# Manufacturing Process of Metal Powder by Direct Current Plasma Arc Thermal Atomization Method

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***Abstract*—Metal powder is a raw material needed in metal injection molding and additive manufacturing. Atomization method is often used to produce metal powders in large quantities. This study aims to develop a metal powder atomization tool using DC plasma-cutting thermal atomization method, which has a fire temperature of approximately 24.726 °C to melt 316L stainless steel wire into spherical metal powder. In the experiment, this method was conducted to set electric current variables of 25, 30, and 35 amp; 0.02 Bar pressurized air; and a feed rate of 2 mm/s for 1 sprayer. This study uses 316L stainless steel commercial wire material with length of 100 mm and diameter of 1.6 mm to produce metal powder ranging from 25–200 µm and depict surface shapes with scanning electron microscope results in spherical shapes with smooth surfaces without satellite rubbles.**

***Keywords—atomization; 316L stainless steel; DC plasma***

## I. INTRODUCTION

Metal powder is a raw material needed in the manufacturing process of metal injection molding (MIM) and additive manufacturing. Atomization is a method often used in the mass production of metal powder. Several known atomization methods are water, gas, and centrifugal atomization methods. Gas and centrifugal atomization methods can produce small and spherical powders [1].

Particle size distribution requirements vary with the application <45 µm for MIM, 20–45 µm for selective laser melting, 10–45 µm for cold spraying, and 45–106 µm for electron beam melting [2]. Finer powder is increasingly needed in the manufacture of high-precision equipment components such as medical, military, automotive, and aerospace materials [3]. The manufacturing requires a minimal increase in dimensional tolerance or component parts that require a strong surface finish, where powders with a small diameter and spherical shape have high flowability and good conditions when compaction of part formation occurs.

Equipment and costs for making metal powders with atomization methods are relatively expensive, so a new atomization method is needed to produce metal powders characterized by a smaller diameter and perfect spherical shape. Therefore, a new approach is used as an energy source for the process of atomizing metal powders using the direct current (DC) plasma arc thermal system, where plasma arcs have a high enough temperature of approximately 5.726–24.726 $^{o}$C at the welding flame core [4].

This study aims to develop metal powder atomization tools. Manufacture of metal powder atomization tool using DC arc heat plasma inverter produces sparks to melt wire. Through these process variables, we expect that the metal powder produced can meet the characteristics needed in various branches in the field of powder metallurgy [5]. Process variables used include variations in electric current, air pressure, number of nozzles, and speed of wire feed. According to German [6], the atomization process is generally ligamental, rounded, teardrop, angular, and spherical. The metal used was 316L stainless steel for the application of MIM so that the characteristics of the metal powder required were spherical with powder size in the range of <35–200 µm.

## II. MATERIALS AND METHODS

Figure 1 shows the diagram of atomization that we have developed using a DC plasma arc heat system. The plasma system consists of a DC inverter power supply, carbon graphite as a cathode–anode, reactor chamber, and 316L stainless steel wire.

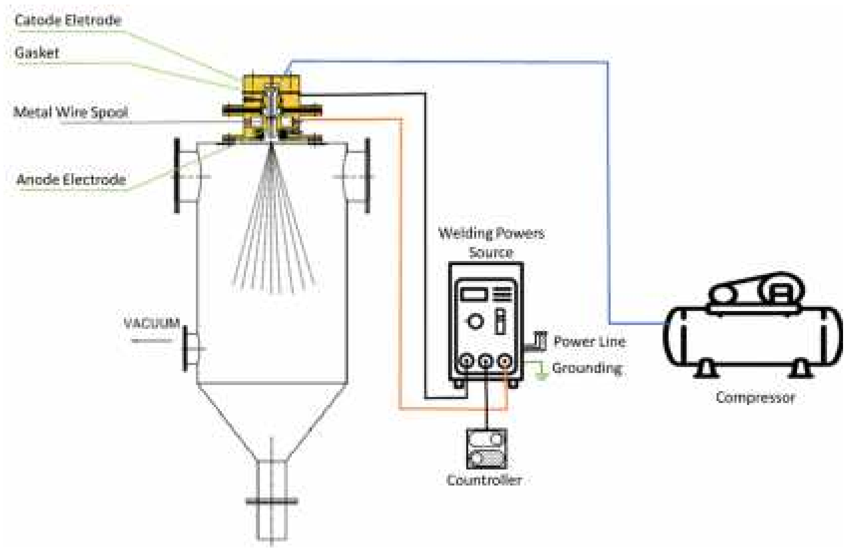



Fig. 1. Composition of plasma atomization equipment with air compressors

Operating a power supply of 25, 30, and 35 amp produces a number of periodic electrical spark jumps in the gap between the cathode and anode driven by 0.02 bar high-pressure air to the shrinking nozzle, thereby resulting in a thermal plasma jet to atomize the wire material and increase the spray jet. The feeder material is 316L stainless steel commercial wire shown in Figure 2, the initial weight of the rod is 15–16 gr/stem, the diameter is 1.6 mm, and the length is 1000 mm. The wire is fed into the nozzle chamber with a constant speed of 2 mm/s resulting in particles of granules flying in the reactor chamber, and then falling together in a collecting container with water as a damper for particle temperature after combustion. Metal powder particles are produced with a size in the range of 35–200 µm in the spherical shape.

Dimensional testing is conducted after the powder mixed with water is dried, and then the dimensions of metal powder particles are determined using the sieving method. Furthermore, metal powder is weighed collectively and then sifted using screens with sizes of #100, #120, #180, #200, and #325 with 150, 125, 80, 75, and 45 µm openings using ASTM-E standardization. 11-61, the sieve is moved using a sieve shaker for 5 min to obtain metal powder at each mesh size. Continued weighted metal mesh per mesh using AND GF-300 digital scales to determine the characteristics of the size and size distribution of metal powders.

Fig. 2. Working material of stainless steel 316L wire

The test was continued with microstructure observation to determine the final form of SS 316L metal powder resulting from plasma atomization combustion. Microstructure test equipment included a AM7915MZTL Dino-Lite digital microscope with 200X magnification. Samples were tested using specimens from sieves with 325 mesh sizes from the three experts with variations of 25, 30, and 35 amp of electric current.

## III. RESULTS AND DISCUSSION

### A. *Atomization with variations in electric current*

In this research experiment, the parameters were electrical currents at 25, 30, and 35 amp. The other parameters were compressor air pressure of 0.02 bars, wire length of 100 mm, wire diameter of 1.6 mm, number of sprayer nozzles used (1 piece), and constant speed of wire fusing (2 mm/sec).

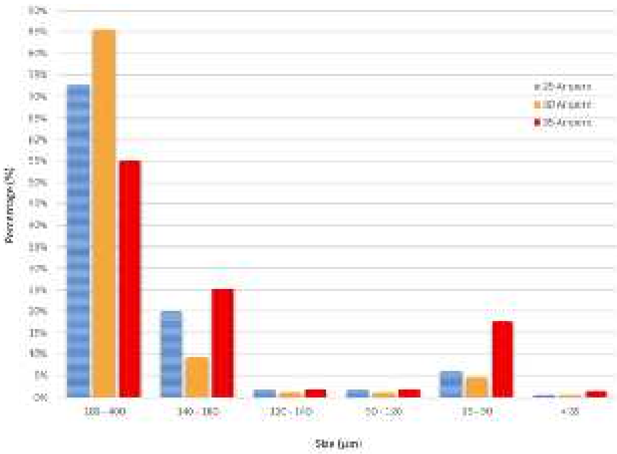


Fig. 3. Percentage of particle size of SS 316L metal powder

Figure 3 shows that the variation of electric current is 35 amp and air pressure is 0.02 bar size <30 µm. The efficiency of the atomization process is relatively low at 2%. The reasons are first, less pressurized air is available for driving the flame torch spark produced by the cathode electrode, an electrode anode that converts the electrical energy supplied to the center of the plasma into kinetic energy. High kinetic energy produced by the plasma is translated into very high speeds at the center of the nozzle. The two metal melts are not completely burned, thereby causing an obstacle to the pressure of the air flow in the nozzle.

As shown in Figure 4, the powder produced by the thermal atomization process of the DC plasma arc with pressurized air, viewed using a digital microscope, has a spherical shape and a smooth surface. This atomization process can also produce the powder with a small size of <35 µm, spherical shape, and a smooth surface that is well suited for the manufacture of products with the type of powder metallurgy process. The color of the powder is darker than the gray of the initial stainless steel material, which shows that during the atomization process, the metal rod undergoes oxidation and the powder also undergoes carburizing [7].

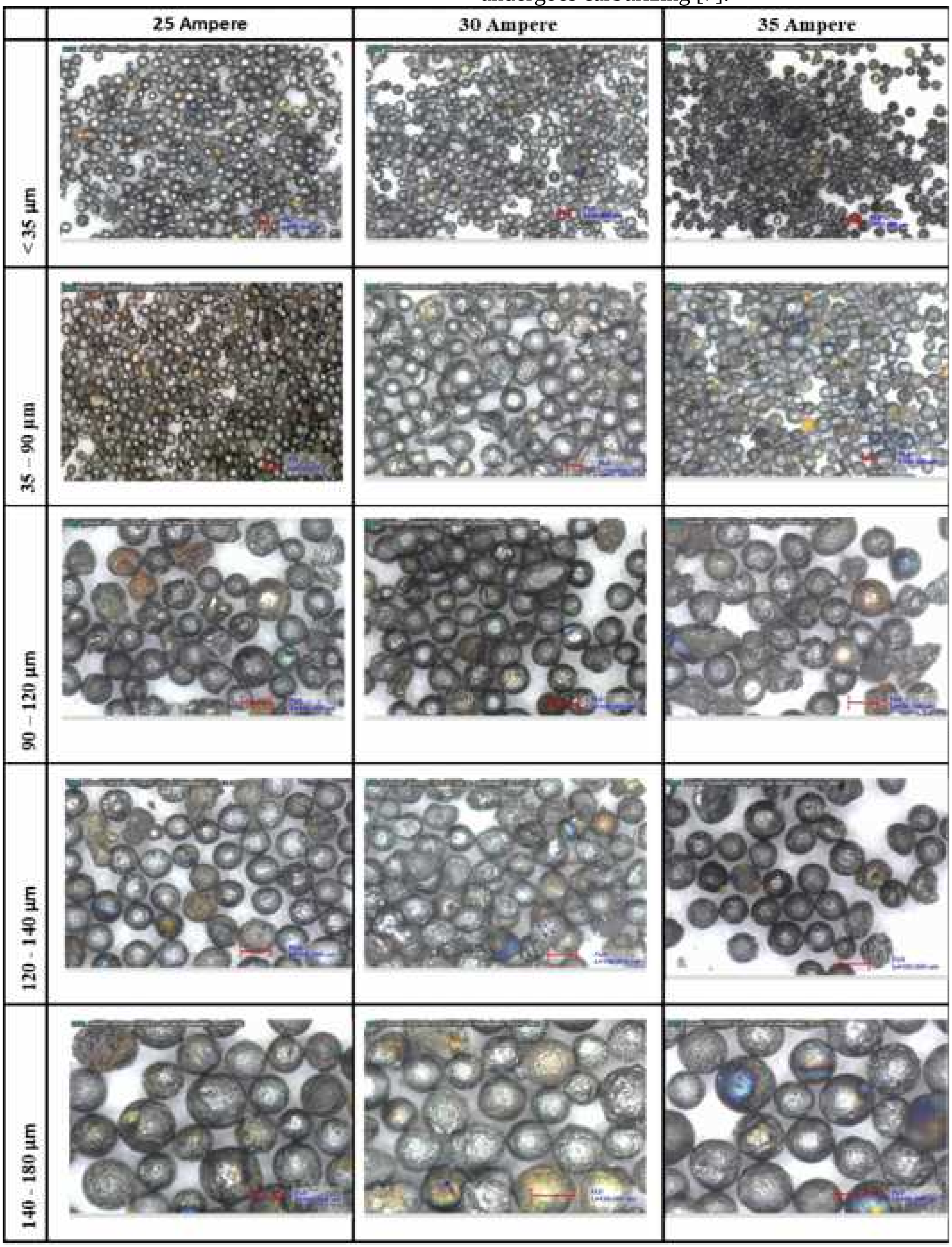



Fig. 4. Comparison of shape and micro size of SS 316L metal powder with 200X magnification as a result of DC arc thermal atomization with electric current variations of 25, 30, and 35 amp

### B. *Structure Characterization*

XRD pattern of the SS 316L wire and the sample burned is shown in Figure 5. Many sharp peaks are observed according to the XRD pattern of austenite. Other weak peaks are found, which indicates a secondary phase in base metal.

The XRD test results are a graph of the relationship between 2θ and intensity. Data from diffraction test results are taken from 2θ 100 to 900. With the wavelength, K-Alpha is 1.54060 Å. X-ray firing was conducted on SS 316L wire specimens. Thereafter, the results of the graphics obtained were matched with the diffraction peak data from PDFcard. The compounds shown at the highest peaks of the X-ray diffraction patterns are FeCrNi and Fe3O4. The FeCrNi compound is found at the first highest peak at 2 theta 26.50 on metal powders at electric current of 35 amp.

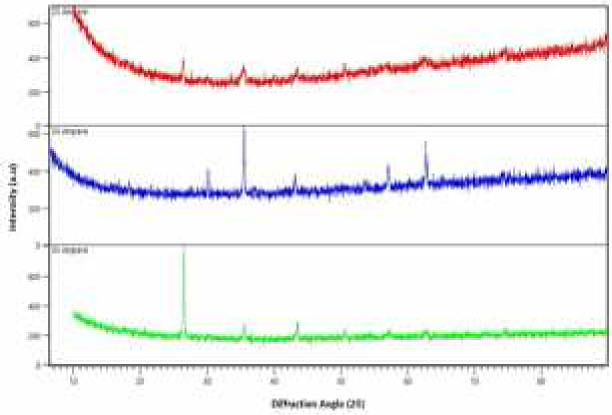


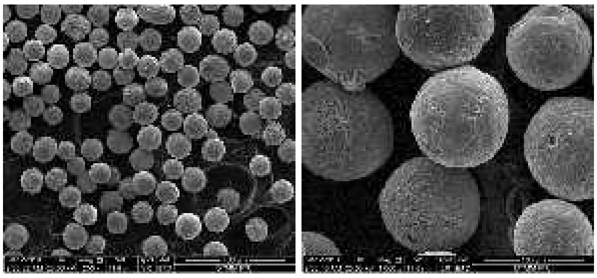
Fig. 5. XRD pattern of surface SS 316L (FeCrNi) metal powder after smelting with variations in electric current

### C. *Microstructure Analysis*

Microstructure observation of 316L stainless steel metal powder from combustion was performed using the scanning electron microscope (SEM) energy dispersive X-ray tool. SEM observations of stainless steel metal powder samples have a spherical shape shown in Figure 6. Typical results of atomization treatment with the DC plasma arc thermal system 316L stainless steel wire uses pressurized air.

SEM observations were conducted on the results of combustion of wires with a current of 35 amp, explaining that electron micrographs from heat-treated wire material show lattes in addition to powder spheroidization even though thermal deposition treatment can remove satellite rubbles on the particle surface.

The EDX test results in Table 1 show the elemental content or composition (wt.%) of SS 316L metal constituents before smelting is done. Three dominant elements were obtained: Fe (62.07%), Cr (18.15%), and Ni (11.17%). After the combustion on the wire, oxygen content was 29.97% and the other elements decreased.



(a) (b)

Fig. 6. Electron micrograph of 316L stainless steel powder at 35 amp: (a) spherical shape and (b) smooth surface

TABLE I. SURFACE COMPOSITION OF SS316L METAL POWDER

| *Element* | *Wt%* *SS 316 L* | *Wt%* *EDX* | *At%* *EDX* |
|---|---|---|---|
| *O* | - | 29.97 | 59.58 |
| *Si* | 0.40 | 01.19 | 01.35 |
| *Cr* | 18.15 | 08.46 | 05.18 |
| *Mn* | 1.73 | 00.52 | 00.30 |
| *Fe* | 62 | 42.13 | 23.99 |
| *Ni* | 11.17 | 17.73 | 09.61 |

## IV. CONCLUSIONS

The atomization method with a plasma arc (DC) direct system using cathode and anode electrode converts electrical energy into kinetic energy that can be used to make 316L stainless steel metal powder. The metal powder produced from this atomization process has the characteristics of a perfectly spherical shape. The resulting size is relatively small, that is, in the range of <35–200 µm. The powder also has a smooth surface, undergoing oxidation and carburizing processes.

The shape and size of the atomization process use the parameters of electric currents. The higher the electric current, the more thermal energy is generated by the plasma arcs. A high air pressure that is jet sprayed accelerates the melting of metals that form powders floating in reactor tubes and cooling the space effectively.

## ACKNOWLEDGMENT

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