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Validation of precision powder injection molding process simulations using a spiral test geometry

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Abstract. Like in many other areas of engineering, process simulations find application in precision injection molding to assist and optimize the quality and design of precise products and the molding process. Injection molding comprises mainly the manufacturing of plastic components. However, the variant of precision powder injection molding for the production of metallic and ceramic micro parts raises more and more interest though. Consequently, in the entire field the demand for simulation tools increases constantly, too. The present work reports the material characterization of feedstocks which are used for powder injection molding. This characterization includes measurements of rheological, thermal, and pvT behavior of the powder-binder-mixes. The acquired material data was used to generate new material models for the database of the commercially available Autodesk Moldflow® simulation software. The necessary data and the implementation procedure of the new material models are outlined. In order to validate the simulation studies and evaluate their accuracy, the simulation results are compared with experiments performed using a spiral test geometry.

Keywords: powder injection molding, process simulations, powder feedstocks.

INTRODUCTION

Like plastic injection molding, powder injection molding of ceramic or metallic feedstocks is one of the most efficient and widely used process technology for the large-scale production of complex precision parts. Together with the number of applications and the interest in the technology, the demand for reliable simulation tools increases [1,2]. In (powder) injection molding, simulations are a very useful tool to accompany and support the design process of the actual part as well as of the mold and the process. In that way, costly re-engineering and prototyping can be avoided and the design can already be optimized before the manufacturing starts [1,3].

Different simulations tools in order to simulate and model the injection molding process are commercially available today. Nevertheless, the target group of such software packages is mainly the plastic industry. As a result, the number of plastics being available in the data bases of the software tools is very large and growing, whereas there is hardly any material data available for powder feedstocks, neither for ceramic, nor for metallic ones [3]. In order to conduct simulations of the powder feedstock, it is consequently necessary to characterize the feedstocks of interest and constitute the according material data.

Prior to the actual simulation efforts, this work will focus therefore also on the material characterization and the procedure of how to create the necessary material model for the simulation software.

PROCEDURE FOR MATERIAL MODELING

The simulations of the injection molding process can be used in order to investigate the behavior of the polymer during the filling and packing phase, e.g. to predict the flow front of the polymer, the shear rate, and the temperature of the melt, but also to evaluate the quality of the resulting part, e.g. the warpage and flatness of the molded part.

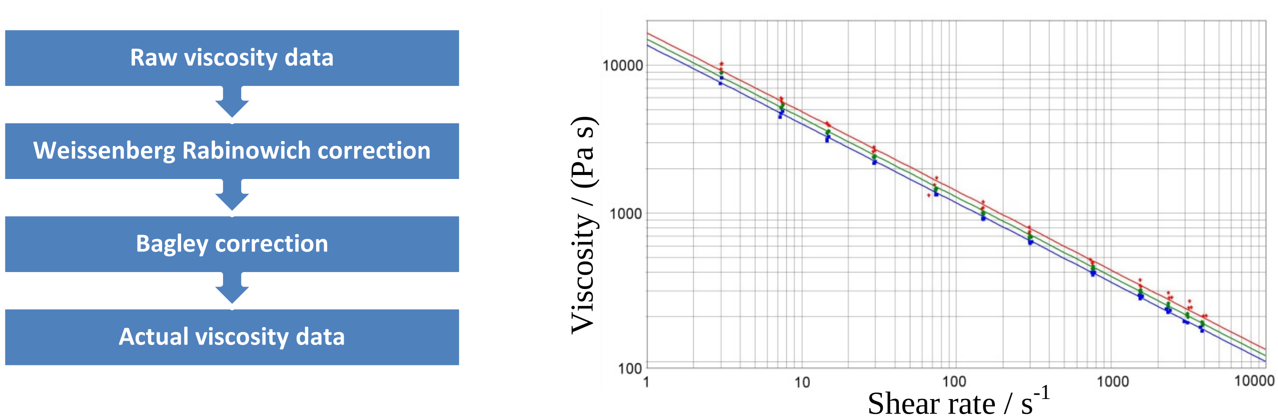
Hence, the material data has to comprise processing, rheology, and mechanical data. This work focusses however on the measurement of viscosity and the pvT curves – the major rheological data. The measurement equipment for both material properties was a high-pressure capillary rheometer. The investigated material was a metallic feedstock for the production of parts in stainless steel of grade 17-4PH.

The pvT measurement was carried out with a temperature sweep at several pressure levels in order to evaluate the volumetric change. The recorded pvT data points could be directly used. They were fitted to the 2-domain Tait pvT model which is working in the background of Autodesk Moldflow describing the pvT behavior of the material.

Similarly to the pvT investigation, the viscosity measurements were carried out at three different temperature levels and with three different capillary geometries. The gathered raw data of the viscosity, also called apparent viscosity, had to undergo a correction process in order to be used in the simulation.

The course of action for the correction of the viscosity data is summarized in FIGURE 1 (a). First, the Weissenberg Rabinowich correction was applied. It is used to compute the actual velocity and thus shear rate distribution inside the non-Newtonian fluid. [4,5]

Afterwards, the Bagley correction was applied. This correction method compensates for the different capillary geometries, i.e. the resulting entrance pressure and outlet extension [4,5]. As a result, the true viscosity data is yielded. The data points were subsequently fitted to the Cross-WLF model which is the standard model for the viscosity in Autodesk Moldflow®. The finally obtained viscosity curve for the metallic feedstock is illustrated in FIGURE 1 (b).



(a) (b)

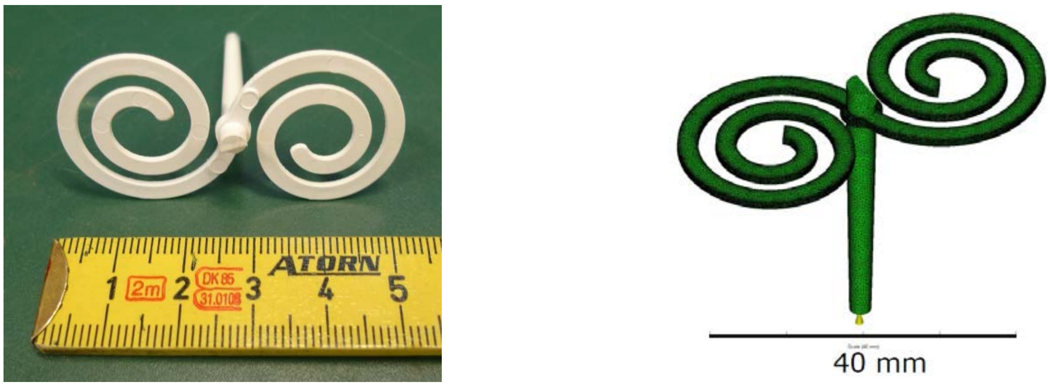
FIGURE 1. (a) Flow diagram of viscosity correction process; (b) viscosity curves for the metallic feedstock resulting from the measurements with subsequent corrections.

MOLDING OF TEST SPIRAL

The investigated geometry is a test spiral part, as shown in FIGURE 1 (a). The part was molded in metallic feedstock by means of a conventional injection molding machine of type Arburg Allrounder 420 C which has a screw size of 15 mm and provides 600 kN of maximum clamping force. The melt temperature was chosen to be in the range of 170-200 °C (at the first heating zone after the hopper and the nozzle, respectively). The mold temperature for powder feedstocks is usually very high compared to plastics and was chosen as about 130 °C.

SIMULATIONS OF TEST SPIRAL

The used software for the process simulations of the powder injection molding process is Autodesk Moldflow® 2015. For this investigation, the part including the sprue was modeled in 3D with approximately one million tetrahedral elements, as shown in FIGURE 1 (b). The carried out fill and pack analyses were based on the newly created material model of the metallic feedstock. The process settings for the simulation were chosen accordingly to the experiments in order to achieve the best comparability. In addition, the machine was modeled, too, taking the response time and the actual speed profile into consideration.



(a) (b)

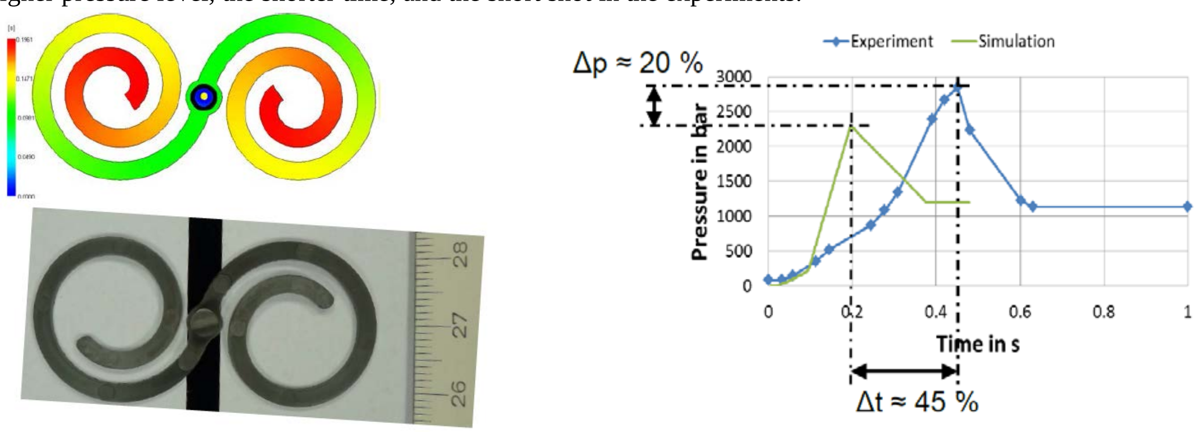
FIGURE 2. (a) Molded spiral test geometry; (b) meshed 3D simulation model of the investigated test spiral with sprue.

RESULTS

The filling behavior of the polymer was investigated and compared to the experiments. It was found that the simulation shows a complete filling of the cavity, whereas the experiments with the same process settings resulted in a short shot with incomplete filling. The comparison is illustrated in FIGURE 3 (a). It can clearly be seen that the flow length of the metallic feedstock is shorter in the experiment than in the simulation.

In addition, the injection pressure and time were investigated. The pressure development over time is depicted in FIGURE 3 (b). At the beginning of the injection, the curve of the simulation follows the experimental one until about 0.1 s, and also the overall shape of the curves is in quite good agreement. However, the simulation predicts lower values for the maximum injection pressure (approximately 20 % lower) and also for the injection time (time until cavity is filled, without subsequent packing phase; approximately 45 % lower).

A possible reason for this underestimation is the limited suitability of the simulation tools for powder injection molding, as for instance Autodesk Moldflow® is officially made for plastics only. In particular, the simulations were conducted with the default heat transfer coefficient which might not be suitable for powder feedstocks. A possibly higher heat transfer coefficient will also increase the viscosity of the molten material. This behavior would explain the higher pressure level, the shorter time, and the short shot in the experiments.



(a) (b)

FIGURE 3. (a) Comparison of the predicted flow length of the simulation (top) and the real flow length of the molding (bottom); (b) comparison between the predicted injection pressure over time for the simulation and the experiments.

CONCLUSIONS AND OUTLOOK

An extensive material characterization was carried out to lay the basis for a new material data base entry in Autodesk Moldflow®. The required material properties and the workflow for the creation of a comprehensive material data set were outlined in this work. Furthermore, it was in shown in detail how the viscosity data for the material data set was measured and corrected.

The newly established material data model was successfully applied in the process simulation of a spiral test geometry. The spiral was actually manufactured by the powder injection molding process of which the process parameters were used as input for the simulation analysis.

The process analysis showed no major problems with the new material model. The simulations yielded promising first results, but differences in the flow length and an underestimation of the maximum injection pressure and the injection time were found. This indicates the still existing deficiency of commercially available simulation tools to describe the material behavior of feedstocks correctly. However, it is believed that with adapted viscosity models and heat transfer coefficients as well as more advanced simulation models, the numerical results of the simulations can be noticeably improved with regard to the actual experimental values.

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