Effect of gas pressure on conduit plasma atomization for fabricating spherical stainless steel powder

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Abstract. In this study, spherical stainless steel powders are produced using the conduit plasma atomization. Parameters of the conduit plasma atomization process with gas variations of 1.5 bar pressure, 2 bar pressure, 2.5 bar pressure with 316L stainless steel raw material with a current of 25 Amperes, feed speed of 2 mm³/s. The results of stainless steel powders were observed using a digital microscope (Dino-Lite AM4115), scanning electron microscopy (SEM-FEI-Inspect F50), and energy dispersive spectroscopy (EDS). To ensure the purity of the resulting 316L stainless steel spherical powder, EDS was used for qualitative and quantitative elemental analysis. The results showed that the 316L stainless steel spherical powder particles varied in size from 35 µm to 140 µm, making them ideal for powders metallurgy application. The effect of gas pressure on the powder weight percentages for particle sizes 50 µm – 100 µm for 1.5 bar pressure, 2.0 bar pressure, and 2.5 bar pressure were 67.14%, 78.71%, and 81.73%, respectively. It is possible that this could happen because to break down molten metal into smaller size droplets, it is needed the kinetic energy of larger gas pressure. So that large gas pressure can produce more small particle size compared to small gas pressure.

1. Introduction

Currently, the development of the manufacturing industry in the world is increasingly advanced, according to the industry, which is based on the metal powder. The preferred shape of the metal powder particles is the spherical metal powder. Spherical metal powder can be produced using gas atomization [1, 2] and plasma atomization[3]. Metal powder materials suitable for powders metallurgy application that have sizes between 5 µm to 200 µm [4]. Powder particles of this size are often used in additive manufacturing applications and metal injection molding applications.

There are two main types of classification using particle size distribution in additive manufacturing applications, including powders below 50 µm are used for most powder manufacturing systems. Powder particles with sizes below 10 or 20 µm must be avoided because it can reduce the powder's flowability. Powders with sizes between 50 and 100-150 µm are used for Electron Beam Fusion (EBM) and Laser Metal Deposition (LMD) technology. The favorable particle shape in the powder metallurgy among them is that it has a spherical shape because it has good powder flow properties and
can help the process of forming a uniform powder layer. Especially applied to metal injection molding [5].

One of the most widely used powder metallurgy applications in the large scale manufacturing industry is Metal Injection Molding (MIM). MIM uses metal powder as the base material for making feedstock [6, 7]. MIM can produce small components with the right size with a smoother surface roughness quality compared to the investment casting process [5]. In addition, MIM has the advantage of saving production costs because there is almost no waste material that is wasted [8-10].

Metal powders widely used in the MIM process include stainless steel spherical powder with almost no satellites, homogeneous particle size distribution. It aims to improve the flowability of powder to enter the mold of MIM [11]. Stainless steel spherical powders with almost no satellites that have homogeneous particle size distributions can be made with plasma conduit atomization machines [12].

Plasma atomization previously used three plasma torch sources without a plasma conduit, so direct thermal energy spread to the entire tank, while this study was enough to use one plasma torch equipped with a plasma conduit. Plasma heat remains concentrated focused on the plasma conduit, and the molten metal can heat up longer so that there is sufficient heating time to produce perfectly spherical particles.

This study aims at investigating the effect of pressure on the conduit plasma atomization from 1.5 bar, 2 bar, and 2.5 bar pressure variations, in terms of the results of 316L stainless steel metal powder.

2. Methods
The scheme of the conduit plasma atomization is shown in Figure 1. The conduit plasma atomization uses a DC (Direct Current) plasma arc heat system. The plasma system consists of a high-frequency DC power supply, carbon graphite as an anode-cathode nozzle, reactor chamber, and 316L stainless steel wire as its initial raw material. The current used 25 amperes producing a number of high frequency periodic electric spark jumps between cathode and anode, which is driven by compressed air to the shrinking nozzle, which produces a thermal plasma jet to melt the wire material to form droplets of particles.

![Figure 1. Schematic of a conduit plasma atomization](image)

The feed material is 316L stainless steel wire with a diameter of 1.6 mm. The wire is inserted into the nozzle chamber at a constant speed of 2 mm/sec, which produces a particle droplet in the reactor
chamber, then falls together in a collection container filled with water as a cooling. Testing of metal powder particles using the sieving method on the metal powders collectively using mesh sizes # 100, # 200, and # 325 with each opening 100-180 μm, 50-100 μm, and <50 μm and weighing method on according to ASTM standards E. 11-61. The sieving results were weighed using digital scales to determine the size characteristics and particle size distribution of metal powders.

3. Results and Discussion
The results of the plasma arc flame on the conduit plasma atomization at a pressure variations of 1.5 bar, 2 bar, and 2.5 bar can be seen in Figure 2.

![Figure 2](image)

**Figure 2.** Photograph of plasma arc flame at pressure: (a) 1.5 bar, (b) 2 bar, dan (c) 2.5 bar

Figure 2 shows that most plasma arc frames from a video at a pressure of 1.5 bar have a more stable plasma arc flame than a plasma arc at a pressure of 2 bar or 2.5 bar. The possibility of an unstable plasma arc flame can be caused by high pressure, which can increase cathode erosion or anode erosion. Higher the gas pressure, so greater the kinetic energy that will make erosion easier [13].

![Figure 3](image)

**Figure 3.** SEM of 316L stainless steel powder particle size <50 μm
Figure 3 shows SEM of 316L stainless steel powder from conduit plasma atomization at a particle size of <50 μm where particles show spherical shape with almost no satellites.

The results of conduit plasma atomization at a pressure variations of 1.5 bar, 2 bar, 2.5 bar with 316L stainless steel wire raw material at a current of 25 amperes, and feed speed of 2 mm3/s, as shown in Table 1.

Table 1. Digital microscope images of 316L stainless steel spherical powder of conduit plasma atomization

| Gas Pressure | <50 μm | 50-100 μm | 100-140 μm |
|--------------|--------|-----------|------------|
| 1.5 bar      | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |
| 2.0 bar      | ![Image](image4.png) | ![Image](image5.png) | ![Image](image6.png) |
| 2.5 bar      | ![Image](image7.png) | ![Image](image8.png) | ![Image](image9.png) |

Figure 4. EDS of 316L stainless steel powder particle size <50 μm
Figure 4 shows the EDS results of 316L stainless steel powder, which has a chrome and nickel content of 12.78% and 14.29%. In comparison, the initial composition of 316L stainless steel wire raw material has a chrome and nickel content of 18.15% and 11.17%, respectively.

Figure 5. Particle size distribution of 316L stainless steel results of conduit plasma atomization variation of 1.5 bar pressure, 2 bar pressure, 2.5 bar pressure

The effect of gas pressure variation on the percentage of powder weight at a particle size of 50 μm - 100 μm at a pressure of 1.5 bar, 2 bar, and 2.5 bar are 67.14%, 78.71%, and 81.73% respectively. Higher gas pressure it can produce an increasing number of powders produced at a particle size of 50 μm - 100 μm. It is possible that this could happen to break down because the liquid metal into smaller size droplets need the kinetic energy of greater gas pressure so that large gas pressure can produce smaller particle sizes compared to small gas pressure. While the percentage of powder weight at particle size <50 μm at a pressure 1.5 bar, 2.0 bar, and 2.5 bar are 28.03%, 17.61%, and 14.35%, respectively, the higher gas pressure can produce a small amount of powder produced at particle sizes <50 μm. This is possible because the plasma arc flame 1.5 bar is more stable than the 2 bar or 2.5 bar plasma arc flame. Unstable plasma arcs can be caused by cathode erosion, or anode erosion, so high erosion is possible to reduce the plasma arc temperature [13]. The unstable plasma arc flame causes a decrease in heat, which can be indicated by a decrease in the amount of weight of the powder produced at a particle size <50 μm. Interesting future research is to make the plasma arc stable by adding an intelligent control system [14, 15].

4. Conclusion

The effect of gas pressure variation on the percentage of powder weight at a particle size of 50 μm - 100 μm at a pressure 1.5 bar, 2.0 bar, and 2.5 bar are 67.14%, 78.71%, and 81.73% respectively. Higher gas pressure it can produce an increasing number of powders produced. It is possible that this could happen to break down the liquid metal into smaller-sized droplets. The kinetic energy of greater
gas pressure is needed so that large gas pressure can produce smaller particle sizes compared to small gas pressure.

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References
[1] S. Supriadi, T. I. Susimah, M. H. S. Akbar, B. Suharno, and A. S. Baskoro 2020 Designs and evaluations of a gas atomizer to fabricate stainless steel metal powder to be applied at a metal injection molding in Key Engineering Materials 40-47
[2] S. Supriadi, T. I. Susimah, M. H. S. Akbar, B. Suharno, and A. S. Baskoro 2020 Effect of pressure on the gas atomizer to fabricate stainless steel metal powder in Key Engineering Materials 54-58
[3] G. Chen, S. Zhao, P. Tan, J. Wang, C. Xiang, and H. Tang 2018, A comparative study of Ti-6Al-4V powders for additive manufacturing by gas atomization, plasma rotating electrode process and plasma atomization Powder technology 333 38-46
[4] P. K. Samal and J. W. Newkirk 2015 ASM Handbook Volume 7: Powder Metallurgy ASM International 1-907
[5] J. Džugan and Z. Nový 2017 Powder application in additive manufacturing of metallic parts powder metallurgy: fundamentals and case studies 183
[6] B. Suharno, F. Mawardi, S. Dewantoro, B. Irawan, M. Doloksaribu, and S. Supriadi 2019 Effect of powder loading on local feedstock injection behavior for fabrication process of orthodontic bracket SS 17-4 PH using metal injection molding in AIP Conference Proceedings 020030
[7] S. Supriadi, S. Dewantoro, F. A. Mawardi, B. Irawan, M. Doloksaribu, and B. Suharno 2019 Preparation of feedstock using beeswax binder and SS 17-4PH powder for fabrication process of orthodontic bracket by metal injection molding in AIP Conference Proceedings 020029
[8] G. Schieleper 2006 A manufacturing process for precision engineering components Powder metallurgy association, United Kingdom
[9] S. Supriadi, T. W. Sitanggang, B. Irawan, B. Suharno, G. Kiswanto, and T. Prasetyadi 2017 Orthodontic bracket fabrication using the investment casting process Int. J. Technol., 42015 613-621
[10] K. Higashitani, H. Makino, and S. Matsusaka 2019 Powder technology handbook: CRC Press
[11] A. Dehghan-Manshadi, M. Bermingham, M. Dargusch, D. StJohn, and M. Qian 2017 Metal injection moulding of titanium and titanium alloys: Challenges and recent development Powder Technology 319 289-301
[12] Dharmanto, S. Supriadi, Baskoro A.S E 2019 Effect of feed metal mow rate on mow-cost Plasma Atomizer for Fabricating 316L Stainless Steel Powder," International Journal of Technology, 10 1593-1601
[13] R. Knight, R. Smith, and D. Apelian 2020 Application of plasma arc melting technology to processing of reactive metals International materials reviews 36 221-252
[14] A. S. Baskoro and S. Supriadi 2019 Review on plasma atomizer technology for metal powder," in MATEC Web of Conferences 05004
[15] A. S. Baskoro, R. Tandian, A. Edyanto, and A. S. Saragih 2016 Automatic tungsten inert gas (TIG) welding using machine vision and neural network on material SS304 in International Conference on Advanced Computer Science and Information Systems (ICACSI) 427-432