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Ultrasonic injection moulding of polypropylene and thermal visualisation of the process using a bespoke injection mould tool

M Gulcur, B R Whiteside, K Nair, M Babenko, P D Coates

[1]RKT Centre for Polymer MNT, Faculty of Engineering and Informatics, University of Bradford, UK

m.gulcur@bradford.ac.uk

Abstract

Ultrasonic injection moulding technology has been drawing attention in the recent years for manufacturing of small scaled polymeric components especially for medical applications. The technology offers some unique potential advantages over the conventional microinjection moulding processes which includes avoiding residence times of the molten polymeric material, less energy comsumption and reduced pressure requirements during the injection. Despite these advantages, randomly shaped pellets cause inconsistencies in the moulding process and repeatability of the process is highly affected. Also, tangential forces during the injection arise from the curved surfaces of the pellets during moulding and maintaining the ultrasonic frequency of the sonotrode is problematic.
In order to overcome these problems, disc shaped preforms of the polymer material to be used are fabricated using a disc shaped cavity and used in the ultrasonic injection moulding process. Thermal camera and novel tool design allow to visualise the cavity with mould inserts which has microneedle features. The effect of the feedstock shape on ultrasonic injection moulding were assessed analysing maximum temperature distributions obtained from the cavity filling events.

Ultrasonic injection moulding, thermal imaging, microneedles, feature replication

1. Introduction

Moulding and replication of micron sized features on mould tools are becoming increasingly important because of the need for micron sized parts and functional surfaces in lots of different applications such as medical and pharmaceutical technologies [1]. Micro injection moulding still stands as the most cost effective production method for these applications but residence times of large amounts of polymer material in the plastication barrels sometimes hinder the production of pharmaceutical or medical products due to thermal degredation. Also, the final product is connected to the sprue and runners which form more than %90 of the material to be injected. Medical grade plastics are usually costly and the final products should be produced with material waste as small as possible.

Ultrasonic injection moulding process addresses these problems by melting only the small amount of material which is needed to fill the cavity of the micro part. The melting and filling process takes place in a few seconds meaning that the material is exposed to high temperatures for a very short time as opposed to the conventional micro injection moulding processes. However, since the melting process is initiated and sometimes dominated by the interfacial friction between the pellets some inconsistencies in the amount of heat generated during the melting process which affects the melt homogeniety. Pellet shaped feedstock has been used in ultrasonic injection moulding recently and there are no reports on other shapes such as discs or spheres to the authors knowledge. In order to maintain a better melt homogeneity and temperature distribution as well as a good initial contact between the ultrasonic horn and the feedstock, disc shaped samples were moulded in a conventional micro moulding machine. In this work, using a novel cavity visualisation tool maximum temperature distributions were recorded and analysed for different disc thicknesses. Also, replicated micro features analysed using a confocal microscope and the results has been discussed.

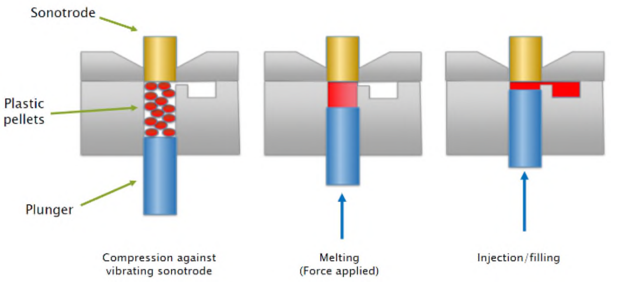
2. Experimental

In this study a high speed thermal camera was used to monitor the maximum temperature distributions in the cavity during an ultrasonic injection moulding process. The effect of the feedstock geometry is studied by using randomly shaped pellets and GA12 polypropylene discs with thicknesses of 0.5, 1 and 1.5 mm. The microneedle features on the samples were measured using an Olympus brand confocal microscope and compared.

2.1. Machine description and process parameters

The only commercial ultrasonic injection moulding machine is Ultrasion – Sonorus 1G which is used in this work. The ultrasonic injection moulding process is briefly described in Figure 1. Sonorus 1G uses a sonotrode that vibrates at 30 kHz with amplitudes ranging from 10 to 100 µm. First, the polymer feedstock is compressed against the vibrating sonotrode with a plunger, initiating the melting process. Then, the melted material is injected via the plunger to the mould cavity.

Since the material used was a semi-crystalline polymer, a relatively high ultrasonic amplitude of 100 µm was used. The injection force were selected as 625 N with a 500 N force stroke at the beginning to arrange the pellets before the

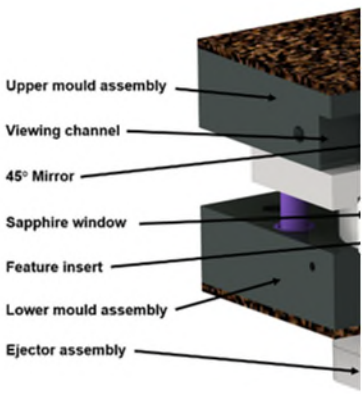


sonication. The sonication time of 6 s was used in order to fill the whole cavity.

Figure 1. Ultrasonic injection moulding process

2.2. Thermal imaging and mould tool

Thermal imaging experiments were carried out using a bespoke flow visualisation mould tool which was used in previous studies [2] and a FLIR X6540 sc thermal camera. It records filling events with a frame size of 640x512 and integration time between 40-50 µs.



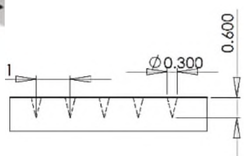


Figure 2. Flow visualisation mould tool designed for Sonorus 1G

The mould tool is modular and allows the use of different mould inserts. In this work, a mould insert with 5x5 microneedle array was used. The shape of the part and details of the microneedle features are given in Figure 3.

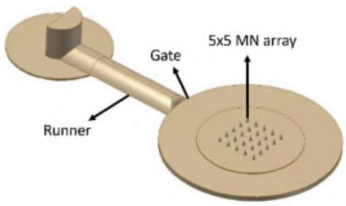


Figure 3. 3D generated model of the part and dimensions of the microneedle features.

3. Results and discussion

Maximum temperature distributions for cavity filling events were obtained using the cameras software interface for pellets and different disc thicknesses. The values were recorded in the software and average maximum temperature values for different feedstock geometries are given in Figure 4. These results suggest that having more interfaces have a direct impact on heating since there is an increasing trend for the average maximum temperature from thicker to thinner discs. Also, after inspection of the discs fabricated in conventional micro moulding machine, it was seen that there were shrinkage marks on the surfaces which might have an impact on the variances of the maximum temperature values for discs.

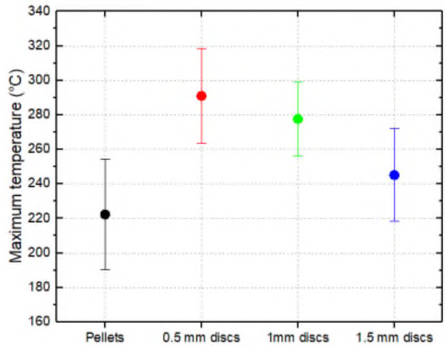


Figure 4. Maximum temperature data for different feedstock geometries

The average heights of the microneedle features are given in Figure 5. To make a comparison with the conventional micromoulding machine, a reference sample which is indicated with light blue was inclided in the measurements. Although 0.5 mm discs showed higher maximum temperatures which might suggest better melting and homogeneity, the needle height measurements suggest that this thickness was not the best parameter in terms of the filling of the microneedle cavities. The cavity events were quite fast for 0.5 mm discs which might be the reason for this situation. Once more, it was seen that the shrinkage marks also affected the filling of the cavities as can be seen from the data points for 1.5 mm thick discs.

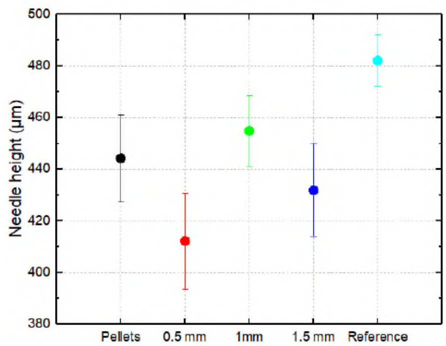


Figure 5. Microneedle height data for different feedstock geometries

5. Conclusion

In this work, convenience of using flat surfaced feedstock for ultrasonic injection moulding is demonstrated. With better control of the disc shape at the beginning and control of other parameters, the technology shows promise for obtaining micro parts with adequate properties.

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