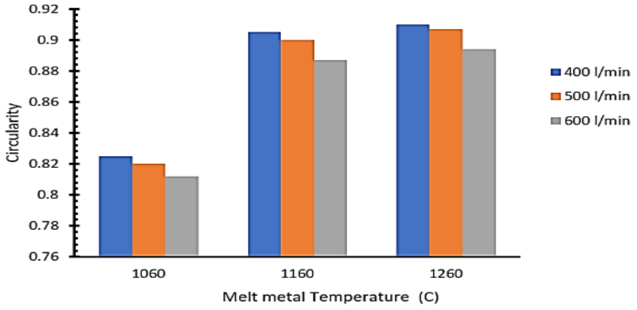


Fig. 7. Graph comparing the roundness values of particles at different conditions.

Influence of factors related to the metal powder production process that affect the size and size distribution of metal powder particles.

Studying the influence of related factors affecting the size and distribution of metal powder particles using a laser particle size distribution analyzer (Baitimerov et al., 2018), it was found that the temperature increase of the metal powder water as a result, the particle size tends to be smaller (Kassym et al., 2020). For example: In the case of the metal powder production experiment with a constant gas flow rate of 400 l/min and a metal water temperature of 1060°C, the metal powder particles produced had a particle size of 94.111 µm, but when the metal water temperature increased to 1160°C. C and 1260°C resulted in smaller particle sizes of 93.592 µm and 90.776 µm, respectively, as shown in the comparison graph shown in Fig. 8, as the temperature of the metal water increased. This tends to result in the metal droplets generated from atomization not being split into smaller droplets due to the viscosity of the metal water decreasing and the adhesion force between the metal atom bonds decreasing (Li et al., 2019) the gas flow rate increased, the particle size also tended to become smaller, which is consistent with the research results of (Cacace et al., 2023). The atomization process parameters for the gas treatment is changed to increase the gas/metal ratio to reduce the particle size. For example, in the case of a metal powder production experiment where the metal water temperature was set at a constant 1060°C, the gas flow rate was 400 l/min and the metal powder particles have a roundness of 94.11 µm, which is uniform. Consistent with the research results of (Mathias et al., 2023) (Vock et al., 2019), experiments were conducted with 925 silver metal, which has a low particle size distribution. The shape of the metal powder particles is spherical. or particles that are nearly spherical the particle surface has a dendritic structure. This is due to the metal droplets cooling faster than equilibrium under different experimental conditions.

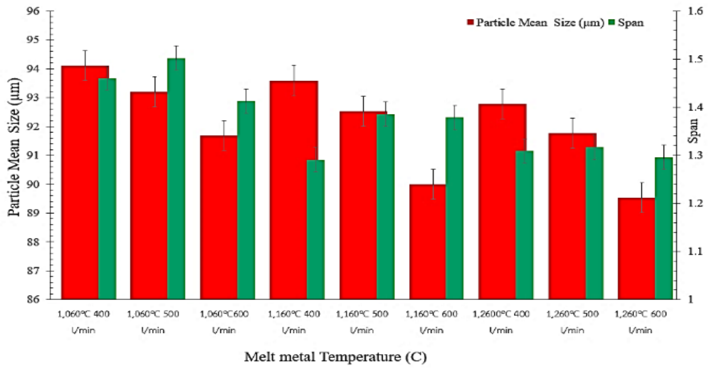


Fig. 8. Gas flow rate on metal powder particle size and size distribution The three experimental temperatures were 1,060 ºC, 1,160 ºC and 1,260 ºC and Span

5. Conclusions

In an analytical study, the morphology of 925 silver alloy powder particles was experimentally produced by the researchers' prototype gas atomizer. To support the needs of the jewelry manufacturing industry in the country. It considers influences/factors related to the metal powder production process. that consists of metal stream size metal water temperature The flow rate of the gas from the belly hits the metal stream so that the metal water breaks down into liquid droplets. The information obtained from the research is useful for selecting appropriate conditions for controlling the production of metal powders to ensure consistent quality in terms of shape, size, and particle size distribution, and has a positive effect on confidence and consideration for selection for Production of jewelry pieces by entrepreneurs in this industry according to the guidelines. The results of the experiment found that the metal water temperature and gas flow rate affect the particle morphology in terms of roundness. Particle size and distribution the roundness of the particles tends to increase and, in addition, the particle size tends to be smaller and the particle size distribution of The metal powder becomes narrower. Characterization of the shape of the metal powder particles using SEM images revealed that the temperature of the metal water had no effect on the shape of the particles being different. This is because most particles have a similar spherical shape. There are satellite particles attached to the surface of the main particles and some particles have the appearance of long lines (ligament) and flat pellets mixed in slightly, as in all temperatures of the experiment. All of this summary information can help explain the differences in the morphological analysis of 925 silver alloy powder particles from the gas atomization process.

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