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Influence of nano powder on rheological behavior of bimodal feedstock in powder injection molding

Joo Won Oh [a], Won Sik Lee [b], Seong Jin Park [a,]*

[a] Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), 77 Cheongam-Ro, Nam-Gu, Pohang, Gyeongbuk 37673, Republic of Korea
[b] Korea Institute of Industrial Technology, 156 Gaetbeol-ro, Yeonsu-gu, Incheon 21999, Republic of Korea

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ABSTRACT

Rheological behavior of feedstock, which highly affects the condition of green body, is substantial issue in powder injection molding process. In this paper, the influence of nano powder contents in bimodal feedstock on solids loading and rheological behavior has been investigated. The bimodal powders were fabricated with 100 nm and 4 μm sized 316L stainless steel powders, and mixed with wax-based binder system. The critical solids loading for each powder was measured by torque rheometer. In order to analyze net effect of nano powder ratio, all feedstocks were formulated as solids loading of 42 vol.%. Feedstock homogeneity was evaluated by rotational rheometer. Capillary rheometer test was conducted to measure the viscosity of feedstock with different temperatures, shear rates and nano powder ratios. Rheological parameters, like flow index, flow activation energy and moldability index, were calculated based on the capillary rheometer test. The results indicated the critical solids loading and feedstock homogeneity decreased as nano power ratio increased in bimodal feedstock. Rheological parameters were also affected by nano powder ratio, and the optimal mixing ratio of nano powder for moldability index was investigated as 12 vol.%.

1. Introduction

Powder processing technologies have various advantages, such as recycling of powders and less energy consumption due to lower sintering temperature than melting point. However, traditional powder metallurgy (PM) process has low design flexibility since it is generally coordinated with die compaction, which uses uniaxial pressure. As a result, 3 dimensional complex parts are hardly fabricated by this process. Powder injection molding (PIM) process was introduced to overcome such limitation of traditional PM process. PIM is a combination process of powder metallurgy and injection molding process. Since it contains the injection molding step, PIM process is one of the most appropriate mass production processes for complex structural components [1–2]. PIM process is also near-net shaping technique with tight tolerances. For these reasons, various studies of microfabrication with PIM process have been investigated [3–6], and nano powder was introduced in PIM process because the particle size needs to be at least 10 times smaller than the minimum feature size [7].

Nano powder in powder processing provides several benefits. Samples fabricated with nano powder show more isotropic behavior, better surface roughness and wear resistance. Nano powder is also sintered at lower temperature than micro powder [7]. However, at the same time, nano powder shows low solids loading and high feedstock viscosity due to agglomerated particles and high interparticle friction, caused from its large specific surface area [7–9]. High cost is also a critical issue of nano powder. These limitations of nano powder can be reduced by formulating nano/micro bimodal powder. Bimodal powder is a mixture of two different sized powders. Nano/micro bimodal powder can decrease disadvantages of nano powder while keeping its merits. J. Rajabi et al. [10] used 150 nm and 5 μm powders, and investigated the effect of nano powder on mechanical properties by increasing nano powder ratio from 0 to 30 wt.%. They reported addition of nano powder increased sintered density and improved mechanical properties, while it decreased grain size and surface roughness. J. W. Oh et al. [11] analyzed the nano powder effect on debinding and sintering behaviors with 100 nm and 4 μm powders. The results indicated nano powder highly influenced both of behaviors. Nano powder also showed the effect of grain refinement, and as a result, hardness of sintered samples increased as nano powder ratio increased. The phenomenon of grain refinement was explained by J. P. Choi et al. [12]. They added 25 wt.% nano powder, and observed the microstructures of samples in different sintering temperatures. They concluded that grain boundaries of nano powder prevented grain growth by pinning effect.

In PIM process, the injection molding is an important step for successful manufacturing [1]. Improper green body can result in crack, distortion and warpage during debinding and sintering [2,13–15]. Therefore, rheological characteristics of feedstock, which highly affect

* Corresponding author.
E-mail address: sjpark87@postech.ac.kr (S.J. Park).

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Table 1
Powder characterization of each powder.

Powder		Micro	Bimodal 12:88	Bimodal 25:75	Bimodal 50:50	Bimodal 75:25
Nano powder ratio (vol.%)		0	12	25	50	75
Particle size (μm)	D_{10}	2.10	1.55	0.48	0.14	0.10
	D_{50}	4.16	3.98	3.84	2.58	0.31
	D_{90}	7.64	7.60	7.56	5.95	3.31
Distribution slope parameter (S_w)		4.56	3.71	2.14	1.57	1.68
BET surface area (m^2/g)		0.19	1.13	2.18	3.22	5.52
Pycnometer density (g/cm^3)		7.84	7.81	7.74	7.63	7.56

the quality of green body, need to be analyzed to predict flow behavior of feedstock during molding. Many studies were conducted to investigate the rheological behavior of feedstock, and some of them dealt with bimodal feedstock. M. E. Sotomayor et al. [14] analyzed the effect of powder ratio in bimodal feedstock. They mixed 5 μm and 12 μm powders with different ratios, and studied the change of the critical solids loading and rheological parameters depending on powder distribution. However, the particle size ratio of bimodal powder was about 2, which was too small value to show the bimodal effect [16]. B. N. Mukund et al. [17] used 5 different micro sized powders to fabricate various bimodal feedstocks. They studied distortion of samples, viscosity and powder-binder separation with bimodal feedstocks. A few papers handled nano/micro bimodal feedstock. M. Müller et al. [18] fabricated nano/sub-micro bimodal feedstock, and showed the effect of nano powder on the critical solids loading and viscosity. K. H. Kate et al. [15] did simulation study with 20 nm and 1 μm bimodal feedstock. They stated nano powder in bimodal feedstock had significant effect on the rheological properties of the feedstock. V. P. Onbattuvelli et al. [19] found the critical solids loading increased by adding small amount of nano powder in micro powder with SiC and AlN powders, and compared the viscosity of micro and bimodal feedstocks. J. P. Choi et al. [20] determined the optimal solids loading of bimodal feedstock with rheological parameters in different solids loading. Although those papers covered nano/micro bimodal feedstock, all of them dealt with fixed amount of nano powder, and it was only <25%. The influence of nano powder ratio in bimodal feedstock on rheological behavior has not been investigated yet. In this paper, the effect of nano powder from 0 to 75 vol.% in bimodal feedstock on rheological properties has been studied. The critical solids loading, feedstock homogeneity and rheological parameters were analyzed.

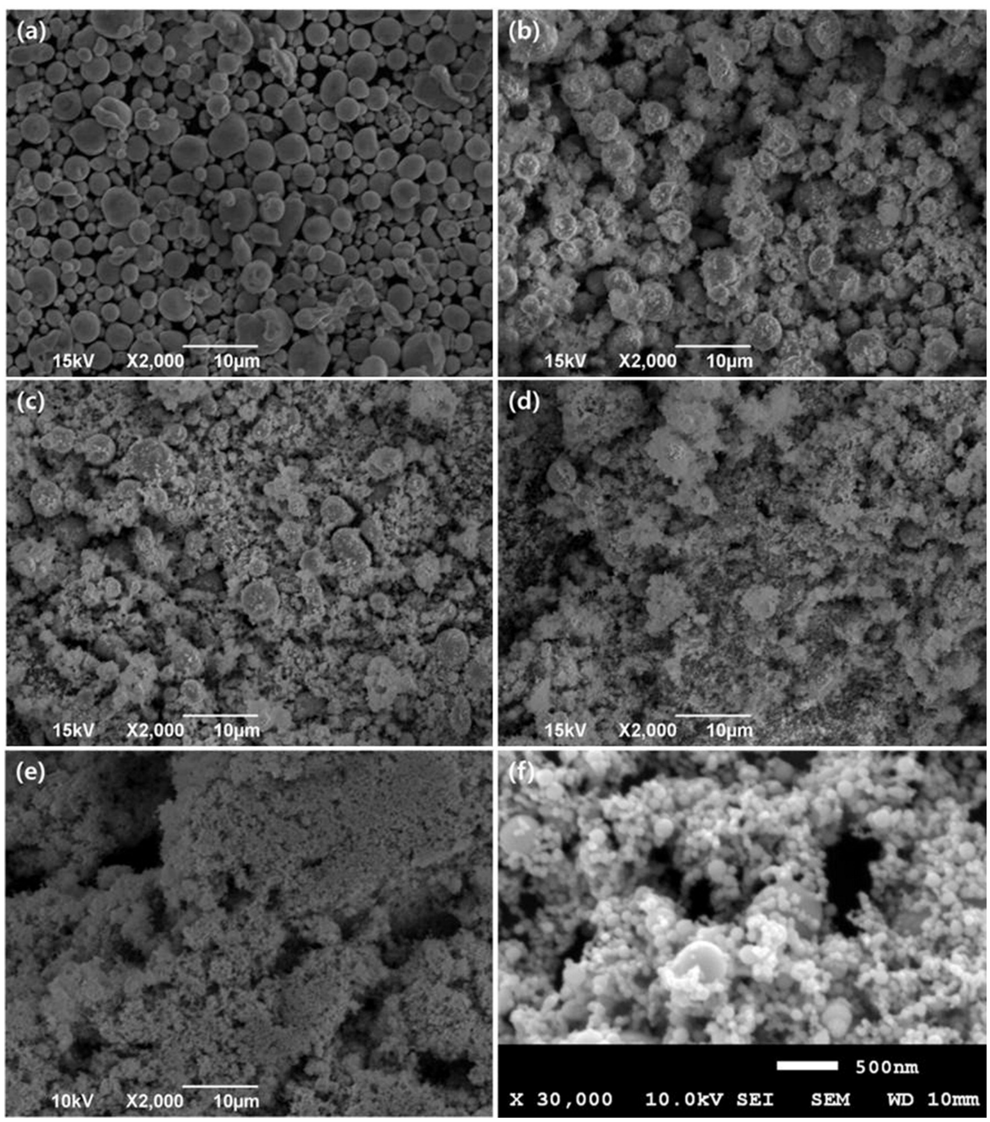

Fig. 1. SEM images of powders: (a) micro, (b) 25:75, (c) 50:50, (d) 75:25 and (e, f) nano.