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Comparative analysis of different process simulation settings of a micro injection molded part featuring conformal cooling

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Abstract
Process simulations are applied in all fields of engineering in order to support and optimize the design and quality of products and their manufacturing processes. Micro injection molding is not an exception in this regard. Simulations enable to investigate the process and the part quality. In the reported work, process simulations using Autodesk Moldflow Insight 2015® are applied to a micro mechanical part to be fabricated by micro injection molding and with over-all dimensions of 12.0 × 3.0 × 0.8 mm³ and micro features (micro hole, diameter of 580 µm, and sharp radii down to 100 µm). Three different simulation models are established: a version including the part without the surrounding mold block, an advanced version including the mold block and conventional cooling channels, and a third version alike the second with additional conformal cooling for efficient thermal management. The implementation strategy for these configurations is presented focusing on the application of a multi-scale mesh with mesh sizes of 100-800 µm, 50 µm, and 100 µm for feeding system, gate area, and the micro component, respectively. The three models are compared with each other to demonstrate the influence of the implementation of the actual mold block, conventional cooling, and conformal cooling. In the comparison, characteristic quality criteria for injection molding are studied, such as the filling behavior of the cavity, the injection pressure, the temperature distribution, and the resulting part warpage. Additionally, the analysis of the cooling channels exploiting computational fluid dynamics is introduced as helpful tool for the mold design process. It is observed that the comprehensive implementation of the actual injection molding system and conditions is highly relevant at sub-mm/micro dimensional scales, and that the level of detail of the model influences the simulation outcome. Warpage of the micro component in the range of 85-105 µm could be simulated depending on the simulation configuration.

Keywords: micro injection molding, process simulation, meshing, conformal cooling

1. Introduction

With micro injection molding (µIM) being one of the major technologies for the low cost, feasibly fully automated, and high-volume production of micro plastic components, plastic engineers and designers in this area demand reliable simulation tools also for micro-scaled parts . Alike in many engineering fields, simulations in micro injection molding target optimizing the part, mold, and process design, avoiding costly re-engineering, and shortening the development time [1–3].

Commercially available simulation tools from conventional injection molding can be adapted, but their capabilities of analyzing micro parts and the implementation of relevant phenomena are limited leading to missing accuracy of the simulation output [2]. This work shows the significant influence of the implementation strategy and of the considered elements of the model, when it comes to micro injection molding. Three differently complex simulation models based on the geometry of a micro mechanical part are established, and the simulation results are compared. Besides, the investigation also addresses the topic of conformal cooling in one of these models.

2. Methodology

By means of Autodesk Simulation Moldflow Insight (ASMI) 2015®, a micro mechanical part with outer dimensions of 12.0 × 3.0 × 0.8 mm³ (length × width × height) was investigated. The component is shown in Figure 1. It exhibits several micro features, e.g. a hole of 580 µm diameter, rounded edges with radii down to 100 µm, and tolerances in size in the order of 10 µm. The material for the simulation was Ultraform N2320C BK120 Q600, a polyoxymethylene (POM) grade made by BASF, Ludwigshafen, Germany. Three different models varying in the extent of the modeled injection molding entities were applied:

- part only (PO): part and feed system are meshed and considered for the simulation; the surrounding mold is by default assumed as infinite block of constant temperature; insert and cooling channels are not included; applied mesh size: 50-800 µm; resulting number of tetrahedrons: 800 000;
- simple cooling (SC): in addition to part and feed system, the mold is modeled as finite steel block which contains a simple network of straight cooling channels like they are produced by drilling; mesh size: 50 µm to 6 mm; number of tetrahedrons: 4 900 000;
- conformal cooling (CC): similar to the SC model, but the mold block also features small conformal cooling structures besides the straight channels; mesh size: 50 µm to 6 mm; number of tetrahedrons: 5 100 000.

Due to the large difference in size of the injection molding entities (e.g. part and mold), a multi-scale mesh (see Figure 2) was applied which is reflected in the broad range of the mesh size. Quality criteria for the evaluation of the models were the filling behavior of the polymer (time, pressure, flow pattern) and the warpage of the part.

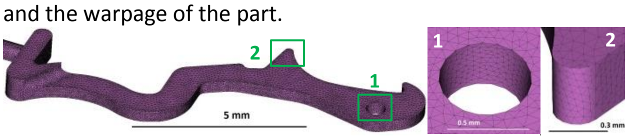

Figure 1. Meshed model of the investigated micro mechanical part with details (hole and radius).

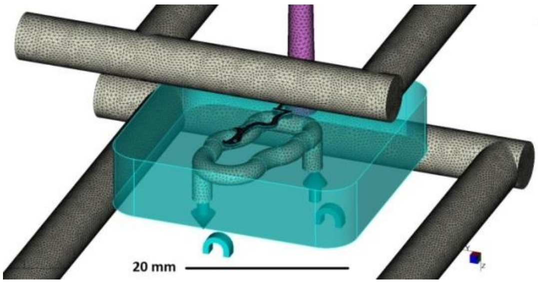

Figure 2. Simulation model with straight and conformal cooling channels, sprue, and part; all being of different mesh size. The mould insert is highlighted; the mould blocks are not shown.

3. Results and discussion

Table 1 summarizes the major results of the three presented and investigated simulation models. The maximum injection pressure is about 47 MPa and almost equal for all models, whereas the SC model shows a greater injection time than the other two models. Due to some artefact, the simulation time had to be manually evaluated and was estimated as 0.35 s (about 17 % higher). The pattern of the polymer flow front is depicted in Figure 3. The simulation predicts a complete fill for every model. However, the position of the flow front becomes different when the flow reaches the last third of the part cavity. After passing at the hole, the flow in the SC model lags behind compared to the PO and CC model. This proves the longer injection time of the SC model. The warpage and shear rate predictions of the simulation differ noticeably between the models (warpage see Figure 4). Compared to the PO model, the SC model shows for both criteria lower values, namely about 13 % less warpage and about 8 % smaller shear rate. The lower shear rate goes along with slower flow which proves also the longer injection time. All differences can be attributed to the different extent of the simulation models.

The analysis of the conformal cooling channel of the CC model is depicted in Figure 5. The flow velocity inside the channel is rather homogenous, meaning that constant cooling performance along the channel can be achieved and the two branches of the channel are well balanced.

Table 1. Numerical results for the filling of the three simulation models.

Model	PO	SC	CC
Injection time	0.295 s	0.350 s	0.299 s
Max. injection pressure	46.6 MPa	46.8 MPa	46.7 MPa
Max. warpage	100 µm	87 µm	105 µm
Max. shear rate	61 000 s^{-1}	56 000 s^{-1}	62 000 s^{-1}

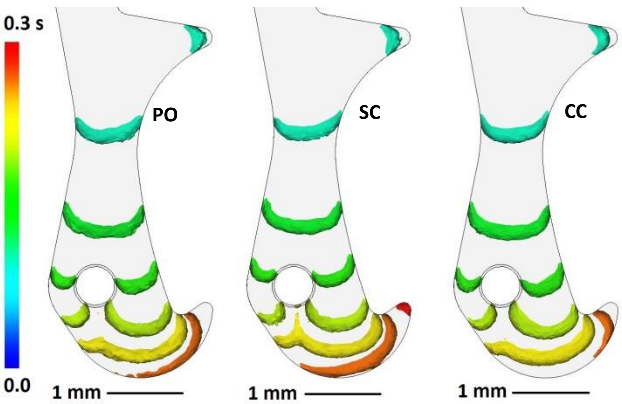

Figure 3. Position of flow front in the end of the part for the three simulation models. The time step between each front is 31 ms.

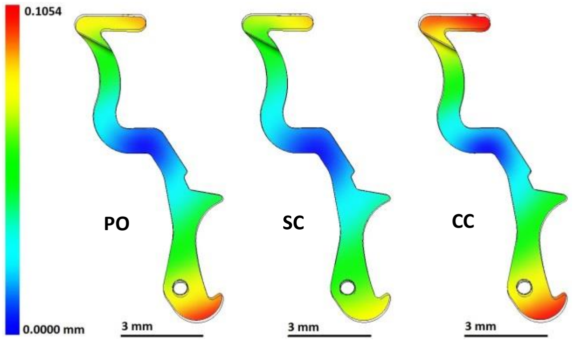

Figure 4. Warpage prediction of the three simulation models. The implementation of cooling in SC and CC influence the part's warpage.

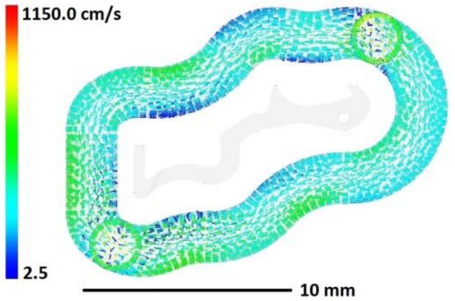

Figure 5. Velocity of the coolant in the conformal cooling channel. The homogenous shading of the channel proves even and balanced flow.

4. Conclusion and outlook

Process simulations were successfully applied to a polymer micro mechanical component. Three models of different complexity were built up, and the analysis of the molding process was conducted. Complete filling was achieved for all models, but differences in the flow pattern could be identified. The models showed approximately the same injection pressure. Depending on the model, the injection times differed however by 17 %, the maximum injection pressure by about 18 %. The comparison of the warpage and shear rate prediction yielded differences of about 13 % and 8 %, respectively.

The simulations thus showed that the extent and complexity of the model influences significantly the simulation results. It also proves the limitations and necessity of careful and critical application of the simulation tools when it comes to micro components and micro injection molding.

The simulation is also a powerful tool for the correct design of the mold's cooling network. It enables the evaluation of the influence of the layout and the behavior of the coolant.

In the future, the next possible step will be the verification of the simulation results. Experimental molding studies and measurement on the presented plastic part will be used to evaluate the simulation's accuracy.

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