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Evaluation of mold surface roughness and wettability in micro injection molding of thin cavities

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Abstract

Injection molding of micro components is more and more an emerging technology for its ability to manufacture low cost and high repeatable micro polymeric parts relevant to many different fields, from IT to healthcare, to medicine. In particular, micro injection molding of thin cavities is an interesting challenge due to the large surface to volume ratio that characterizes the process. This condition emphasizes the heat transfer at the polymer/mold interface, especially when the depth of the mold cavity becomes very thin. Furthermore, the boundary conditions, neglected in macro scale, affect the process and hence the mold surfaces show high influence during products filling and not only on their final quality. Thus, the mold roughness should be considered in evaluating the polymer flow behaviour in filling micro thin cavities. In this work, three inserts were designed to evaluate roughness contribution during molding and were manufactured by micro electrical discharge machining process obtaining three thin cavities (depth of 100µm and different roughness values). These inserts were used for molding polymeric micro plates and the flow lengths, reached inside these parts, were measured as process quality response. The results show that the cavity roughness affects the micro injection process favouring the filling of the thin cavities. In fact, the samples, molded with the insert having the highest roughness, show the longest flow length. Finally, wettability measurements were performed on the mold inserts and also these results sustain the occurred relation suggesting a decrease of the heat transfer in the process at the increase of mold surface roughness.

Micro-injection molding, thin cavity, roughness, wettability

1. Introduction

In micro molding process, the roughness of the mold could affect both the surface quality of the produced micro component, as in the macro process, but also the capability of filling the cavity completely. In this condition, the thickness of the parts is not negligible with respect to the other dimensions as in the conventional process. Current studies on this topic report considerations for roughness values in the range of 0.07-5 µm and a mold-cavity depth in the range of 250-500 µm as Griffiths et al. [1][2], Zhang et al. [3][4], Ong et al. [5][6]. The study of Nguyen et al. [7] highlights a complex roughness effect due to two opposite phenomena. The first phenomenon is the shear thinning and heating behaviour, which reduces the melt viscosity thus enhancing fluidity. The second phenomenon concerns the heat losses through the rough mold that are responsible for the melt temperature decrease and consequent viscosity increase. This second mechanism seems to be predominant with respect to the first.

In this context the rheological behaviour of the polymer melt within the part is considerably important. However, the current published studies are still not exhaustive, since more work is required, especially in the area of slip mechanisms for the tool-surface finishing. The purposes of the present work is to evaluate the roughness effect on melt flow in these critical conditions.

2. Materials and methods

2.1. Polymers, mold and inserts

Two semi-crystalline thermoplastic polymers, Polyoxy-methilene - POM (BASF Ultraform N2320 003, MVR 7.50 cm^3/10min and density 1400 kg/m^3), and a High-Density Polyethylene - HDPE (Polimeri Europa Eraclene MP 90 C, MVR 7.29 cm^3/10min and density 960 kg/m^3) have been chosen for this study. The mold main cavity (Figure 1a) was manufactured by the micro-milling process and it possesses the housing for the inserts on which the test plates were machined via micro-EDM milling (Figure 1b). The three inserts were realized with depth of 100 µm and three different surface finishing obtained by adopting distinct energy levels in the micro-EDM process. The inserts have been evaluated by topographic measurements carried out by microscope (Zeiss Axio CSM 700) and 3D optical profiler (Sensofar, Plu Neox). Table 1 reports the real depth and roughness of the inserts.

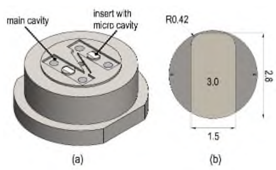

Figure 1. (a) Mold cavity and (b) dimensions (mm) of the mold insert

Table 1
Mold inserts depth and roughness characterization

Insert	Depth (μm)	Ra (μm)
1	100.6 ± 0.8	0.26 ± 0.04
2	103.5 ± 0.5	0.79 ± 0.08
3	103.6 ± 0.2	1.43 ± 0.20

2.2. Experimental and characterization

For the micro molding trials was utilized the DesmaTec FormicaPlast 1K machine fully described in reference [8]. The used process parameter settings are: melt temperature 230°C for POM and 260°C for HDPE, mold temperature 85°C, injection speed increasing directly in the injection phase 60-260 mm/s, holding pressure and holding time 0s, and cooling time 5s. During the experimental phase, after process stabilization, 30 samples were collected and 10 of them were randomly selected to measure the melt-flow lengths (defined in Figure 2 as distance of the filling front from the starting section). All trials were replicated 2 times. The Reduced peak height (R_{pk}) of molded samples have been evaluated for comparison with the Reduced valley depth (R_{vk}) of mold.

2.3. Wetting properties

The wettability of the two polymers for each mold insert was analyzed by monitoring the evolution of the contact angle over time, at a fixed temperature (corresponding to μIM experiments melt temperature). The used samples were obtained by cutting polymer pellets with average weight of $6x10^{-3}$ g. Three different substrates were machined by μEDM, using the same process conditions adopted for the realization of the mold inserts.

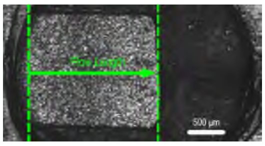

Figure 2. Flow length measurements of the molded parts

3. Results and discussion

The flow length measurements for the different experiments conditions evidence that for POM, at the increase of mold surface roughness, the parts have a longer flow length even if an asymmetric front shape is evident for all the parts. This trend is still evident, but less pronounced, for HDPE confirming the hypothesis that surface roughness markedly affects the polymer flow length. The results of the wettability analysis of the two materials, in relation with surface roughness, show that by varying the roughness from 0.26 to 1.43μm, there is an increase in contact angle by 17% for POM and by 24% for HDPE. Moreover, the average contact angle is smaller for HDPE than for POM and this is related mainly to the material properties.

The different behaviour of the injected material could be explained considering the interaction between the wettability properties and the polymer flow length (Figure 3). As suggested previously [9], materials with higher wettability properties, facilitate the replication of the mold surface. Thus, a higher replication of the roughed surface leads to a higher contact area at the interface, facilitating the heat transfer between polymer and mold. Vice versa, a worse replication of the mold surface, increase the amount of air trapped between the mold and the polymer, causing a significant reduction in heat transfer ability. Considering the results obtained for POM, by increasing the average value of Ra, the flow length increases with a linear trend, the same shown by the contact angle (Figure 3). Also for HDPE this trend is evident when passing from the lowest roughness value to the intermediate one, but it is less evident when varying Ra from insert 2 to 3. This result is confirmed also in Figure 4 that shows the trend for mold R_{vk} and for injected specimen R_{pk} of POM and HDPE vs the surface roughness of inserts. By increasing mold roughness the difference between the mold and parts increases, showing a worse replication of the mold cavity from polymers and suggesting the presence of high quantity of trapped air. This result is consistent with previous one.

Probably, other phenomena contribute to the results. In particular, when a polymer flows along a wall with relative higher surface roughness, the progress of the lower layer is not homogenous and could reduce friction strengths at the wall and hence promotes slips at the wall-polymer interface [2].

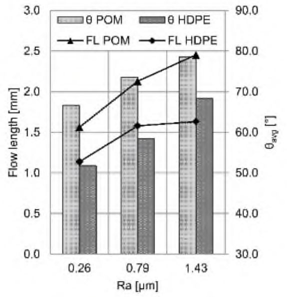

Figure 3. Comparison between the flow length (FL) and contact angle (θ) of the two different polymers in function of surface roughness (Ra)

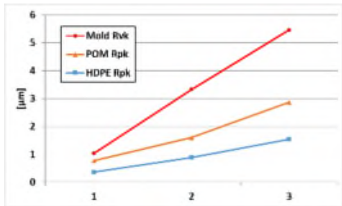

Figure 4. Mold R_{vk} and part R_{pk} (for POM and HDPE) vs insert roughness

4. Conclusions

The present experimental study aimed to investigate the influence of surface roughness on the filling of thin cavities by micro injection molding process and the correlation with polymer wettability. The results show that the cavity roughness affects the process favouring the filling of the thin cavities. In fact, the samples, molded with the insert having the highest roughness, show the longest flow length. The results of wettability measurements performed on the mold inserts also sustain the occurred relation suggesting a decrease of the heat transfer at the increase of mold surface roughness.

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