INJECTION MOULDING OF POLYMERS WITH MICRO AND NANO SCALE RIDGE AND CHANNEL FEATURES

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Summary Future development of MEMS, micro fluidics and lab-on-chip devices with micro/nano scale features will depend on mass production processes that combine high replication accuracy with low manufacturing costs. We have used bulk metallic glass mould inserts to replicate micro/nano scale features that are typically used in such devices. High density polyethylene was used as the moulding material. Design of Experiments (DOE) was adopted to investigate the relationship between machine parameters, real process conditions and replication quality. The peak cavity pressure and temperature were selected as process characteristic values to describe the real process conditions that material experienced during the filling process. The experiments revealed that the replication of ridges, including feature edge, profile and filling height, was sensitive to the flow direction; cavity pressure and temperature both increased with holding pressure and mould temperature; replication quality can be improved by increasing cavity pressure and temperature within a certain range.

INTRODUCTION

The dimensions of channels and ridges in today's microfluidic devices range from 10 to 100 µm; future features will need to be in the range of single microns to hundreds of nanometers and smaller. This demands that mass production processes with high replication accuracy need to be developed to manufacture such devices. Polymer is the most promising material for both MEMS and microsystems, due to its low cost, available fabrication technologies and wide range of mechanical and optical properties and chemical resistances, etc [1]. On the basis of conventional injection moulding technology, micro injection moulding has demonstrated itself to be a key enabling fabrication technology to mass produce polymer micro components with complex shapes and products with high quality surface features [2].

However, because of the high surface to volume ratio of micro/nano features, especially for higher aspect ratios, earlier solidification will prevent the filling of micro/nano cavities. Therefore, high injection pressure and material temperature are required to avoid premature solidification. As a result, the polymer materials in micro injection moulding are subject to higher shear rates and thermal gradients than in conventional injection moulding. Unique morphological features and lower mechanical properties have also been reported for micro injection moulding [3]. As the quality of micro components is very sensitive to process variations [4], it is important to understand a material's thermo-mechanical history during moulding. However, because of limited space to install sensors in a micro cavity, it is difficult to investigate actual process conditions during micro injection moulding. We have used embedded pressure and temperature sensors to characterise and to optimise the micro injection moulding process.

In this work, we replicated micro/nano scale features from a bulk metallic glass (BMG) mould insert with the micro injection moulding process. In addition, we used pressure and temperature sensors embedded into a micro cavity to monitor the cavity pressure and temperature that the material experienced in the moulding process. We also systematically investigated the correlations between machine parameter settings, process conditions and the replication quality of features. The influences of flow direction and channel width on the replication quality of micro/nano features were studied under the optimized combination of process parameters obtained from the correlation study.

MATERIALS AND METHODS

All experiments were implemented using a Fanuc Roboshot S-2000i 15B reciprocating micro injection moulding machine. The mould cavity was a steel mould insert with an embedded BMG insert on the top; the moulded part is in the shape of a dog-bone coupon and is around 25.34mm^3 in volume with a designed cavity thickness of 0.5mm. High density polyethylene (HDPE HMA016 grade) was selected as the moulding material for this study because of its wide processing window and excellent processability with good impact strength and dimensional stability.

A FEI Quanta 3D FEG Dual Beam FIB (focused ion beam) was used to machine the sub-micron and nano scale features on the surface of the BMG insert. Four groups of features were milled near the shoulder of the dog-bone cavity, which is farthest away from the gate. Two groups are channels and the other two groups are ridges, which have been arranged along and against the flow direction, as seen in Fig. 1 (a) & (b). The depth of channels on the BMG is 2.238±0.07µm with width ranging from 4 µm to 0.3 µm. The height of ridges is 1.905±0.14µm with width from 4 µm to 0.45 µm respectively. The logo of University College Dublin (UCD) was also machined as a nanostructured surface on the BMG insert, as shown in Fig. 1 (c). Each sample for measurement was randomly selected from 30 parts which were moulded under the same combination of machine process parameters. The replicated heights of features were measured by an optical profilometer. A FIB milling technique was used to cut away a section of the features in order to observe the profile of the features. A Pt strip layer was deposited via e-beam across the ridges and channels to protect the integrity of each feature during FIB milling. A rectangular section was cut directly in front of the deposited Pt layer.

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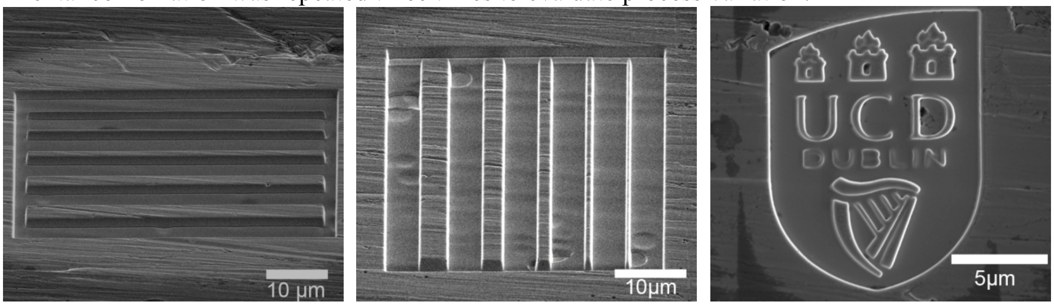
The DOE method was used to systematically investigate the relationship between machine parameters, process conditions and micro/nano feature replication height. Five machine process parameters were selected: injection speed (V_i = 450 or 100 mm/s), holding pressure (P_h = 120 or 70 MPa), holding time (t_h = 0.6 or 0.2 s), barrel temperature (T_b) and mould temperature (T_m = 70 or 40 ºC). A two level, half factorial 16 run (2^{5-1}), resolution-V design was constructed. Each experimental combination was repeated three times to evaluate process variation.

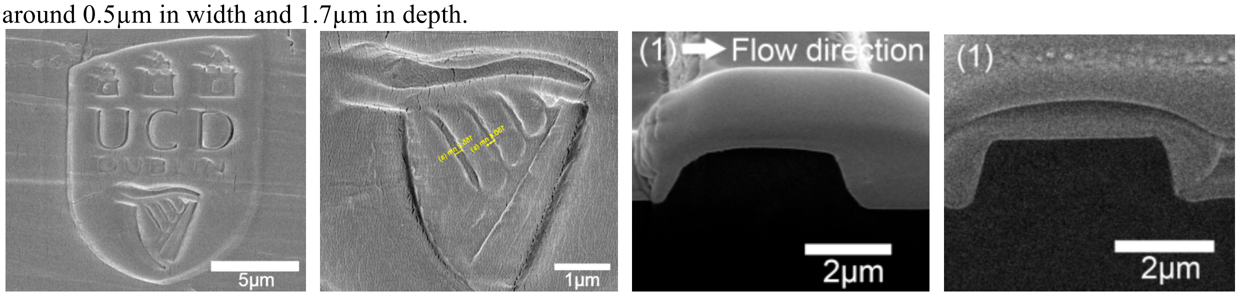


(a) (b) (c)

Figure 1: *Micro/nano features on BMG mould insert: (a) ridges parallel to flow direction, (b) ridges perpendicular to flow direction, (c) logo of UCD.*

RESULTS

Figure 2 exhibits the SEM images of features replicated by micro injection moulding. The minimum feature we have successfully replicated is around 150 nm, which is the spacing of the harp strings located on the replicated UCD logo. Ridges along the flow direction have a better replication quality than those against the flow direction, especially for smaller features. However, channels along the flow direction have similar replication quality to those against the flow direction. In order to gain further insight into the replication quality of micro channels and ridges, the FIB milling technique was used to expose the profile of micro/nano channels and ridges. As shown in Figs 2(c) & (d), ridges against the flow direction present round edges and their profile tend to incline with the flow direction. Ridges along the flow direction have sharp edges, especially for ridges wider than 1µm. Ridges of less than 1µm width along the flow direction also exhibit bigger replicated heights than those against the flow direction. This indicates that smaller features, especially nano scale features are more sensitive to the flow direction. The height and profile of replicated channels are insensitive to melt flow direction, even for nano-scale channels. The minimum channel we have successfully replicated is around 0.5µm in width and 1.7µm in depth.



(a) (b) (c) (d)

Figure 2: *Replicated micro/nano features in HDPE: (a) UCD crest, (b) detail of UCD crest, (c) ridges oriented against the polymer melt flow direction (d) ridges oriented along the polymer melt flow direction.*

CONCLUSIONS

Micro and nano scale textured surfaces were well replicated with the micro injection moulding process by using a BMG insert. The minimum feature we can replicate is around 150nm and the micro/nano ridges and channels we can successfully replicate range from 4µm to 300nm, with the maximum aspect ratio being 1.9. The quality of micro/nano features is sensitive to the polymer melt flow direction. Ridges that are oriented against the flow direction have round edges and their profiles are inclined with the flow direction. On the other hand, ridges parallel to the flow direction have the sharp edges and better replicated heights. Channels exhibit fewer significant differences than ridges. This manufacturing process offers significant promise for next generation microfluidic devices.

References

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