Properties and filtration performance of microporous metal membranes fabricated by rolling process

Jiyeong Park, Seok-Hong Min, Won-Hee Lee, No-Suk Park, Hyung-Soo Kim and Jong-Oh Kim

ABSTRACT

We evaluated the filtration performance of microporous metal membranes fabricated by the rolling process. Metal wire meshes were rolled with thickness reduction ratios of 10, 20, and 30%. The pore size of the metal wire mesh membrane decreased with increasing rolling ratio, whereas the removal efficiency of the suspended solids and turbidity showed a very slight increase compared to that of an unrolled mesh membrane. The metal powder was dispersed on the surface of the rolled metal wire mesh membrane and bound with polyvinyl alcohol, then dried at 100 °C for 1 h, and finally sintered at 1,000 °C for 3 h. The mean pore size, suspended solids, and turbidity of the metal powder membrane at a rolling ratio of 30% were approximately 0.7 μm, 84% and 83%, respectively. Therefore, microporous metal membranes successfully fabricated by the rolling process were also sufficiently permeable filters.

Key words | metal mesh, metal powder, metal wire, porous metal membrane, rolling, sintering

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INTRODUCTION

Water conservation and reuse are major issues in groundwater management, desertification, and climate change. Drinking water shortages threaten the survival of the world's population because nearly 50% of the water is used in industry and agriculture (Tang & Chen 2002; Kim *et al.* 2007; Kujawa *et al.* 2013).

Porous materials have been used in separation, filtration, absorption, and other chemical processes because of their excellent thermal, acoustic, electrical, and mechanical properties (Liu 2010; Jin *et al.* 2014). Polymeric membranes are not suitable for use in high concentrations of chlorides, high pH, and high temperature and pressure conditions. Ceramic membranes are brittle if exposed to rapid pressure or temperature variations, whereas metal membranes are not (Rubow *et al.* 1999; Wang *et al.* 2004). Metal porous filters are made of sintered metal powders, metal wire mesh, and metal fibers as foundation, can withstand pressures up to 1 MPa and temperatures up to 350 °C, and are resistant to oxidation. Metal porous filters have a long lifetime, and this minimizes the maintenance cost. Metal porous filters are sturdy and have constant permeability, high corrosion resistance, and high thermal stability. Consequently, metal membranes have numerous applications in the chemical, electrical and power, environmental, and pharmaceutical industries (Snow *et al.* 1995; Kim *et al.* 2005; Herrmann & Morgan 2009).

In this study, we evaluated the fabrication and filtration performance of microporous metal membranes fabricated by the rolling process. Metal wire meshes were rolled with reduction ratios of 10, 20, and 30% (reduction is the

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decrease in metal thickness). Metal powder membranes were fabricated by dispersing the metal powder on the surface of the rolled metal wire mesh membranes using polyvinyl alcohol (PVA) as binder, then drying at 100 °C for 1 h, and finally sintering at 1,000 °C for 3 h.

METHODS

Porous metal wire meshes and metal powder membranes were fabricated by rolling–sintering and dip coating, respectively. Metal wire mesh membranes were prepared using metal meshes #165/1450, #270/2000, and #510/3600. Metal wire mesh (disk-type) of approximately $10 \times 10\ cm^2$ was rolled with thickness reduction ratios of 10, 20, and 30%. Then, the five-layer sintered metal mesh membrane was fabricated by rolling and sintering under vacuum (1×10^{-5} Torr) and pressure (10 kgf/cm^2) at 1,200 °C for 1 h. To fabricate the metal powder membranes, we used SUS 316L metal powder with a mean particle size of 5 μm. Prior to rolling, the metal powder was washed by sonication in ethanol and deionized water and then dried in an oven at 80 °C for 2 h. The metal powder was dispersed on the surface of the rolled metal wire mesh membrane (#40/200), using PVA as the binder, dried at 100 °C for 1 h, and sintered at 1,000 °C for 3 h.

The microstructure of the porous metal membranes was studied by using a Hitachi SU-70 field emission scanning electron microscope (FE-SEM) equipped with an energy dispersive X-ray spectrometer. The mean flow pore diameter (the value for which the flow is decreased almost by half in a partial flow test device) and pore pressure were measured using a capillary flow porometer (PMI, Inc.). The filtration performance of the porous metal membranes was evaluated by measuring the turbidity with a DR/2010 spectrophotometer and the total suspended solids (SS) using Standard Method 2540 (APHA 2005).

RESULTS AND DISCUSSION

Fabrication and filtration performance of the metal mesh membranes

Figure 1 shows SEM images of the pore shape of the metal mesh prepared by the rolling process. The width of the horizontal line increases with the increasing reduction ratio of the metal mesh, whereas the pore size decreases gradually.

Figure 2(a) shows the relationship between the mean flow pore diameter and the reduction ratio of the metal mesh membranes. For an increase in the reduction ratio of between 10 and 30%, the mean flow pore diameter decreased. The smallest pore diameter was observed at a reduction ratio of 30%, and the mean flow pore diameter of the #510/3600 metal mesh membrane was approximately 4.56 μm and approximately 2.7 and 1.8 times smaller than the #165/1450 and #270/2000 membranes, respectively. Figure 2(b) shows the mean flow pore pressure of the metal mesh membranes. The mean flow pore pressure increased with increasing reduction ratio. At a reduction ratio of 30%, the #510/3600 metal mesh membrane, the mean flow pore pressure was approximately 10.05 kPa and approximately 2.7 and 1.8 times greater than that of the

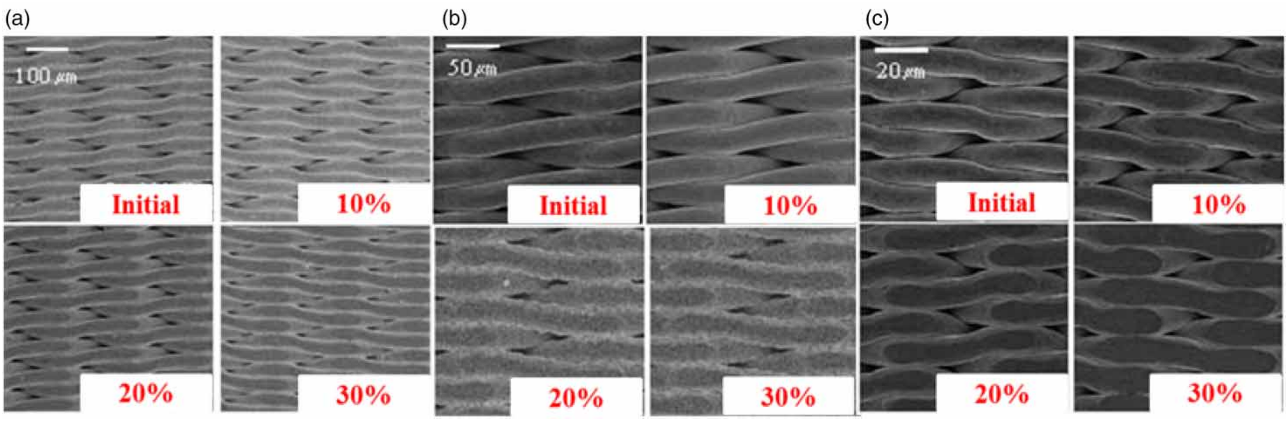

Figure 1 | SEM images of pore shape as a function of the reduction ratio of metal mesh using the rolling process: (a) #165/1450, (b) #270/2000, and (c) #510/3600.

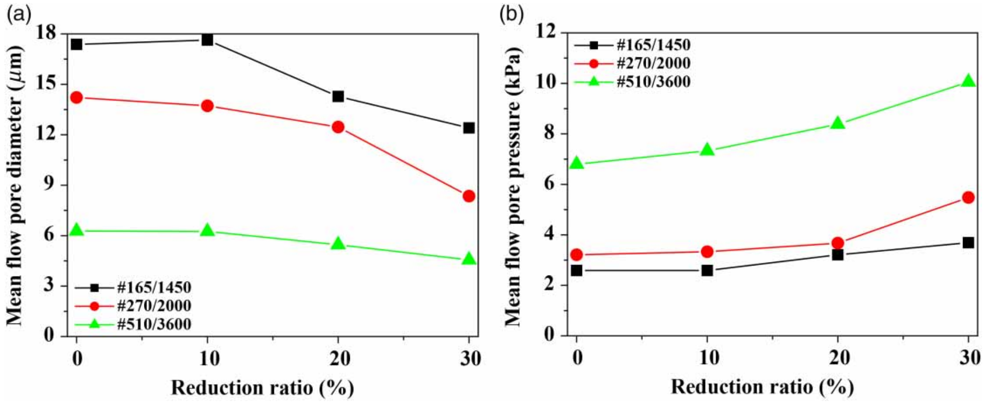

Figure 2 | (a) Mean flow pore diameter and (b) mean flow pore pressure of metal mesh membrane using the rolling process.

#165/1450 and #270/2000 membranes, respectively. This is attributed to the decrease in pore size because of rolling.

Figure 3 shows the filtration performance vs. the reduction ratio of the metal mesh membranes. The suction pressure was 34 kPa, the initial pH was 6.6, and the operation time was 10 min. The SS and turbidity of the metal mesh membranes increased with the increasing reduction ratio. At a reduction ratio of 30%, the SS and turbidity of the #165/1450, #270/2000, and #510/3600 metal mesh membranes were approximately 63% and 63%, 71% and 70%, and 77% and 74%, respectively.

Fabrication and filtration performance of the metal powder membrane

The metal powder membranes were fabricated by dispersing metal powder with a mean particle size of 5 μm on the surface of the rolled metal wire mesh membrane (#40/200) using PVA as the binder, drying at 100 °C for 1 h, and finally sintering at 1,000 °C for 3 h. Figure 4 shows SEM images of metal powder with reduction ratios of 0%, 10%, 20%, and 30%. Clearly, the deformation of the metal powder particles increased as the reduction ratio increases from 10% to 30%.

Figure 5(a) shows the relation between pore diameter and the reduction ratio of the metal powder membrane. The best pore diameter of the mean flow pore diameter and bubble-point pore diameter was observed at a reduction ratio of 30%, but the pore diameter increased between the reduction ratios of 10% and 20%. This may be attributed to the cracks between the rolled metal wire and metal powder in the rolling–sintering process. Figure 5(b) illustrates the mean flow pore pressure and bubble-point pore pressure of the metal powder membrane. At a reduction ratio of 30%, the mean flow pore pressure and

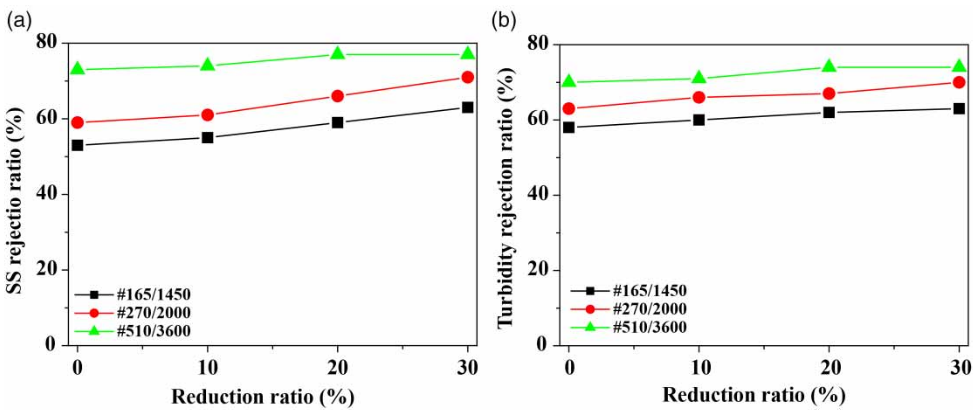

Figure 3 | (a) SS and (b) turbidity rejection ratio of metal mesh membranes (conditions: operation time 10 min, suction pressure 34 kPa, initial pH 6.6, SS 90 mg/L, turbidity 70 NTU).

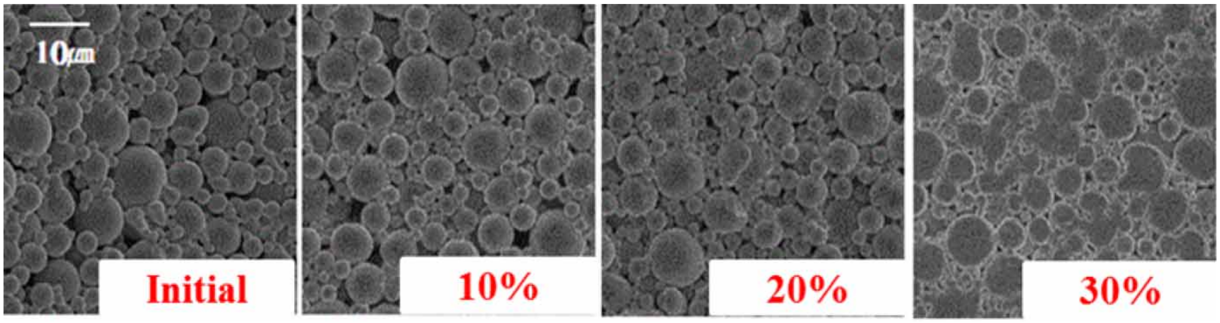

Figure 4 | SEM images of metal powder body on the reduction ratio using the rolling process.

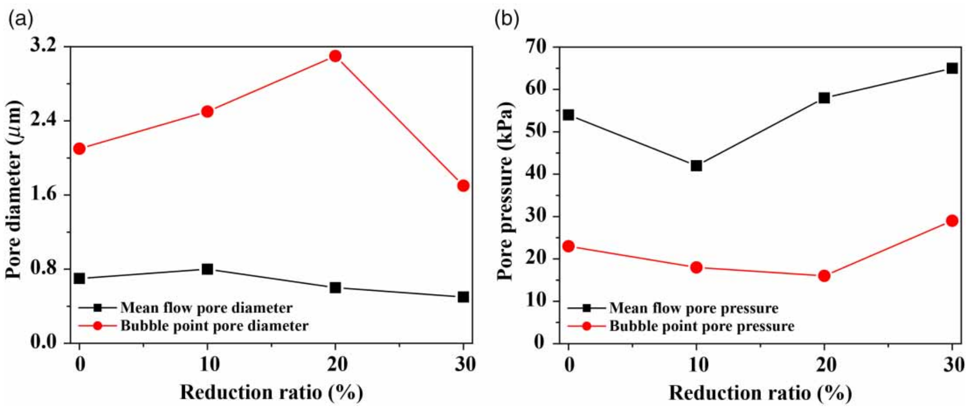

Figure 5 | (a) Pore diameter and (b) pore pressure of metal powder membrane using the rolling process.

bubble-point pore pressure were approximately 65 kPa and 29 kPa, respectively, and approximately 1.6 and 1.5 times, 1.1 and 1.8 times higher than those at 10% and 20%, respectively.

Figure 6 shows the filtration performance vs. the reduction ratio of the metal powder membrane. The highest SS and turbidity correspond to the reduction ratio of 30%.

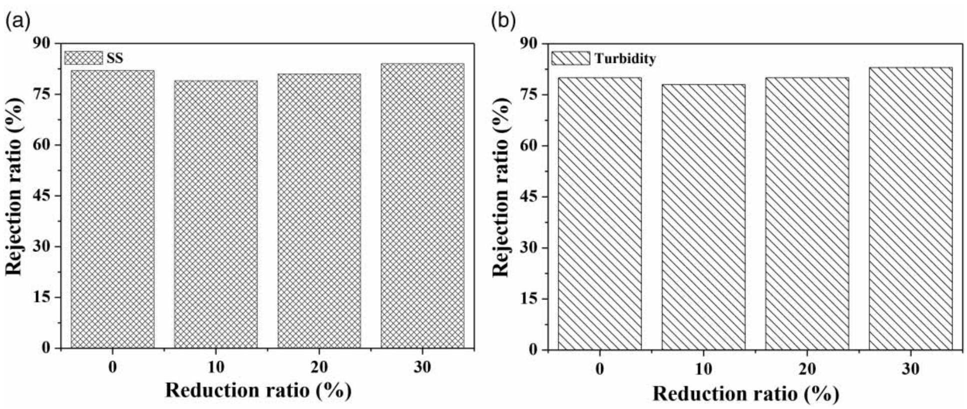

Figure 6 | (a) SS and (b) turbidity rejection ratio of metal powder membranes (conditions: operation time 10 min, suction pressure 34 kPa, initial pH 7.1, SS 110 mg/L, turbidity 91 NTU).

CONCLUSIONS

We fabricated porous metal membranes by the rolling process. The structural properties and filtration performance were evaluated by considering SEM images, pore diameter, pore pressure, SS and turbidity. The metal membranes were rolled with a thickness reduction ratio of 10, 20, and 30%. The pore size of the pure metal mesh membrane decreased with increasing rolling ratio, whereas the removal efficiency of SS and turbidity showed a very slight increase compared to that of the unrolled metal mesh membrane. The mean pore size, SS, and turbidity removal of the metal powder membrane with a rolling ratio of 30% were approximately 0.7 μm, 84%, and 83%, respectively. Porous metal membranes were successfully fabricated by the rolling process, and showed adequate filtration performance as membrane filters.

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