Thermal Debinding Behavior of PIM Components Produced with Different Powder Sizes and Shapes

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Abstract

To understand the effect of powder characteristics on the thermal debinding behavior, PIM parts produced with powders with different particle sizes and particle shapes were examined to determine their weight losses during thermal debinding. The results show that the average diameter of the pore channel in the compact increased when the temperature increased and when coarse powders were used. However, the weight loss rates did not increase proportionally with the pore size. This suggests that the different powders that are frequently used in PIM parts do not affect the thermal debinding rate significantly. This is because the pore size is much larger than the mean free path of the decomposed gas molecules. Thus, the diffusion rates of the gases are not rate-controlling in thermal debinding. The controlling mechanism of the thermal debinding rate is the decomposition of the backbone binder in the PIM parts.

Keywords: powder injection molding, thermal debinding, powder characteristics, metal injection molding

1. Introduction

Powder Injection Molding (PIM) has been widely accepted by the manufacturing industries due to its capability of producing complex-shaped parts with a homogenous microstructure, high density, and high performance. The PIM process includes molding, debinding, and sintering. Among these three main steps, debinding is the slowest operation. To improve its efficiency, a tandem process, ie., solvent debinding followed by thermal debinding has been developed.[1, 2] The solvent debinding step removes most of the soluble binder. This leaves interconnected pore channels, through which the decomposed gas produced during thermal debinding can escape to the ambient.[3]

In the case of thermal debinding, it is generally believed that the debinding rate is affected by the particle size. However, since little direct experiment evidence has been reported in the literature, the objective of this study was thus to investigate in detail the effect of powder characteristics on thermal debinding behavior of PIM products.

2. Experimental and Results

Two stainless steel powders were used in this study to compare the effect of powder shape on thermal debinding. The characteristics of these powders are given in Table 1.

Table 1. The characteristics of stainless steel powders used in this study

Powder Characteristics	Irregular 316L	Spherical 316L
Supplier	ATMIX	UFP
Average Particle Size	13.51μm	12.89μm
Pycnometer Density	7.95g/cm^3	7.89g/cm^3
C, wt%	0.025	0.021
S, wt%	0.002	0.004
N, wt%	0.307	0.213
O, wt%	0.032	0.022

To understand the influence of the particle size on the thermal debinding behavior, carbonyl iron powder with particle size of 4.5μm and water atomized iron powder with a particle size of 45μm were selected as the base powders. The characteristics of these powders are given in Table 2. To prepare the feedstock, the powders were kneaded with 7wt% binder. This feedstock was later transferred to an injection molding machine where flat specimens (4x10x100mm) were made. Molded samples were immersed in n-heptane at 50°C until about 85% of the soluble binder components had been removed. To measure the weight loss during thermal debinding, samples were heated at 5°C/min to the set temperature and then immediately cooled to room temperature. To understand the pore structure evolution during thermal debinding, a mercury porosimeter was employed to measure the pore size distribution of each sample.

Table 2. The characteristics of the iron powders used in this study

Powder Characteristics	Carbonyl iron powder	Water atomized iron powder
Designation	ISP-1641	ASC-300
Average Particle Size	4.5μm	45μm
Pycnometer Density	7.56g/cm^3	7.85g/cm^3
C, wt%	0.736	0.005
S, wt%	0.002	0.002
N, wt%	0.659	0.003
O, wt%	0.830	0.002

Fig. 1 and Fig. 2 show the profiles of cumulative pore volume and pore diameter for specimens heated to 400 and 650°C, respectively. Fig. 1 shows that most pores were between 2 and 4μm. When the debinding temperature increased to 650°C, the cumulative pore volume of all compacts, except carbonyl iron powders, increased from 0.05 to 0.08ml/g because all backbone binder had been removed from the specimen. The reason why the fine carbonyl iron powder compact had a smaller cumulative pore volume, from 0.05 to 0.06ml/g, is that shrinkage had already occurred during thermal debinding due to its fine particle size. The average pore diameter also increased as the temperature increased. For mixed iron powder, the average diameter increased from 4 to 10.5μm.

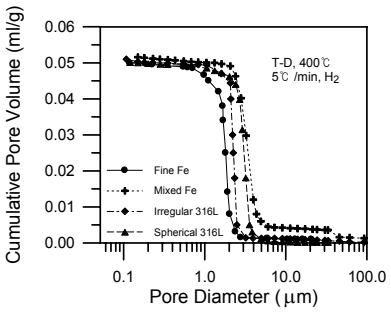

Fig. 1. The pore size distribution in the compacts prepared using fine Fe, mixed Fe, irregular 316, and spherical 316L powders that were heated to 400°C.

To understand whether the powder characteristics will affect the debinding rate, the weight losses of each specimen were recorded throughout the thermal debinding. Fig. 3 shows that the weight loss increased rapidly as the temperature reached approximately 300°C. After 500°C, the polymer removal had reached more than 90%. Most binder decomposed in the temperature range of 300 to 500°C. All curves show almost the same debinding behavior. This is not surprising, as the size of the decomposed gas molecules is usually in the μm range and the mean free path of low molecular weight gases is also small. Thus, all decomposed gases can escape easily to the ambient through the pore channels which had an average diameter of at least 1.5μm at 400°C and 2μm at 600°C. This demonstrated that the powder characteristics did not influence the thermal debinding behavior significantly.

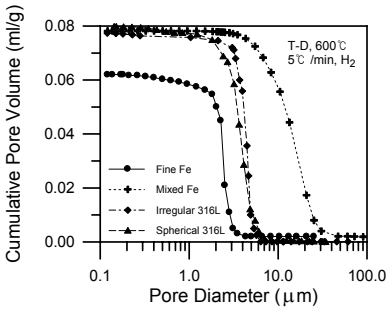

Fig. 2. The pore size distribution in the compacts prepared using fine Fe, mixed Fe, irregular 316, and spherical 316L powders that were heated to 600°C.

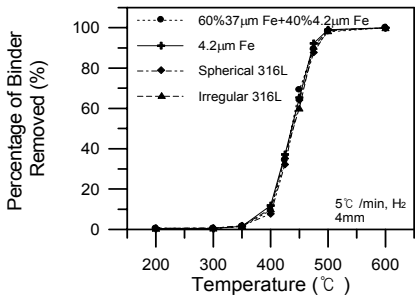

Fig. 3. The percentage of the binder removed during thermal debinding from the specimens that were prepared using different powders.

3. Summary

The pore channel in the compact increased when the debinding temperature increased and when coarse powders were used. However, the weight loss rates were not comparable for all parts. This suggests that the controlling mechanism of the thermal debinding rate is the decomposition of the backbone binder in the PIM parts.

4. References

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