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THE EFFECT OF THE SIZE OF SUS316L FLAKE POWDER ON THE CHARACTERISTICS OF METAL POWDER FILTERS WITH A DOUBLE-LAYERED PORE STRUCTURE FABRICATED BY THE WPS PROCESS

When fabricating a metal powder filter with a double-layered pore structure, which includes a microporous layer, by coating flake-shaped powder using the Wet Powder Spray (WPS) process, it is crucial to ensure that the coating is applied parallel to the surface of the metal powder filter. Failure to do so can result in a non-uniform pore structure, leading to a rapid decline in particle filtration efficiency. Therefore, it is necessary to improve the alignment of the coated flake-shaped powder on the filter surface. In this study, a metal powder filter with a double-layered pore structure was fabricated by applying a flake-shaped metal powder coating to a tube-shaped SUS316L powder filter using the WPS process. In order to improve the flake-shaped powder orientation of coating layer, the impact of the rolling process was investigated. The characteristics of the pores were analyzed based on the powder size and the rolling time. The microstructure of the fabricated metal powder filter was observed using an optical microscope, surface roughness, variations in thickness, and air permeability were analysed.

Keywords: WPS (Wet Powder Spraying Process); Double-layered pore structure; Pore characteristics; SUS316L filter

1. Introduction

Porous metal materials are used in various industries such as catalysts, sensors, aerospace, automobiles, biomedical materials, and filters [1-4]. Among these applications, porous metal powder filters have gained considerable attention, particularly in the semiconductor manufacturing sector. With the increasing importance of contamination control technology in semiconductor manufacturing environments and infrastructure, it has surpassed the significance of equipment technology development [5].

The study of porous metal materials has been ongoing since the mid-1920s and has found widespread applications [6]. The manufacturing methods for porous metals and metal filters can be categorized based on the state of the material being processed, namely solid, liquid, gas [7]. Among these methods, the use of a slurry consisting of metal powder, dispersant, and binder in the production of porous metals offers advantages such as improved packing uniformity and control over microstructure compared to powder consolidation [8-10]. Recently, various studies have been conducted on the WPS process, which is one of the processes using slurry. The WPS process involves controlling process variables such as spray nozzle size, coating time, process rotation speed, slurry supply rate, and spray pressure. This method allows for the coating of multiple plate-shaped and tube-shaped filters in a single spray, making it simpler in comparison to other methods [11-12].

In this study, the metal powder filter with a double-layered porous structure capable of filtering nano-scale particles was fabricated by using the WPS process. This was accomplished by preparing a slurry consisting of flake metal powder, solvent, and binder. To improve the alignment of the flake-shaped powder layer after coating, rolling was introduced. The pore structure was controlled through the rolling process, and the properties were evaluated.

2. Experimental

Fig. 1 show the schematic diagram of the process for manufacturing a metal powder filter using the WPS process. The WPS process involves preparing a slurry by mixing metal powder and binder in a solvent such as ethanol and then using a spray gun to spray the slurry onto the tube shape substrate for coating. In this study, tube-shaped metal powder filter (Φ30 mm × 70 mm)

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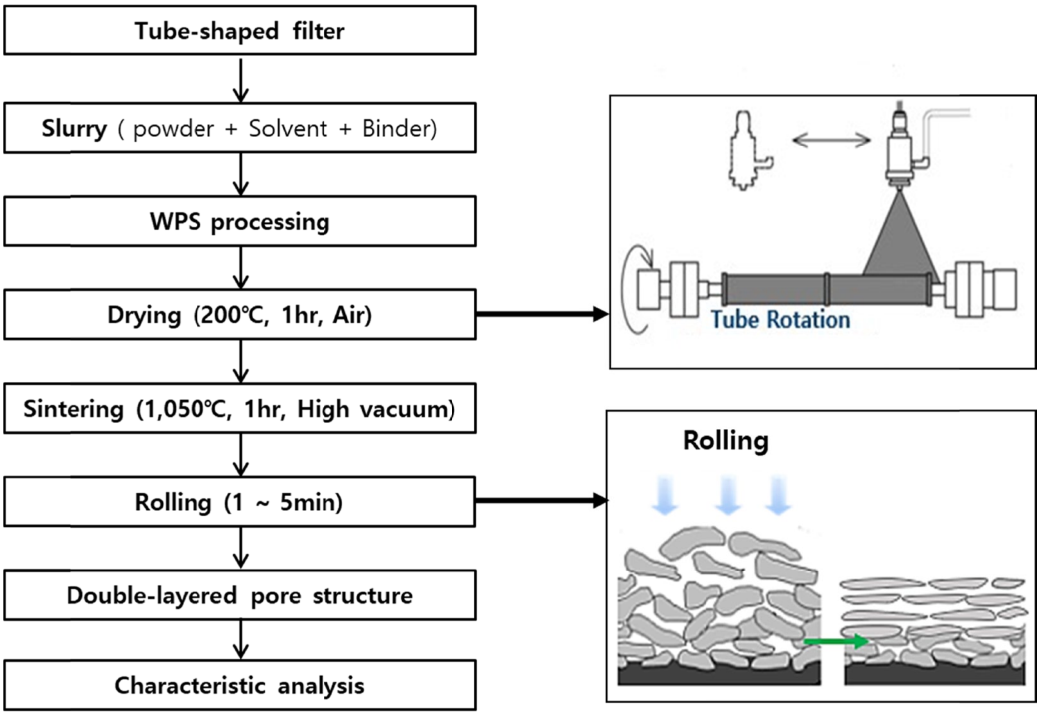

Fig. 1. Schematic diagram for the fabrication of metal powder filter using WPS process

with approximately 25-30% was used as a substrate, which was manufactured using the CIP (Cold Isostatic Press process) with SUS316L powders produced by water atomization. TABLE 1 shows the variables used in the WPS process, and the experiment was conducted based on the powder size. Fig. 2 show a comparison between the surface image of the SUS316L flake-shaped powder used in this study and the powder size distribution. Both powders exhibit a flake shape, and their average powder sizes

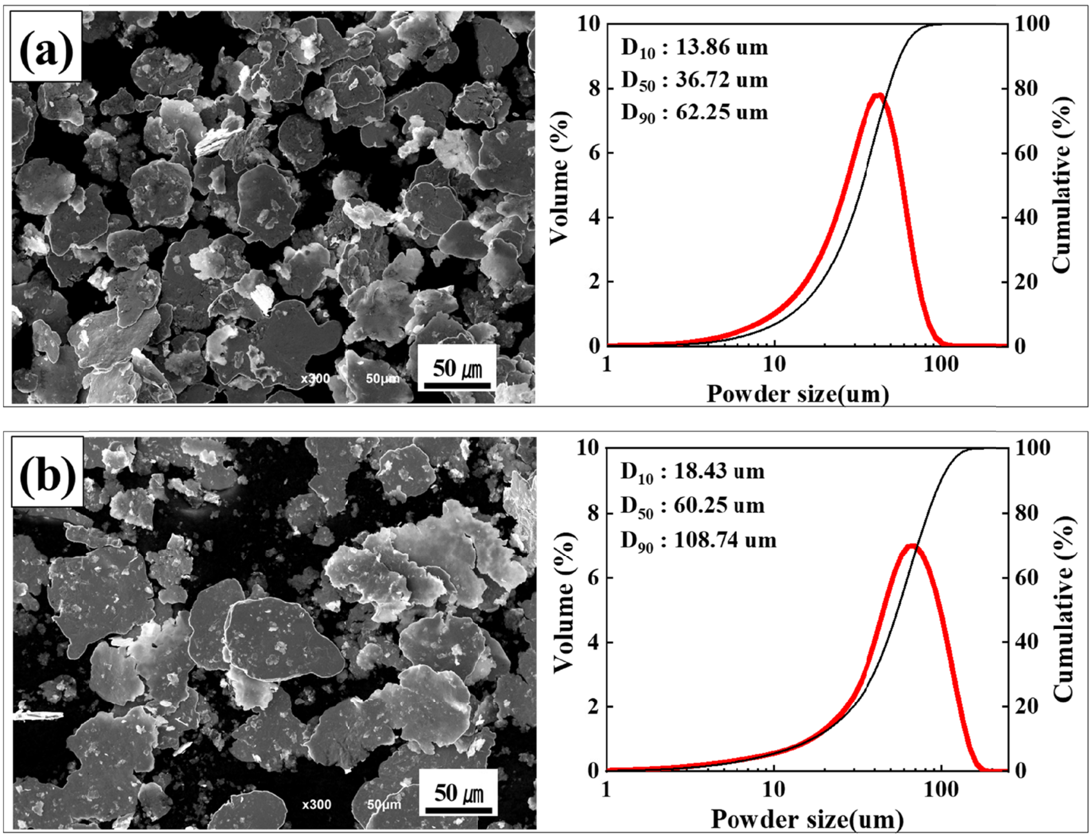

Fig. 2. SEM image of the SUS316L powder morphology and powder size distributions of (a) 36 μm flake-shape powder and (b) 60 μm flake-shape powder

TABLE 1

WPS experiments conditions

Tube shape porous substrate	Exterior diameter (30 mm), Inner diameter (25.5 mm), Length (70 mm)
Spray nozzle type	Vortex (Atomax BN90)
Binder solution	MC 4 wt.% + Distilled water 96 wt.%
Slurry	Powder 40 wt.% + Binder solution 20 wt.% + Ethanol 40 wt.%
Slurry flow rate (ml/min)	200
Air pressure (MPa)	0.25
Distance between nozzle tip and tube (mm)	130
Width of movement (mm)	523
Nozzle moving speed (mm/sec)	80.46

were measured to be 36 μm and 60 μm, respectively. Additionally, ethyl alcohol was used as the solvent, and a binder solution was prepared by mixing 4 wt.% of (hydroxypropyl)methyl cellulose with 96 wt.% of distilled water. The produced slurry was mixed with binder solution, ethanol and metal powder. After applying the microporous layer onto the surface of the tube-shaped metal powder filter using the WPS process, the fabricated filter was dried in air at 200°C for 1 hour and sintered in a high vacuum ($<5\times10^{-5}$ torr) at 1,050°C for 1 hour. To improve the surface characteristics of the fabricated metal powder filter, a rolling process was conducted for 1-5 minutes. The surface roughness was measured as a function of rolling time. The air permeability of the filter was then measured to assess the impact of the rolling process. The air permeability, surface roughness and overall thickness of the filter were measured before and after the rolling process to analyze alterations in permeability and microstructure.

The powder size analysis of the two types of flake-shaped powders used prior to the WPS process was conducted using a Laser particle size analyzer (LS13, Beckman Coulter, USA) under dry atmospheric conditions. After the fabrication of the metal powder filter, the filter was mounted, polished, and the microstructure was examined using an optical microscope (Nikon ECLIPSE MA200, JAPAN). Additionally, the air permeability was analyzed using a Capillary Flow Porometer (CFP1200AEL, PMI, USA) at room temperature. Surface roughness values were measured using a surface roughness tester (SJ-410, Mitutoyo, Japan).

3. Results and discussion

In the fabrication process of a metal powder filter with a double-layered pore structure using the WPS process, where a microporous layer is formed on the surface of the tube-shaped metal powder filter support, the flake-shaped powder exhibits somewhat uneven orientation due to its lower tap density compared to irregular-shaped powders. In severe cases, this phenomenon can result in significant decrease in particle filtration efficiency due to the direct connection between the pore structure and the surface. For this reason, it is necessary to improve the orientation of the coated flake-shaped powder on the filter surface [13].

Fig. 3 shows the microstructure of double-layered pore structure metal powder filter, showing the changes in flake coating layer before and after the rolling process. As evident in Figs. 3(a) and 3(c), despite using the same WPS process

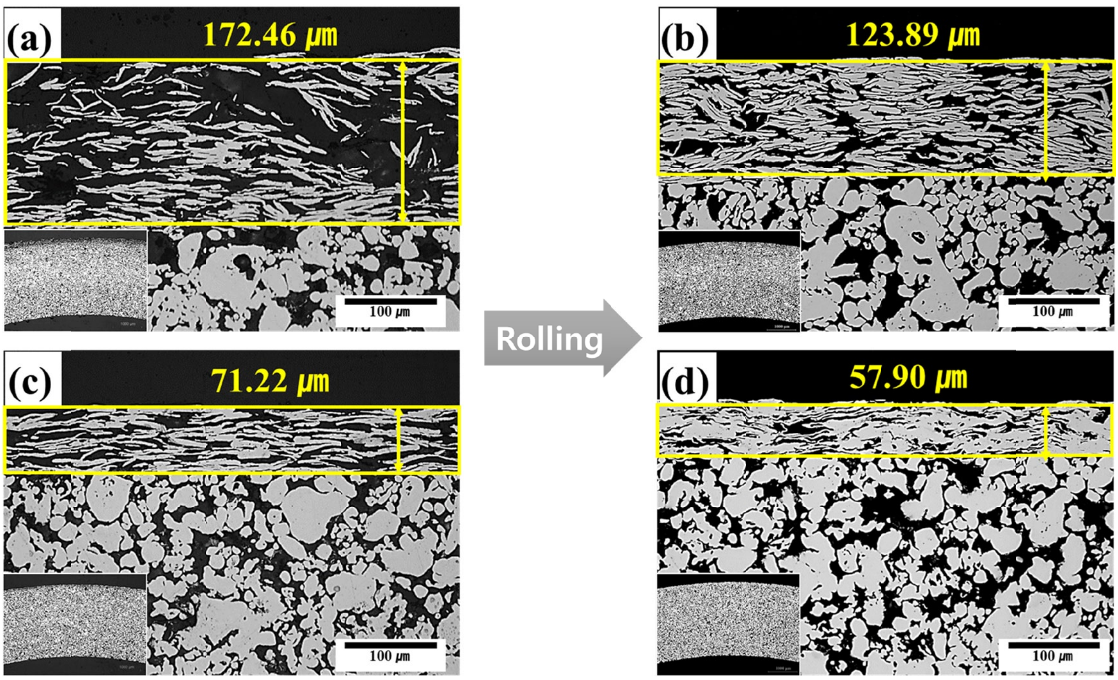

Fig. 3. Cross section images of non-rolling specimens fabricated by (a) 36 μm flake-shape powder and (c) 60 μm flake-shape powder and the cross-section images of the rolling specimens fabricated using (b) 36 μm flake-shape powder and (d) 60 μm flake-shape powder

parameters for coating, the coating thickness of the metal powder filter decreased from 172.46 µm to 71.22 µm as the average powder size increased from 37 µm to 60 µm. When comparing the microstructure of each coating layer, it is observed that the flake-shaped powder with an average powder size of 37 µm exhibits less uniform powder orientation, uneven pore distribution, and higher pore volume. On the other hand, when the rolling process is conducted for 5 minutes, as shown in Figs. 3(b) and 3(d), the coating thickness of the metal powder filter decreases from 172.46 µm to 123.89 µm for an average powder size of 36 µm, and from 71.22 µm to 57.90 µm for an average powder size of 60 µm. As a result, the overall thickness of the filter decreases from 2.88 mm to 2.69 mm for the metal powder filter with an average powder size of 36 µm, and from 2.73 mm to 2.65 mm for the metal powder filter with an average powder size of 60 µm. This indicates that the flake-shaped metal powder is arranged parallel to the cross-sectional direction of the filter surface, resulting in an increased powder orientation and a more uniform pore distribution.

As shown in TABLE 2, it can be observed that the surface roughness also decreases as the rolling process is carried out. These results indicate an increase in the proportion of the flake-shaped metal powder's orientation aligning parallel to the cross-section of the filter surface.

TABLE 2

The surface roughness as a function of powder size and rolling time

Rolling time (min)	Surface roughness Ra (µm)	
	36 µm flake-shaped powder	60 µm flake-shaped powder
0	4.47	3.11
1	1.30	1.05
3	1.12	0.82
5	1.12	0.70

In Fig. 4, the air permeability characteristics of metal powder filters with a double-layered pore structure fabricated by the WPS process and the effect of the rolling process are presented. Overall, the air permeability of tube-shaped metal powder filters with macroscopic pores is higher than that of metal powder filters with a double-layered pore structure coated with flake powder. As shown in Fig. 4(a) and (b), the metal powder filter with an average powder size of 36 µm has higher air permeability than the metal powder filter with an average powder size of 60 µm. These results can be attributed to the microstructure of the coating layer, as shown in Fig. 3, where the metal powder filters fabricated with flake-shaped powder of an average size of 36 µm have a thicker coating thickness but a more uneven distribution of internal pores. Increasing the rolling process leads to a higher proportion of flakes aligning parallel to the filter surface, which hinders airflow more and results in lower air permeability.

Through the control of powder size, it was possible to fabricate metal powder filters with a double-layered pore structure that exhibit various pore structures and air permeability characteristics. Additionally, it was confirmed that by conducting the rolling process, the microporous layer structure can be oriented parallel to the cross-section of the tube-shaped metal powder filter.

4. Conclusions

In this study, a metal powder filter with a double-layered pore structure was fabricated by using the WPS process, and the pore characteristics according to the flake-shaped SUS316L powder size and rolling process were analyzed. As a result, it was confirmed that the coating layer thickness of the metal powder filter decreased as the average powder size of the flake-shaped powder increased from 37 µm to 60 µm, despite the coating using the same WPS process variable. In addition, when the rolling process was conducted for 5 minutes, it was found that the thickness of coating layers decreased regardless of the powder size, and the overall thickness of the filter decreased accord-

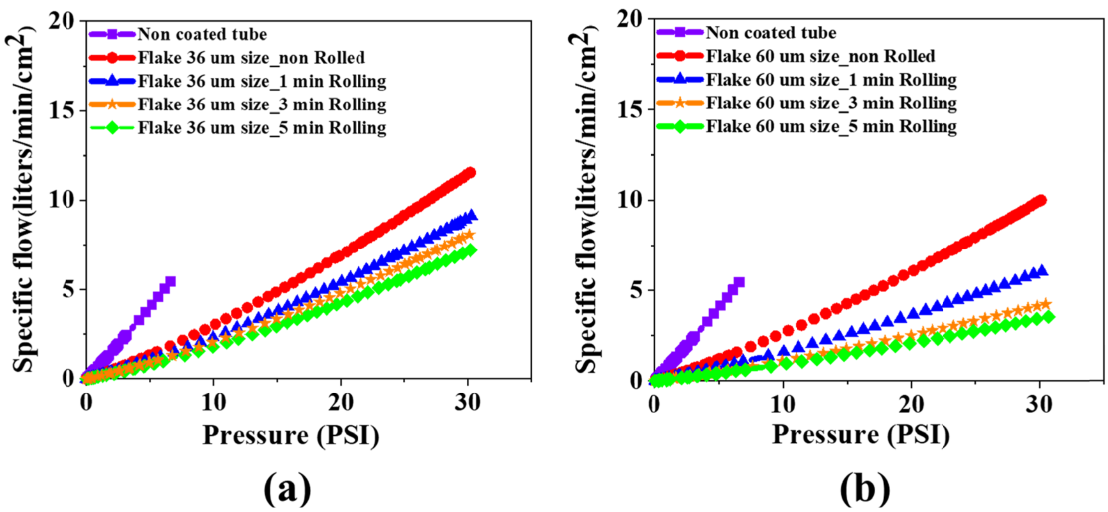

Fig. 4. The air permeability of the metal powder filter with a double-layered pore structure fabricated by (a) 36 µm flake-shape powder and (b) 60 µm flake-shape powder

ingly. It was confirmed that this also reduced surface roughness. This phenomenon is estimated to be due to an increase in the proportion of flake-shaped powders oriented parallel to the cross-sectional direction of the filter surface, the air permeability of the metal filter with a double-layered pore structure is lower than that of the powder filter with tube-shaped metal powder filter with macroscopic pore, and the air permeability decreases as the rolling time increases.

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