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Verification of the Simulation Results for Mold Filling Processes in Ceramic Injection Molding

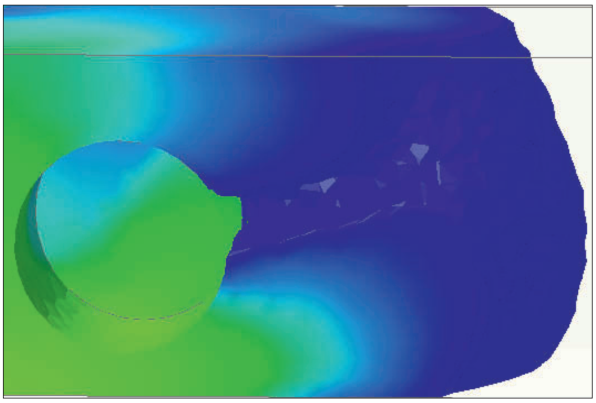

Fig. 1 Filling simulation (Moldex3D®) for a prismatic rod with a blind hole and a 40 % filling on the basis of the modified cross model

Fig. 2
Real mold filling experiment based on the injection parameters of the simulation (Fig. 1)

Introduction

In April 2008, the Expert Group on Ceramic Injection Molding was established within the German Ceramic Society. The expert group is a network which consists of fifteen companies and two research institutions and applies ceramic injection molding as innovative shaping method to produce ceramic components in large quantities. It is one objective of the network to jointly solve technological problems in order to increase the importance of CIM and to spread this shaping method. One of these questions deals with commercially available simulation tools. It is studied to what extent they can be used to exactly reflect critical aspects of mold filling processes such as jetting, formation of weld lines or the influence of different material and process param-eters on the filling behavior. For this reason, the members of the Expert Group on Ceramic Injection Molding designed and built a test tool with numerous inserts by means of which different kinds of mold filling aspects can be studied and compared with the simulation results. In a round robin test the filling behavior of two feedstocks is simulated with different simulation tools and compared with the real filling behavior experimentally studied. For this comparison, light-microscopic im-ages of the filling fronts and x-ray computed tomography images of the green bodies as well as data of internal pressure sensors are used.

Experimental

The test tool designed by *Arburg GmbH + Co KG* allows one to injection-mold a prismatic rod of the dimensions 7 mm × 7 mm × 70 mm either as full rod or with through or blind holes. In addition, one surface can be equipped with a zigzag insert. The sprue system can be realized as film or as semicircular gate. The tool can be operated under vacuum. Furthermore, it has two temperature control systems. One channel provides an optimal temperature control of the two cavities, the other one results in a bad temperature distribution. An infrared camera was used to study the heating behavior of the tool in dependence of the selected temperature control system.

The alumina feedstocks Catamold® AO-F (BASF SE) and INMAFEED K1008 (*Inmatec Technologies GmbH)* were used for the filling simulations and experiments. For both materials the simulation input data such as pVT diagrams, thermal conductivity, specific heat, Young's modulus, shear viscosity, extensional viscosity and density were determined. For the simulations, three commercially available simulation tools were used: Moldex3D *(Simpatec GmbH)*, Moldflow *(Autodesk)* and Sigmasoft *(Sigma GmbH)*. In order to verify the simulation data the mold filling process as well as the pressure distribution were used whereas the thermal behavior and thermal stress in the injection-molded components were not considered in detail. In the mold filling experiments the tool temperature, injection speed and sprue geometry were varied. Furthermore, the influence of a vacuum was investigated. The temperature setting of nozzle and the injection unit were selected according to the specifications of the feedstock manufacturers, and maintained at a consistent level during the experiments. The injection-molded components were debinded and sintered according to the manufacturer's specifications.

The components were characterized by light-microscopic images and density determinations. In addition, both alumina feedstocks were mixed with maximum five weight percent zirconia feedstock, based on the same binder systems, in the plastication unit in order to obtain a bad mixing of both materials. This mass was used to injection-mold test specimens which were characterized in the green state by x-ray computed tomography *(CT Compact, Procon X-Ray and Fraunhofer-Entwicklungszentrum Röntgentechnik)*. On account of the material contrast caused by the alumina and zirconia materials, flow lines, wake spaces and weld lines can be well understood and compared with the simulation results.

Discussion and Evaluation

The filling experiments showed that the test tool puts a lot of requirements on the simulation tool despite its relatively simple geometry. The results obtained with the Moldex3D simulation tool make clear that the selection of the model on which the simulation is based and which can freely be chosen by the user, has a decisive influence whether the simulation results are in agreement with the real mold filling behavior. It was

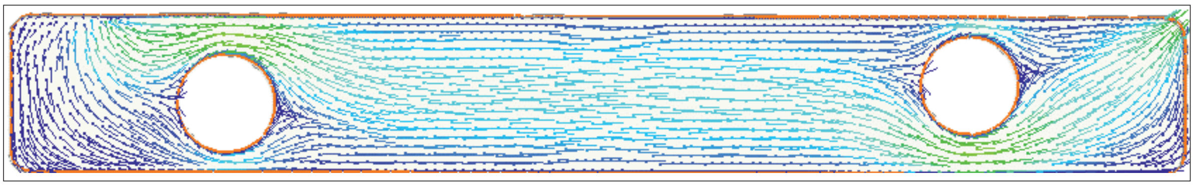

Fig. 3 Simulated speed vectors in a prismatic rod with through holes

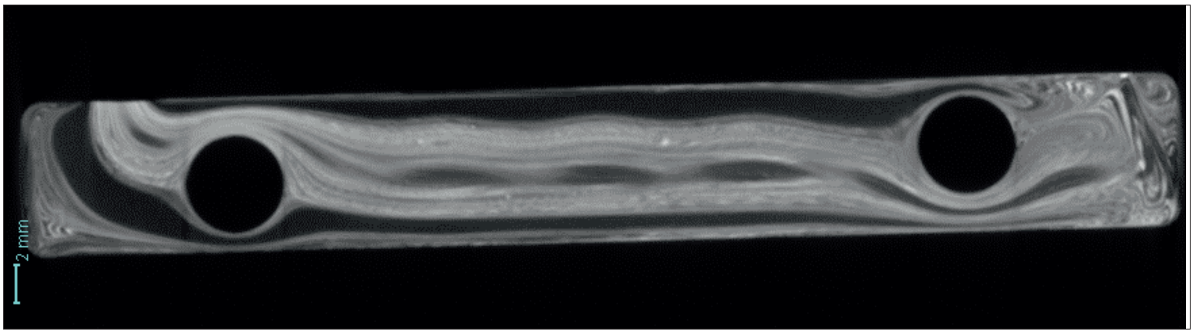

Fig. 4 CT images of a prismatic rod with through holes, injection-molded with a marking feedstock consisting of a mixture of powders with different attenuation coefficients for x-ray emissions

shown that particularly the start of the injection process, when the feedstock flows into the cavity and hits the opposite tool wall, a free jet resulting in weld lines, which are maintained during the whole injection process, is one of the main problems of the simulation. Furthermore, it was proved in experiments and by simulations that the filling process is influenced by the sprue geometry. Additionally, the experiments showed how an applied vacuum affects the filling speed. Particularly valuable results were obtained by characterizing the components made from the marking feedstock by means of x-ray computed tomography. These reconstruction images were compared with the simulated speed vectors and the light-microscopic images of the feedstock front. In this way many correspondences can be recognized between the real component and the simulation.

Summary

The studies showed that there is a significant demand for the further development of existing simulation tools with the aim of better understanding the mold filling process. It was proved that the selection of the model on which the simulation is based has a decisive influence on the precision of the simulation. In the further development of the simu-lation tool it is important to consider the feedstock as multi-component system consisting of a binder system and a powder. Additionally, it must be emphasized that a simulation tool can only be as good as the simu-lation input data determined before. By continuously improving the simu-lation results the requirements on the determination of rheological, mechanical and thermal parameters of the feedstock under consideration of the shape, the specific surface and the particle size distribution of the powder will increase.

Acknowledgment

The members of the Expert Group on Ceramic Injection Molding within the *German Ceramic Society*, especially *Hartmut Walcher (Arburg), Dr. Moritz von Witzleben (INMATEC)* and *Johan ter Maat (BASF SE)*, are gratefully acknowledged for supporting the work.

The test tool and other results from practice are presented at this year's **Hannover Messe** in Ceramics Meeting Point. Visit the Expert Group on Ceramic Injection Molding in **hall 5, booth E40**.