Powder Injection Molding Feedstocks: Relevant Properties for Flow Simulations

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Abstract: Powder injection molding (PIM) is an effective (high added value) and attractive alternative to the traditional metallurgical processes for the production of complex-shaped, small metallic and ceramic parts. The critical step of the process is the flow of highly filled polymer melts into a mold cavity during injection molding. For plastic materials there exist commercially available software programs, which successfully predict the flow situations. For PIM feedstocks simulation analyses crucial to optimize process are still missing. Thus, the tools derived for polymer melts are also applied to predict the flow of PIM feedstocks. The paper shows that the most important factors are a suitable rheological model developed to describe the flow behaviour of these specific feedstocks in the broad shear rate range, and relevant physical properties evaluated with the special regard to the specifics of PIM materials.

Key-Words: flow simulation, PIM technology, injection moulding, rheology, pressure-volume-temperature diagrams

1 Introduction

Powder Injection Molding (PIM) represents a processing route for metallic and ceramic powders that eliminates design restrictions inherent to conventional techniques. During the process the powder must be at first compounded with a suitable polymer binder to obtain highly (typically around 60 vol. %) filled compound, which is then processed on injection molding machines utilized in plastics industry. In the next step, the polymer part is chemically or thermally withdrawn from the molded part prior to its sintering to the final dimensions and density.

2 Problem Formulation

The aim is to produce non-defect parts via careful control of the relevant properties of the feedstocks. The problems created during flow into a mold appear during/after debinding and/or sintering, and therefore, their solution consists in successful simulation of this step of the PIM process. The simulation approaches currently available are built on rheological models describing pseudoplastic flow of polymer melts using mainly Cross model. Especially designed software for PIM compounds called PIMSolver uses the same type of the model.

3 Problem Solution

3.1 Experimental

As a model experimental material aluminium oxide (alumina) powder compounded with a commercial multi-component binder was used to prepare 60 vol.%. feedstock in a form of pellets. Pressure-volume-temperature (PVT) data were obtained with a PVT-100 (SWO, Germany) apparatus and a fully automated high-pressure mercury dilatometer Gnomix (GNOMIX, Inc., USA). Rheological properties of the alumina feedstock were measured using a capillary rheometer Rheograph 2001 (Göttfert, Germany) at shear rates from 10^1 to 10^4 1/s at temperatures 150, 160 and 170 °C. The length-to-diameter (*L/D*) ratio of capillary was 30.

3.2 Results & Discussion

The key information necessary to simulate the process are rheological data as well as compressibility of the powder and polymer-based binder in a pressurized melt-stage, because PIM is a high-pressure molding process.

The rheological data of the considered material can be well described with the model proposed by Hausnerova et al. [1]:

$$\eta = \frac{\eta_1 \exp(-f_1)}{b_1 + \exp(f_1) + \exp(-f_1)} + \frac{\eta_2 \exp(f_2)}{b_2 + \exp(f_2) + \exp(-f_2)}$$

$$f_1 \equiv f(\dot{\gamma}; c_1, p_1) = \log(c_1 \tau)^{p_1} \quad ; \quad f_2 \equiv f(\dot{\gamma}; c_2, p_2) = \log(c_2 \tau)^{p_2}$$

The pressure-volume-temperature (pvT) characteristic provides information about the specific volume of feedstock at the molding temperature and the pressure necessary for the production of defect-free molded parts. The pvT studies on PIM materials are reported scarcely.

It should be stressed that pvT data depend on the technique selected as can be seen from the comparison of the pvT characteristic obtained from unidirectional pressure apparatus (PVT-100, SWO, Germany) or from the technique, where the sample is under hydrostatic pressure at all times due to operation of a confining fluid (Gnomix, GNOMIX, Inc., USA).

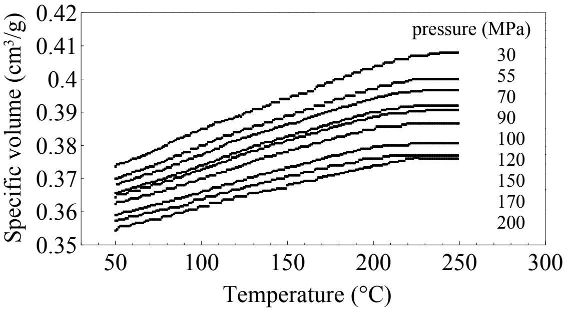

Fig. 1 – Pressure-volume-temperature characteristics of ceramic feedstock under an isobaric mode using PVT-100 (SWO, Germany).

If the relevant data are available, even software primarily used to predict processing conditions in thermoplastic processing can be successfully employed for PIM. With respect to absence of a powder injection molding module its role in analyzes is only to predict the critical places without any quantitative evaluation as powder /binder separation.

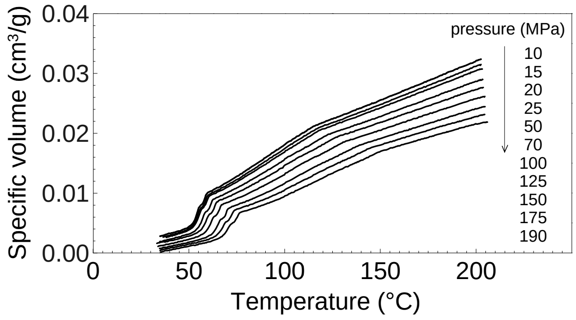

Fig. 2 – Pressure-volume-temperature characteristics of ceramic feedstock under an isobaric mode using Gnomix (GNOMIX, Inc., USA).

In Figure 3 an example of the result from Moldflow analysis is shown. At the inner corner higher shear rate is evaluated according to higher velocity of a bulk material (scaling bar has only informative character). This change in shear rate gradient can be an initiator of powder/binder separation, and thus it is categorized as a critical place with exceed of binder content.

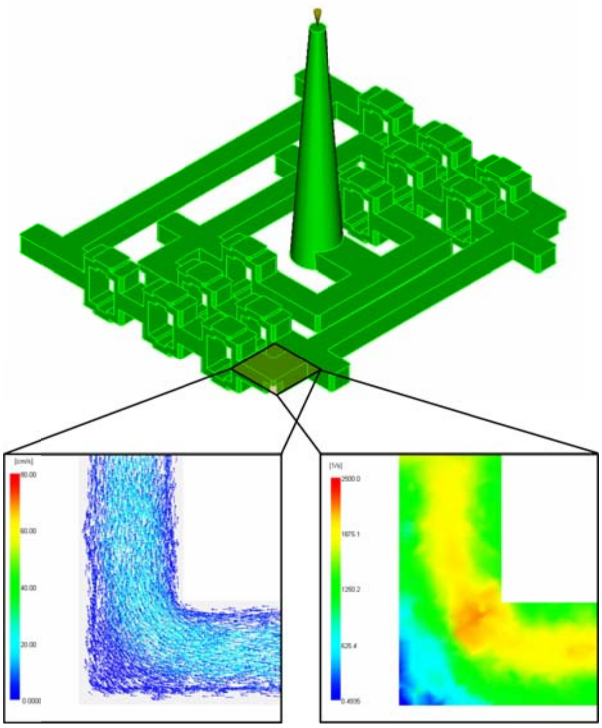

Fig. 3 - Prediction of critical locations according to velocity (left) and shear rate gradient profiles (right).

To summarize, if PIM module in a simulation program is not available, the tool established for polymer melts can be used in the case that the relevant processing properties of a PIM material are carefully evaluated and employed.

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