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YU-JEONG YI[1,2], MIN-JEONG LEE[1,2], SU-JIN YUN[1], MANHO PARK[3],
JU-YONG KIM[4], JUNGWOO LEE[2*], JUNG-YEUL YUN[1*]

FABRICATION OF METAL GAS FILTER BY MATERIAL EXTRUSION ADDITIVE MANUFACTURING PROCESS

Recently, 3D printing processes have been used to manufacture metal powder filters with manufacturing complex-shape. In this study, metal powder filters of various shapes were manufactured using the metal extrusion additive manufacturing (MEAM) process, which is used to manufacture three-dimensional structures by extruding a filament consisting of a metal powder and a binder. Firstly, filaments were prepared by appropriately mixing SUS316 powder with sizes ranging from 7.5 μm to 50 μm and a binder. These filaments were extruded at temperatures of 100°C to 160°C depending on the type of filament being manufactured, to form three types of cylindrical filter. Specimens were sintered in a high vacuum atmosphere furnace at 850°C to 1050°C for 1 hour after debinding. The specimens were analyzed for permeability using a capillary flow porometer, porosity was determined by applying Archimedes' law and microstructure was observed using SEM.

Keywords: Gas Filter; Additive manufacturing; Stainless steel; Porosity; Powder size

1. Introduction

The continuous improvements in semiconductor device sophistication now require ever cleaner components throughout the process gas delivery system. Metal powder filters are applied to remove particulate contamination without affecting inlet gas purity [1]. But to increase the efficiency of such filters, while filtering contaminants they should have high air permeability and low pressure drop when the gas passes through the filter. Metal powder filters are typically manufactured in a disk shape or a cylinder shape. The filtration characteristics of such filters are affected by pore characteristics such as the size, distribution, and number of pores included in the material [2]. In general, when the pore size decreases at the same porosity, the particle filtration efficiency increases, but the air permeability decreases and the pressure drop increases. On the other hand, when the porosity increases with the same pore size, the air permeability increases and the pressure drop decreases, but the particle filtration efficiency decreases [3,4]. To obtain a metal powder filter with a high flow rate while maintaining excellent particle filtration efficiency, it is necessary to manufacture it with a small pore size but high porosity and air permeability [4]. To maintain high purity gas purity, it is necessary to develop various types of filters with excellent air permeability and particle filtration efficiency [5].

3D printing processes have recently been used to manufacture various complex shapes [6]. In this study, one of the 3D printing processes, the metal extrusion additive manufacturing (MEAM) process, was carried out to make metal powder filters with various shapes. The MEAM process is similar to the metal powder injection molding process, but does not need molds, and the metal powder is used in the form of filaments mixed with a binder [6,7]. These filaments are extruded and laminated to produce a structure with a three-dimensional shape [8]. In this study, SUS316L powder with sizes of 7.5 μm, 20 μm, and 50 μm were used as the metal powders for each filament. These filaments were extruded at a temperature of 100°C to 160°C depending on the type of filament, to form three types of cylindrical filters: a double-wall type, straight-sawtooth type and screw-sawtooth type. After removing the binder in a de-binding step, sintering was carried out at three temperatures of 850°C, 950°C, and 1050°C, respectively. The pore characteristics and microstructure of the fabricated filters of various shapes were analyzed and through these results, we attempted to investigate the effects of powder size, filter shape and sintering temperature.

1 KOREA INSTITUTE OF MATERIALS SCIENCE (KIMS), METAL POWDER DEPARTMENT, CHANGWON, 51508, REPUBLIC OF KOREA
2 PUSAN NATIONAL UNIVERSITY, DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, BUSAN, 46241, REPUBLIC OF KOREA
3 R&D CENTER, ASFLOW CO. LTD, HWASUNG, 16648, REPUBLIC OF KOREA
4 3DP R&D CENTER, REPROTECH, SUWON, 16229, REPUBLIC OF KOREA

* Corresponding authors: yjy1706@kims.re.kr, jungwoolee@pusan.ac.kr

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2. Experimental

In this study, three types of filaments made of SUS316L powder were manufactured, and subsequently fabricated using the MEAM process into three-dimensional metal powder filter structures. First, a filament with a diameter of φ30 and a length of 100 mm was prepared to use in the MEAM equipment. As a binder to be mixed with the metal powder, consisting if Polyethylene (PE), ethylene vinyl acetate (EVA), stearic acid (SA), and paraffin wax (PW) were included at a weight ratio of 20:20:3:57, respectively, and mixed uniformly at 175°C and then cooled. The prepared binder was incorporated in the filament at different ratios, depending on the particle size of the SUS316L powder. TABLE 1 shows the binder content according to the particle size of the powder, as a volume ratio. As the particle size of the metal powder increases, more binder is required because material extrusion becomes difficult. Accordingly, a high extrusion temperature of 130°C was required for the 7.5 μm filament with a low binder content.

TABLE 1

Binder content volume ratio according to powder particle size and extrusion temperature

Filament	Powder : binder (Vol. %)	Extrusion Temperature
7.5 μm	61 : 39	130°C
20 μm	52 : 48	125°C
50 μm	45 : 55	115°C

Metal powder filters of three shapes were fabricated using these filaments, and conditions such as nozzle diameter, extrusion amount, and extrusion thickness were appropriately adjusted for each shape using a Simplify3D program. The metal powder filter shapes were named double-wall type, straight-sawtooth type and screw-sawtooth type. To remove the binder, the specimens made by the MEAM process were subjected to solvent debinding and thermal debinding. The former solvent debinding involves immersing the specimens in Haxane solvent for 24 hours, to remove PW and SA. Subsequently, the thermal debinding process was performed using an Ar atmosphere furnace, and held at 800°C for 1 hour. The debinded specimens were sintered. To analyze the effect of the sintering temperature, it was carried out at temperatures of 850°C, 950°C, and 1050°C, respectively. To analyze the characteristics of the sintered metal powder filters, their air permeability was measured using a capillary flow porometer (CFP1200AEL, PMI, USA), the density was calculated by applying Archimedes' law, and the microstructure was observed with SEM (JSM-6610LV, JEOL).

3. Results and discussion

Fig. 1(a) shows the density of the double-wall filter according to the sintering temperature for each powder particle size. As the sintering temperature increased, the density of the filter made of 7.5 μm filaments increased from 7.467 g/cm^2 to 7.671/cm^2, and in the case of the filter made of 50 μm filaments, it increased from 6.476 g/cm^2 to 7.304/cm^2. In addition, it was observed that the density of the filter increased as the particle size became smaller.

Fig. 1(b) shows the density according to the powder particle size for each filter shape sintered at 1050°C. As the powder particle size increased, the density decreased, and depending on the shape. The measured density was highest in the order of double-wall structure > straight-sawtooth structure > screw-sawtooth structure. The double-wall filter was measured to have a higher density than both sawtooth filters. This was assumed to be because the wall thickness of the double-wall filter was relatively thin and the shape was simple, so that more sintering shrinkage occurred. On the other hand, it was found that there was no significant difference in the density of the two types of sawtooth filters with a complex shape.

Fig. 2 shows the microstructure of the metal powder filter after sintering. It can be seen that as the powder particle size of the filament increases, the pores, which are empty spaces between particles, become coarse, and as the sintering temperature increases, a dense structure is formed, thereby reducing porosity.

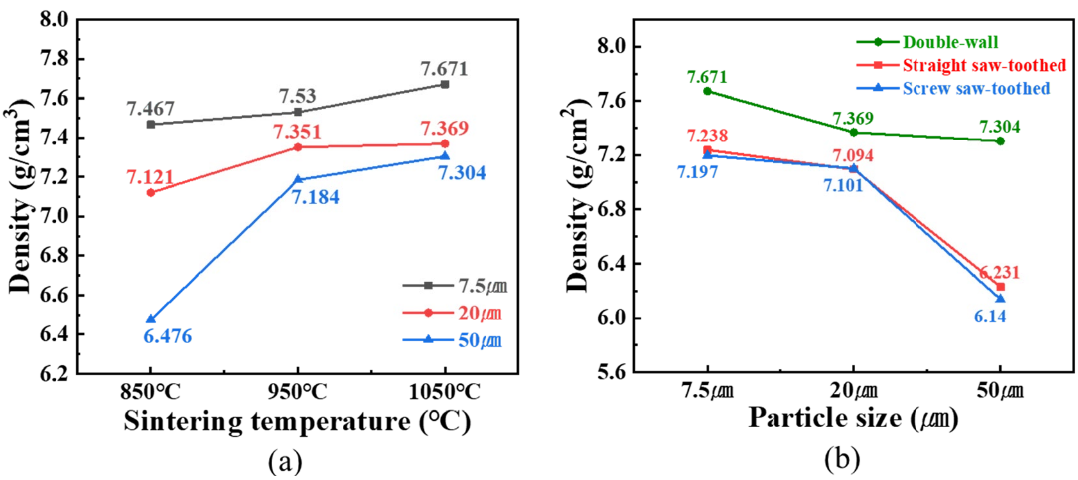
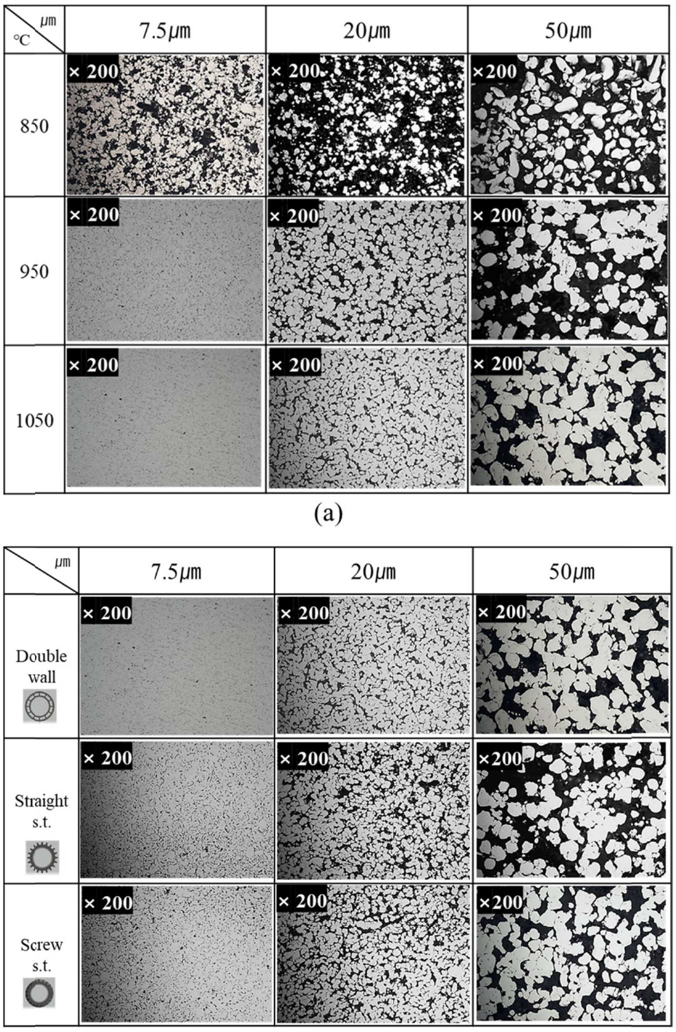


Fig. 1. Density of the metal powder filter manufactured by the MEAM process. (a) Density according to the sintering temperature for powder particle size of the double-wall filter & (b) density according to the powder particle size for each shape of the filter sintered at 1050°C



(a)

(b)

Fig. 2. Microstructure of the metal powder filter manufactured by the MEAM process. (a) Microstructure according to the sintering temperature for powder particle size of the double-wall filter & (b) Microstructure according to powder particle size for each shape of the filter sintered at 1050°C

Also, the double-wall filter formed a structure relatively denser than the two types of sawtooth filters.

Fig. 3 is shows measurements of the wall thickness of the three types of metal powder filters, which were manufactured from filaments with a particle size of 20 μm powder and sintered at 1050°C. For both sawtooth filters, the thickness of the body wall was measured excluding the sawteeth. The screw-sawtooth filter had the thickest wall thickness at 3.35 mm, and in the case of the double-wall filter, the sum of the two wall thicknesses was 2.55 mm, which was the thinnest wall thickness.

Fig. 4 is a graph showing the air permeability characteristics of the metal powder filter manufactured by the MEAM process. Fig. 4(a) shows that the air permeability decreased as the sintering temperature increased, and it was confirmed that the air permeability improved as the powder size increased. In Fig. 4(b), the straight-sawtooth filter had the highest air permeability and the screw-sawtooth structure had the lowest permeability. Factors affecting the air permeability are the thickness of the wall through which the gas passes and the wall-shaped structure.

Although the double-wall filter had a simple structure and the total thickness of the two walls was thinner than that of the straight-sawtooth filter, it exhibited relatively low air permeability. Considering the density in Fig. 1(b) and the microstructure in Fig. 2(b), the double-wall filter with the highest density and densest structure was expected to have the lowest air permeability, but it was higher than the screw-sawtooth filter. This is because the former filter has a double wall structure; as the high-pressure gas passes through the first wall, the pressure decreases, and a pressure loss occurs as it passes through the second wall.

On the other hand, among the two sawtooth filters, the screw-sawtooth filter with a thick wall had the lowest air permeability. From the above results, although the air permeability of the metal powder filter was affected by the density and microstructure of the filter, it is considered that the shape structure of the filter, that is, the wall thickness, has a more significant effect on the air permeability of the filter.

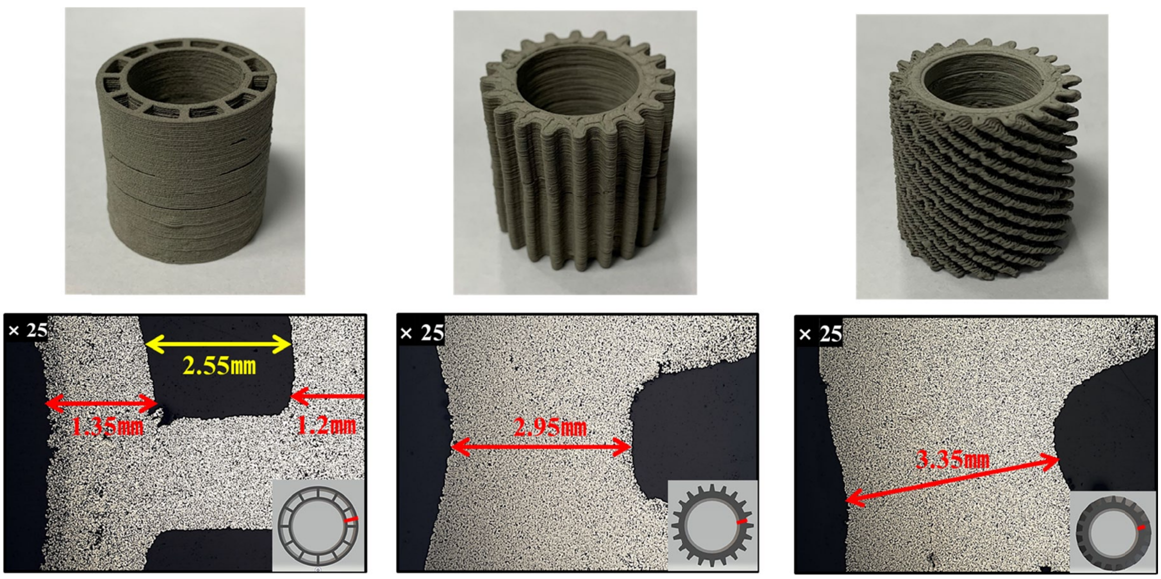


Fig. 3. SEM image of wall thickness according to metal filter sintered at 1050°C

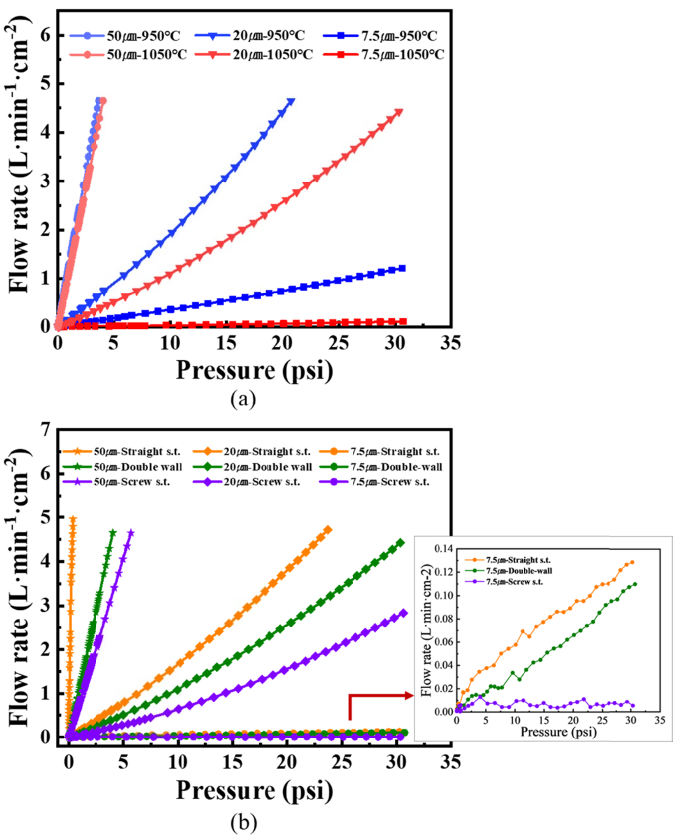


Fig. 4. Air permeability characteristics of the metal powder filter manufactured by the MEAM process. (a) air permeability according to the sintering temperature for powder particle size of the double-wall filter & (b) air permeability according to powder particle size for each shape of the filter sintered at 1050°C

4. Conclusions

In this study, metal filters were manufactured using the MEAM process. They were prepared by varying the filament particle size and the shape of the filter, and it was observed that the density tended to decrease as the sintering temperature increased. When the double-wall filter was sintered at 1050°C, and the filament particle size was increased from 7.5 µm to 50 µm, the density decreased from 7.67 g/cm^3 to 7.30 g/cm^3. When the density of the filter was measured according to filter shape, the density of the double-wall filter was determined to be the highest, and the density of the two sawtooth filters showed similar lower values. When the air permeability was compared according to filter shape, the straight-sawtooth structure exhibited the highest air permeability, while the screw-sawtooth structure showed the lowest air permeability. The result of this study confirmed that the filament particle size and sintering temperature affected the filter density, but the thickness of the wall surface greatly affected the air permeability of the filter.

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