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Effect of thermal conductivity on the achievable flow length of micro injection moulded parts

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Abstract

Micro injection moulding is an established technology that combines the capability of accurately and precisely manufacturing micro components with the cost-effective production of complex and net-shaped plastic parts. A critical aspect of the process lies in the achievement of a complete filling of micro cavities. Numerous factors influence the filling of micro cavities, including the cooling of the polymer melt at the mould-material interface. The cooling at this interface also depends on the thermal conductivity of the mould material and on the injection moulding process parameters employed. This investigation focuses on injection moulding of a micro component with a spiral geometry, considering mould materials with different thermal conductivity. A design of experiments considering different process parameters (injection speed and mould temperature) is performed and off-line measurements are carried out using a digital microscope in order to evaluate the achievable flow length of micro moulded parts.

Keywords: micro injection moulding, flow length, mould materials.

1. Introduction

The need of complex-shaped and miniaturized polymeric components has significantly increased in many industrial fields such as automotive, biotechnology, etc. [1]. This demand led to the development of new manufacturing processes that enable the production of plastic micro components, e.g. micro injection moulding. A difficult aspect of the latter process lies in the achievement of a complete filling of the mould cavity, due to a rapid cooling of the melt material at the mould-melt interface. In correspondence of this interface there is a high thermal gradient between the relatively cold mould wall and the molten polymeric material that causes a consistent heat flux from the melt to the mould wall. In order to limit this phenomenon, mould materials with a relatively low thermal conductivity can be employed [2]. Materials as ceramics have a relatively high thermal resistivity compared to metals. The low thermal conductivity of ceramics lead to a slower solidification of the melt material, which is able to flow into the mould cavity for a longer distance before complete solidification [3, 4].

In this work, the extent to which the insert material influences the achievable flow length of a micro component having a spiral geometry is investigated, considering two insert materials with different thermal conductivity.

2. Part design

Micro injection moulding experiments were performed with moulds made of zirconium oxide and maraging steel 1.2709. The low thermal conductivity of zirconium oxide (2.5 W/[m·K]) compared to the steel material (14.3 W/[m·K]) is intended to prevent a premature solidification of the melt by exploiting its thermal resistivity. The replicated micro part has a spiral geometry with a structure height of 0.12 mm, a width of 1.8 mm and a maximum flow length of approx. 60 mm (cf. Fig. 1). The high surface to volume ratio (A/V) of about 18 makes this geometry suitable to analyse the effect of a reduced thermal conductivity of the mould material.

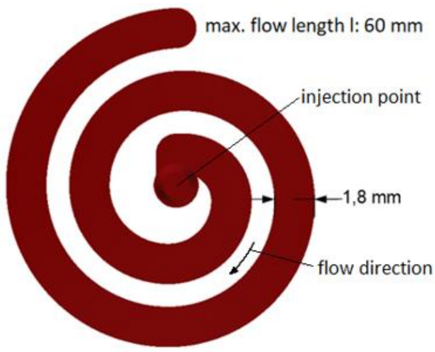

Figure 1. Designed spiral geometry for flow length analysis.

3. Experimental setup

Experiments have been carried out on a micro injection moulding machine (Desma FormicaPlast 2K), consisting of a two phase piston injection unit and a pneumatic injection drive. The polymeric material employed to perform the experiments is TPX DX820, a polymethylpentene (PMP). The cavity was machined into a changeable mould insert that integrates a central ejector pin. The tooling process was carried out on a five axes milling centre DMG Sauer Ultrasonic 20 Linear. For the analysis of the moulded parts, a Keyence digital microscope VHX-500 was employed.

A design of experiments approach was applied considering two levels for the mould temperature (20 °C and 80 °C) and four levels for the injection speed (70, 80, 90, 100 mm/s). The melt temperature was constant at 250 °C for all experiments. The parameters were chosen according to preliminary experiments. For statistical evaluation, three parts of each set of parameters were analysed and each of them was measured three times.

4. Measurement method

The determination of the flow length was carried out by measuring the solidified and demoulded part with the digital microscope. For this purpose, the flow spiral was divided into quadrants (cf. Fig. 2). The maximum flow length was calculated up to the end of each quarter circle. If the last quadrant was not filled completely, a filling ratio of the incomplete filled quadrant was calculated. As example, in Fig. 2 is illustrated a spiral part on which six quadrants were completely filled and the seventh quadrant was filled up to the angle α of the spiral centre contour. The missing fractional flow length (l) from the quadrant six up to the angle α of the centre contour was calculated by Eq. (1):

$$l = r \cdot \pi \cdot \alpha / 180° \quad (1)$$

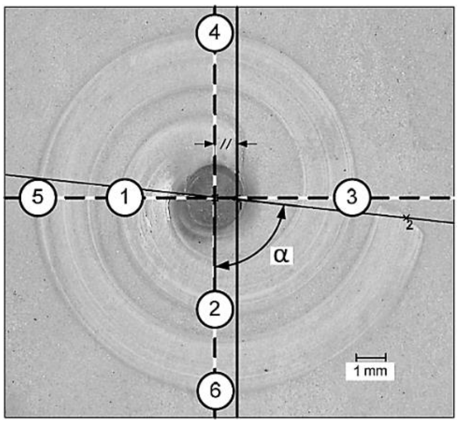

Figure 2. Flow length calculation on micro moulded part.

5. Results and discussion

The results show a significantly higher flow length for the ceramic mould compared to the steel mould (cf. Fig. 3). As in preliminary experiments, low differences in mould temperature did not show significant variation on the achievable flow length. Therefore, quite different mould temperatures (20 °C and 80 °C) were chosen. It can be observed that the mould temperature has a different impact on the kind of material, for different injection speeds. In the case of the ceramic mould, different mould temperatures for 90 and 100 mm/s injection speeds do not cause significant differences in the achievable flow length.

Usually, a higher injection speed leads to higher flow lengths. In the case of the ceramic mould with a mould temperature of 80 °C, there is a slight increase in the achievable flow length for injection speeds of 70, 80 and 90 mm/s. This may be due to the thermal resistivity of the ceramic material, which causes a delay in the melt cooling and consequently the speed with which the spiral channel is filled does not significantly influence the final flow length. The higher error difference for the same process parameters was recorded for the steel mould at 80 mm/s injection speed and 80 °C mould temperature while in the case of the ceramic mould at 90 mm/s injection speed and 80 °C mould temperature the three moulded parts have reached exactly the same flow length. Considering the different injection speeds, the achievable flow length for the ceramic mould at 20°C is on average about 2.5 times higher than the steel mould, while in the case of a mould temperature of 80 °C the achievable flow length is about 2 times higher. This difference can be justified by the fact that for higher mould temperatures, the temperature gradient between mould and melt temperature is lower and consequently the thermal resistivity of the ceramic material is less relevant for the heat flux at the mould-melt interface than for higher temperature gradients.

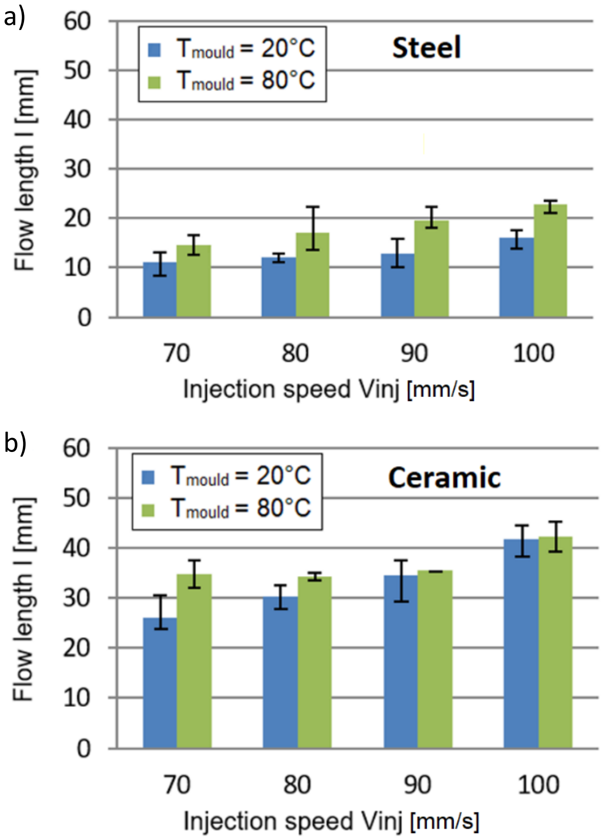

Figure 3. Achievable flow lengths for steel (a) and ceramic (b) mould materials.

6. Conclusion

The achievable flow length of micro moulded parts considering two mould materials (ceramic and steel) and different micro injection moulding process parameters was investigated.
The achieved flow lengths for the ceramic mould are about 2.5 times higher than the steel mould for a mould temperature of 20 °C and about 2 times higher for a mould temperature of 80 °C, considering different injection speeds. This proofs that the application of mould materials with low thermal conductivity are advantageous for the replication of micro parts with high surface to volume ratio.

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References

[1] Brousseau E B, Dimov S, Pham D T, 2010, Some Recent Advances in Multi-Material Micro- And Nano-Manufacturing, *Int. J. of Advanced Manufacturing Technology,* **47(1-4)** 161-180.

[2] Lucchetta G, Ferraris E, Tristo G, Reynaerts D, 2012, Influence of mould thermal properties on the replication of micro parts via injection moulding, *Procedia CIRP,* **2** 113-117.

[3] Meister S, Dietmar D, 2013, Investigation on the Achievable Flow Length in Injection Moulding of Polymeric Materials with Dynamic Mould Tempering, *The Scientific World Journal*, **3**, article ID 845916.

[4] Luca A, Menten A, Flosky C, Riemer O, 2017, Influence of variotherm injection moulding on the flow length of a micro part, *Proc. of the 2017 WCMNM*, 357-360.