Development of Titanium Powder Injection Molding: Rheological and Thermal Analyses

Yunxin Wu[1,a], Seong Jin Park[2,b], Donald F. Heaney[3,c], Xin Zou[1,d], Guosheng Gai[1,e], Young-Sam Kwon[4,f], and Randall M. German[2,g]

[1]Tsinghua University, Dept. of Mechanical Engineering, Beijing 100084, China
[2]Mississippi State University, P.O. Box 5405, Mississippi State, MS 39762, USA
[3]Pennsyvania State University, 118 Research West, University Park, PA 16802, USA
[4]CetaTech, Inc., TIC 296-3, Sacheon, Kyungnam, 664-953, Korea
[a]yxwu@mail.tsinghua.edu.cn, [b]sjpark@cavs.msstate.edu, [c]dfh100@psu.edu, [d]zoux03@mail.tsinghua.edu.cn, [e]gaigs@mail.tsinghua.edu.cn, [f]yskwon@cetatech.com, [g]german@cavs.msstate.edu

Abstract

Powder injection molding (PIM) is a suitable technology for the fabrication of complex shape titanium and its alloys, and has a great potential in many applications. This paper dealt with the injection molding of hydride dehydrogenization (HDH) titanium powder, spheroidized HDH titanium powder and gas atomized titanium powder. Rheological and thermalgravimetric behaviors were compared between the feedstocks of the three powders, and a tentative application of Ti PIM to eye frame temple and bridge was briefed.

Keywords: powder injection molding (PIM), titanium powder, feedstock, rheology

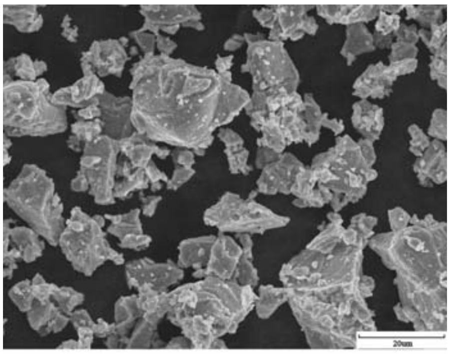
1. Introduction

Titanium and its alloys have low densities, high specific strengths, excellent corrosion resistance and high-temperature endurance as well as good non-magnetic properties. However, their industrial application, especially for those requiring complex shaped components, is limited due to poor machinability and high manufacturing cost. As a new net shaping technology, powder injection molding (PIM) offers unique privileges in the fabrication of complex shaped, microstructurally uniform, and high performance Ti components [1].

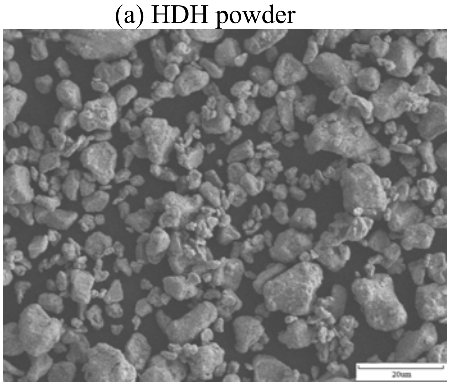
This paper assesses the rheological and thermalgravimetric behaviors of PIM feedstocks prepared withhydride-dehydrogenization (HDH) Ti powder, spheroidized HDH Ti powder, and gas-atomized Ti powder. Then the tentative result of applying Ti PIM to eye frame temple and bridge is briefed.

2. Experimental Procedure and Results

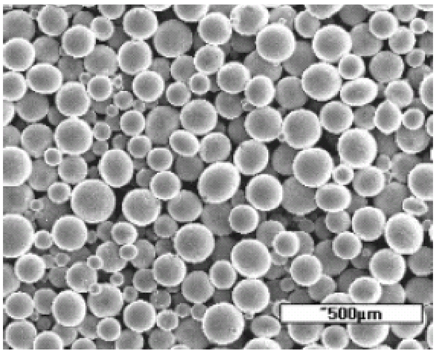
Three types of Ti powders were used in the presentwork: HDH Ti powder, spheroidized HDH Ti powder, and gas-atomized Ti powder. The HDH Ti powder was treated using a Particle Composite System (PCS) for spheroidizing. Figure 1 shows the morphologies of the three powders. Before the spheroidizing treatment, the HDH Ti powder has acicular and irregular shapes with a D_{50} of 18.5 μm (Fig. 1a); after the treatment, the HDH Ti powder is rounded and becomes near-spherical, and its D_{50} is reduced to 14.5 μm (Fig. 1b). The gas-atomized Ti powder has a spherical shape, with a D_{50} of 42.2 μm (Fig. 1c).



(a) HDH powder



(b) Spheroidized HDH powder



(c) gas atomized powder

Fig. 1. SEM micrographs of Ti powders.

In order to achieve a homogeneous feedstock mix which is free of agglomerates, an optimal content of powder and binder should be determined, and high shear rates are required to smear and knead binder between the powders close to critical solid loading [2]. Therefore, a torque rheometer was used to characterize the critical solid loadings of the feedstocks for the three Ti powders, then a twin shaft, co-rotating mixer was utilized to compound the Ti powder and the wax-based binder into feedstocks. After compounding, the feedstocks were granulated for subsequent injection molding.

The critical solid loaings are determined as 63 % for the HDH powder, 66 % for the spheroidized HDH powder, and 71 % for the gas-atomized powder. At critical solid loading in a torque behavior, the mixing torque increases significantly and becomes erratic due to the interparticle friction.

The homogeneous filling of feedstock into the mold depends on viscous flow, and this requests feedstocks have good rheological properties [3]. A capillary rheometer was used to determine the relationship between viscosity and shear rate, and the results are ploted in Fig. 2. As shown, the feedstock made from the gas-atomized Ti powder exhibits lowest viscosities at various shear rates, whereas the HDH Ti powder makes the feedstock least viscous. It is interesting to note that the feedstock of the spheroidized HDH Ti powder has viscosities that are much lower than that of the un-spheroidize HDH Ti powder and very close to that of the gas-atomized Ti powder.

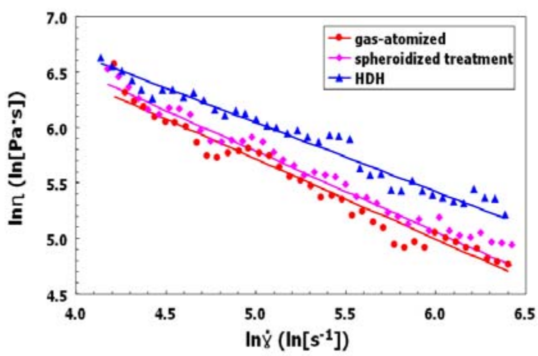


Fig. 2. Viscosity at 160 °C with varying shear rate.

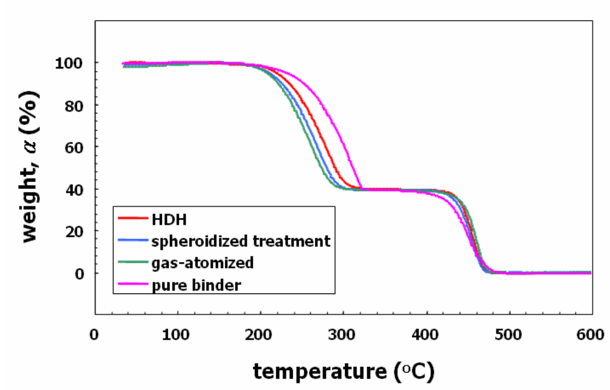


Fig. 3. TGA at 5 °C/min for thermal debining.

The thermalgravimetric analysis (TGA) of feedstocks helps to design the thermal debinding cycles. As shown in Fig. 3, the feedstocks made from the three Ti powders have similar thermalgravimetric behaviors upon heating, and the thermal decomposition of the binder is enhanced in the first sigmoid (< 350 °C) by the catalytic effect of Ti powders.

Fig. 4 shows an example of Ti PIM application: the temple and bridge for eye frame were injection molded, debound and sintered with the gas-atomized Ti powder. In a low solid loading (55 %), cracks were found during debinding, while in a high solid loading (65 %), there was a problem with ejection after injection molding. Therefore, optimization of the Ti PIM processes needs to be done in the future, and the spheroidized HDH Ti powder may find much usages.

Fig. 4. Temple and bridge for eye frame by Ti PIM.

3. Summary

Three Ti powders (HDH, spheroidized HDH, and gas-atomized) were investigated for PIM application in terms of their rheological and thermalgravimetric behaviors. A combination of these powders is expected to provide good solution for real Ti PIM application.

4. References

1. Y. Cao, *Powder Metallurgy Technology*, 19[1], p. 45 (2001).
2. H. R. Z. Sandim and A. F. Padilha, *Key Engineering Materials*, **189-191**, p. 296 (2001).
3. T. Zhang, Z. Jiang, J. Wu, and Z. Chen, *Journal of American Ceramic Society*, **73**, p. 2171 (1990).