Effects of the cavity surface finishing on the polymer filling flow in micro injection moulding

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Abstract. In micro-injection moulding, dimension and shape of the cavity microscale factors, normally negligible in conventional injection moulding, play an important role. More specifically, cavity roughness, which in large scale moulding is relevant only for surface finishing and appearance, at the micro-scale can not only significantly change the cavity volume but also influence the polymer flow and the heat transfer between polymer melt and mould. In the present work the effect of the mould cavity finishing on the micro-injection moulding process was investigated. The phenomenon was analyzed using different channels for melt flow separation and taking advantage of localization of weld lines for differential characterization. To this end different micro-cavities with different surface finishing were generated by means of micro electro discharge machining (µEDM). Cavities surfaces where characterized integrating metrological information from different instruments: scanning probe microscopy (surface roughness), optical profilometry (roughness and volumes) and scanning electron microscopy (weld lines localization).

1. Introduction

Increasing demand for disposable products with micro- and nano-features is pushing research in many fields: from biomedics, to electronics, from micro mechanics, to optics. However, the development of new micro- and nano-scaled devices is highly dependent on the specific manufacturing processes that can produce micro parts in large quantities, reliably and economically. Micro-injection moulding (µ-IM) is a key technology for mass production of polymer micro-components, allowing replication of both miniaturized components and large components with miniaturized features. Currently, micro-injection moulding allows realization of components with sub-micron resolution and relatively high aspect ratios; however µ-IM performance significantly influenced by process parameters and by polymer characteristics [1, 2]. In a traditional injection moulding process, under regular injection velocity and cavity geometry, the melt polymer flow is laminar with a no-slip hydrodynamic boundary condition. On the other hand instabilities occur when geometry exhibits rapid changes, such as in the case of presence of gates or thin sections, especially if combined with high speed injection. The so called wall slip is a well established phenomenon for non-Newtonian fluids which can be ascribed to a disentanglement of the bulk chains when attached to the mould walls [3]. The effect is more problematic in injection moulding of small cavities. Indeed, when downscaling an injection moulding process, the rate between mould cavity surface and cavity volume increases, meaning that physical phenomena taking place at the polymer-mould interface increase their relevance and their influence on the whole process. Using computer tools to simulate and optimize a process is a well consolidated
approach in traditional injection-moulding: but when sizes are downscaled, existing software packages are no longer sufficient to properly simulate the flow behaviour and cavity filling. Such inadequacy has to be ascribed to several limiting factors, but they all can be attributed to the fact that rheological properties of polymer used in current simulation packages are obtained from macroscopic scale measurements. Conversely, within micro scale geometries, surface tension and wall-slip conditions play a significant role, also depending on viscosity, heat transfer and temperature distribution, and roughness of cavity surface. More specifically, cavity roughness, which in large scale moulding is relevant only for surface finishing and appearance, at the micro-scale can not only significantly change the cavity volume but also influence the polymer flow and the heat transfer between polymer melt and mould. In the present work the effect of the mould cavity finishing on the micro-injection moulding process was investigated. The phenomenon was analyzed using different channels for melt flow separation and taking advantage of localization of weld lines for differential characterization.

2. Differential flow analysis
The method presented here for the first time is meant to analyze the specific effect of surface roughness on wall slip and on cavity filling. The method takes advantage of a double channel with a double link configuration, as reported in figure 1. The reference cavity can be divided in 4 main sections. In the first section (p1 in figure 1) the channels are machined with the same width, roughness and volume. As a consequence, when the polymer melt flows meet in the second section (p2) the weld line w1 should be centred symmetrically between the two channels whenever the filling process is not influenced by any asymmetry, due for instance to a bad machining of the cavity, a different distribution of temperatures, etc. If this is the case, the position of the weld line in the first cross-link will be not centred: the displacement can then be used to verify any presence of asymmetries within the cavity and in case to compensate it. Then w1 represent the “zero-position” for the following analysis carried out in the fourth section. The third section (p3) is machined identically to the first one except for the surface roughness, which is different between the two channels. Any flow difference, to be ascribed to different wall-slip effects between the two channels, will be then quantitatively monitored in the fourth section (p4) as a relative displacement on y direction of the second weld line w2 with respect to the first one w1.

![Figure 1. The newly design cavity filled with polymer with weld lines evidencing different wall slip behaviour.](image)

2.1. Cavity manufacturing
To investigate the possibility of using the weld lines as flow markers to characterize the wall slip phenomenon during micro injection moulding, a micro cavity was designed and manufactured by micro electrical discharge machining (µ-EDM, Sarix SX 200). Thin channels, with width ranging from 40 µm to 200 µm and depth ranging 50 µm to 100 µm were produced with a central intersection (see figure 1 and figure 2a). Additionally, different machining processes were implemented in order to
generate channels with a different surface finishing, with average surface roughness $S_a$ comprised between 0.5 and 8 µm. In figure 2b an example is reported, where a reduction of applied voltage by 23% an increase of applied current by 30% and a reduction of energy by 50% allowed a reduction of average surface roughness $S_a$ by almost 70%.

Figure 2. a) Micro machined channels, achieved by µ-EDM. b) Different surface finishing in terms of average surface roughness can be produced modulating µ-EDM crater average size, by modifying discharge parameters: large craters were achieved with a width of 5 µs, a frequency of 130 kHz, voltage 130 V, gap 65 V and relative energy 206; small craters with a width of 6 µs, a frequency of 100 kHz, voltage 100 V, gap 80 V and relative energy 105.

2.2. Cavity filling and polymer flow characterization
In order to evaluate the influence of surface finishing on wall slip, the cavity was filled at different injection speed using a micro injection moulding machine (Battenfeld MicroPower 15). In parallel, a numerical simulation of the filling phase was conducted and the slip velocity was identified by inverse analysis, fitting numerical and experimental weld line position results. For the present work in an optical profilometer was implemented, allowing for 3D reconstruction of surface topography. This was interesting for our study in order to monitor at the same time not only the weld line position, the depth of the weld-line itself (which is a parameter of the quality of the injection moulding operation) and also the height of the polymer part with respect to the cavity height (which indicate the filling degree of the cavity before curing of the polymer flow).

3. Conclusions
The present paper reports a new method for measuring the effect of surface finishing on wall slip in micro injection moulding. By comparing numerical and experimental results regarding the position of the weld lines, it was possible to model the wall slip phenomenon in dependence of cavity surface finishing and geometry, melt speed and temperature and material properties.

References
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