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Review

Experimental analysis and finite element simulation of the co-sintering of bi-material components

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ABSTRACT

This paper investigates the use of numerical simulations to describe solid state diffusion of the sintering stage during a Powder Injection Moulding (PIM) process for micro-bi-material components based on a thermo-elasto-viscoplastic model. The sintering behaviour was studied with dilatometer experiments, gravitational beam-bending and free sintering tests. As a complement to this experimental study, a finite element simulation of the operation was performed. The simulations were based on constitutive equations identified from specific experiments performed for each blend at different sintering heating rates and loadings. Finally, the simulation results are compared to other experimental and simulation results to evaluate the reliability of the proposed model. The numerical results addressing shrinkage and the relative density were found to be fully consistent with the experimental observations.

Contents

1. Introduction

Sintering is a manufacturing process used for making various parts from metal or ceramic powder mixtures. Sintering can be defined as the thermal transformation of bulk materials into compact solids at temperatures below their melting point [1–4]. The main phenomenon is solid state diffusion, which occurs along the different interfaces of the crystals and through any vacancies. Changes in the microstructure during sintering have been previously demonstrated (see Fig. 1). Based on previous experience, the sintered material has to be homogeneous and characteristics such as porosity need to be controlled.

Sintering is a complex process influenced by many factors including temperature, sintering time, pressure and atmospheric composition, all

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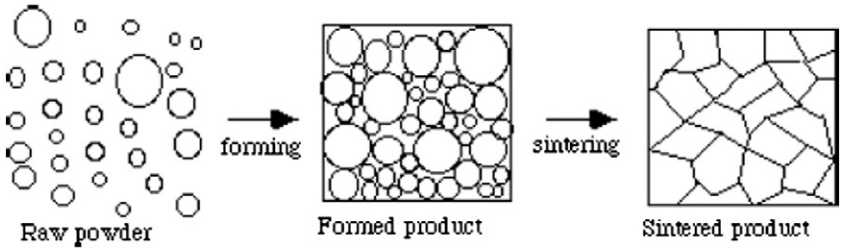

Fig. 1. Microstructure of raw, formed, and sintered metallic products.

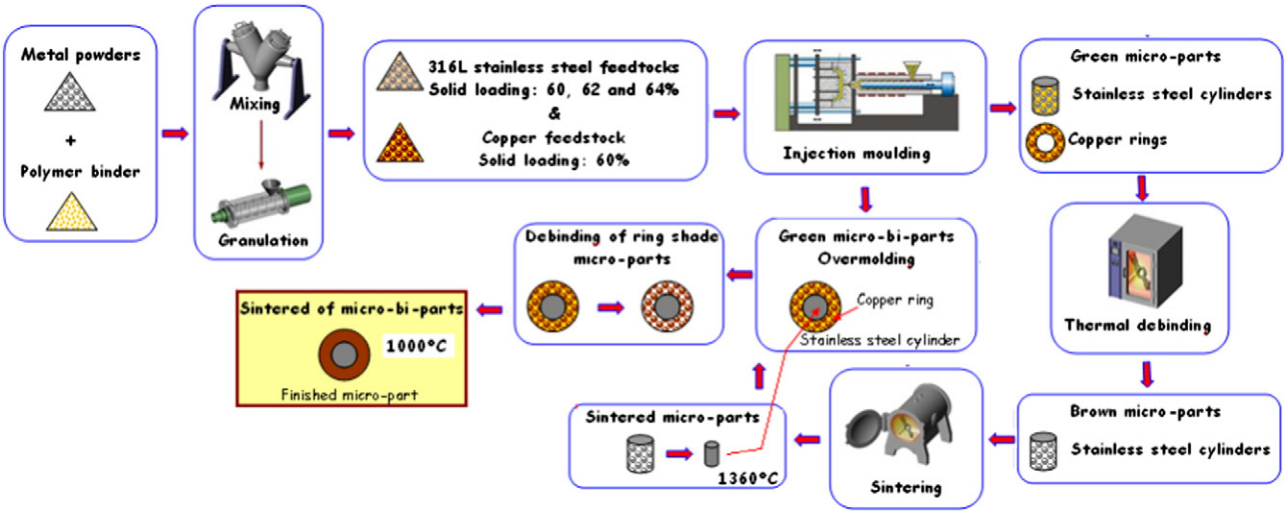

Fig. 2. Schematic diagram of the metal injection moulding (MIM).

of which determine the final properties of the sintered product [5–8]. Modelling can be used to optimise and better understand the sintering process to improve the quality of the sintered components. Modelling of the sintering process is one of the most challenging problems in the field of material modelling. There are different approaches to modelling sintering processes, ranging from continuum phenomenological models to micromechanical and atomistic ones. Different sintering models have been reviewed in Refs. [9–12].

The first analyses of sintering were based on the famous two sphere models that provided a simplified description of inter-particle neck growth and densification through miscellaneous diffusion mechanisms [13–15]. Schoenberg at al. [16] compared analytical calculations and finite element analysis simulations (FEA) to describe the sintering of a barium titanate cylindrical component composed of a high-density and low-density layer. Song et al. [17] investigated simulating the sintering process of 316L stainless steel powder components with a thermo-elasto-viscoplastic model. In this paper, we focus on numerical simulations associated with the sintering stages for micro-bi-material components in an assembly or separately at different powder volume loadings. Frenkel [18] and Kuczynski [19] studied mechanisms for neck growth and shrinkage during early sintering stages (particle bonding) using a two-sphere model. Coble [20] developed a cylindrical pore model. A spherical pore model for the later sintering stages was developed by McKenzie and Shuttleworth [21]. Barriere et al. [22,23] investigated the optimal process parameters by proposing adapted finite element modelling and simulation software for the metal injection moulding stage (MIM) based on a bi-phasic model. More sophisticated models that address the superposition of various sintering mechanisms have been developed by Ashby [24], Arzt [25], and Exner and Arzt [26].

Clearly, modelling can help optimise the process parameters to better obtain near-net shape and crack-free components. The purpose of this paper is to simulate the sintering of bi-material components using a finite element method. First, we introduce constitutive equations that describe the behaviour of both materials during sintering. These equations, which include both thermo-elastic and viscous terms, have been adjusted with data extracted from specific sintering experiments by the inverse method. Then, we plotted the results from the numerical simulation in terms of dimensional changes and relative densities. Fig. 2 shows a schematic of the bi-metal injection moulding process.

2. Experimental procedures

2.1. Powders

Fine spherically shaped 316L stainless steel powder ($D_{50} = 3.4$ μm) and irregularly shaped copper powder ($D_{50} = 6.3$ μm) were provided by Sandvik Osprey Company®. This shape is generally more appropriate for obtaining a feedstock that behaves with a low viscosity. The powders had densities equal to 7.9 g cm^{-3} and 8.9 g cm^{-3}, respectively.

Table 1
Characteristics of the WC–Co powders.

Powder	Particle shape	d_{10}	d_{50}	d_{90}	Density	Tap density
Fine 316L stainless steel	Spherical	1.80 μm	3.40 μm	6.02 μm	7.90 g/cm^3	4.60 g/cm^3
Copper	Irregular	3.73 μm	6.34 μm	10.81 μm	9.82 g/cm^3	4.63 g/cm^3