A NEW MOLD DESIGN FOR QUALIFICATION OF POWDER/BINDER SEPARATION IN PIM TECHNOLOGY

Jakub Huša1,2, Berenika HausnerováL2(∗)

1Faculty of Technology, Dept. of Production Engineering, Tomas Bata University in Zlín, TGM 5555, 760 01 Zlín, Czech Republic
2University Institute, Centre of Polymer Systems, Tomas Bata University in Zlín, Nad Ovčiřnou 3685, 760 01 Zlín, Czech Republic

∗Email: hausnerova@ft.utb.cz

ABSTRACT

In powder injection molding (PIM) polymeric binder and metal/ceramic powder are mixed together to create homogenous feedstock. During injection molding stage shear rate gradients in a bulk material are created due to the rotation of powder particles close to the channel walls at the exposed locations. As a result, in these regions a phase separation may occur. Powder/binder separation of multi-component systems is the main quality issue of the PIM parts, and thus an effort has been put to study it with various molding approaches. This paper compares currently employed geometries of mold cavities for determination of phase separation, and proposes a new design of mold, which intercepts majority of possible critical locations.

Keywords: powder injection molding, phase separation, mould, design.

INTRODUCTION

Powder injection molding (PIM) is a technological process which allows producing metal or ceramic parts by using a conventional plastic injection molding equipment to shape final products. In comparison to injection molding of plastic composites, in PIM technology a polymer binder is removed after injection molding, and remaining porous powder structure is sintered to obtain a final product. Typical PIM processing cycle contains four basic steps: mixing of feedstock, injection molding, debinding and sintering.

According to Walcher and Maetzing (2013) about 70 % of all problems during PIM cycle originate in injection molding stage. In this respect, the separation of powder and polymer binder components is currently the most serious issue. Phase separation is affecting mechanical and physical properties of sintered product as strength reduction and variation in wall thickness due to lack of a powder content. In addition, it is also a noticeable and unacceptable visual defect as can be seen on Fig. 1.

Fig. 1 - Visual aspect of phase separation (Shivashankar et al., 2013)
Up today, three mold designs for assessment of powder/binder separation have been used (Fig. 2). In zig-zag trajectory (German, 1997) an assumption of phase separation is based on different momentum of a system. This theory is based on a claim that both components in the feedstock have the same velocity but different weight (powder is up to 10 times heavier than binder). Thus, for a powder particle, due to higher momentum, it will be more difficult to change the flow direction than for the polymeric binder, and therefore powder starts to separate in dead branches of the mold cavity.

Second mold design is a square spiral die (Jenni et al., 2008) with rectangular cross-section profile. Jenni et al. (2008) found out exceed of powder content in outer corners of a spiral in comparison to the bulk feedstock. In this case was separation measured with differential scanning calorimetry (DSC) and computed tomography (CT) methods.

Third design of a mold cavity has been created in cooperation between TBU in Zlín and IFAM Bremen (Community Design, 2011). This phase separation test specimen contains regions with different shear rates due to various cross-section profiles, outer corners and weld lines.

Molds for powder injection molded parts obviously contain not only one feature supporting phase separation, but a combination of these elements: dead branches, sudden cross-section profiles changes, outer corners, weld lines and places with peaks of shear rate. In order to this consideration it is necessary to ask the question, how the combination of critical features can affect overall phase segregation. In this paper a new mold design concept will be presented and one of the main reasons of phase separation will be outlined.

**METHODS**

To find a cause of phase separation in square spiral and testing mold designed at TBU & IFAM, the flow simulation has been realized. As a material the databased highly filled zirconia material (84.5 wt.%) has been chosen. Square spiral has been meshed by more than 200,000 tetrahedron elements with 1 mm edge length. Temperatures of melt and mold have been set on 165 °C and 40 °C, respectively. Filling stage has been controlled by flow rate of 20 cm³/s.

Simulation of injection molding stage of testing mold designed in cooperation with TBU and IFAM has been done. Simulation material has been chosen the same, highly filled PIM material as in previous case, also processing conditions; temperatures and flow rate are the same. 3D model has been discretized with 266 000 tetrahedron elements with 0.5 mm edge length.
RESULTS AND DISCUSSIONS

From simulation results shear stress is evaluated along the third corner with respect to Jenni et al. (2008). As can be seen on Fig. 3 distribution of shear rate may be a good prediction of phase separation. Brighter color represents region of higher shear rate what is in accordance with powder distribution measured by computer tomography (provided by Jenni et al., 2008) where light color indicates excess of binder. In contrast to darker color, which belongs to region of low shear rate, and consequently higher powder content detected by CT analysis.

![Distribution of shear rate](image1)

Fig. 3 - Distribution of shear rate flow analysis (left), powder distribution measured with CT by Jenni et al. (right)

Effect of shear rate on phase separation can be seen also on TBU/IFAM testing mold (Hausnerova, 2011). Phase segregation has been assessed near the gate to square-shape element, which is confirmed by simulations. Due to a sudden change in cross-section profile it can be considered that shear rate will be the highest near these gate locations. Demonstration of visual effect of phase separation caused by high shear rate is shown on Fig. 4.

![Reported phase separation](image2)

Fig. 4 - Reported phase separation on TBU and IFAM testing mold

Pursuant to findings from analysis a new mold design has been developed and is shown in Fig. 5 – left (Community design, 2014). Proposed new concept of testing mold contains all phase separation supporting features listed above. Designed concept is based on previous studies and geometry is made from three square-shape elements. Every shape contains one core at least, which ensures the creation of weld line after every core pin. In corners is phase segregation formed due to shear rate gradient and this high-potential separation zone is intensified with cross-section changes. These zones can be recognized in shear rate distribution result from a simulation (Fig. 5).
CONCLUSION

In this paper elementary reason of phase separation has been presented. According to these findings the new concept of the mold design for phase separation testing has been proposed. In future work it is necessary to focus on correlation between separation features in a mold and performance of the mold (e.g. stiffness of walls, positioning of ejectors, surface roughness).

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