euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Ultrasonic injection moulding: a study of thermal behaviour and nanofeature replication

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Abstract

Ultrasonic Injection moulding has emerged as an alternative production route for miniature and microscale polymeric components, where it offers some significant benefits over conventional microinjection processes. The primary advantage is the fact that heating is only performed on the volume of feedstock required for the product, so degradation problems due to extended residence time in the screw can be avoided, and the total energy required for heating is significantly lower. In addition, the ultrasonic energy can be sustained during the filling stage in the process which appears to significantly reduce the pressure requirement for cavity filling whilst simultaneously add providing the ability to add heat after cavity filling, allowing molecular chain relaxation and reduced residual stresses.
Here a novel injection mould tool has been used which allows the comparison of conventional and ultrasonic moulding techniques. The tool allows direct viewing of the mould cavity using high speed conventional and infrared imaging which allows direct measurement of the flow rate and thermal consistency of the polymer melt. A test cavity allows the replication of a range of nano-featured nickel inserts in a variety of thermoplastic materials surfaces using the technique. These replication quality of the moulded nanostructures has been assessed using S-parameters and rugosity, and compared with the results of a similar process using conventional moulding techniques,

Keywords: Ultrasonic moulding, feature replication, surface measurement, thermoplastics

1. Introduction

Despite significant advances in additive manufacturing, high precision injection moulding [1] remains the most cost effective and accurate way of producing micron-scale features and tolerances in high volumes. The last decade has seen the emergence of a range of processing equipment dedicated for high precision, low part mass mouldings such as the Wittmann-Battenfeld Micropower 15 and a dedicated micro-injection unit from Arburg. However, these machines have a significant issue for moulding of small component masses in that the requirement for handling commercial granule feedstocks and extruder-based plastication of the material results in a comparatively high volume of material in the plastication system compared to the component size. This results in a long residence time of material at temperature prior to injection and can result in thermal degradation of materials leading to visual defects and poorer physical properties.

Ultrasonic moulding methods are emerging as a route to solve this issue for parts of mess less than one gramme, where only the volume of material required for the shot is melted just prior to injection. This significantly reduces the time spent at temperature and associated degradation problems. In addition, further application of ultrasonic energy after melting, during the filling phase of the process can improve filling behaviour by causing an apparent reduction in viscosity which could provide benefits for thin wall mouldings or replication of high aspect ratio surface features.

2. Experimental

The study performed here uses high speed Infrared imaging techniques to directly view the filling behaviour of a simple mould in an Ultrasion Sonorus 1G ultrasonic moulding machine. The experiments performed here were performed with in Inneos GA12 polypropylene.

2.1. Machine description

The Sonorus 1G machine is an upright machine with a vertical injection axis as shown in Figure 1. Dosing is performed using a laser pellet counting system which dispenses a pre-set number of pellets into a chamber beneath the sonitrode. Injection is perfomed by lowering the sonitrode and applying a 30 kHz ultrasonic wave while simultaneously raising an injection plunger which compresses and melts the material, and injects it into the mould cavity.

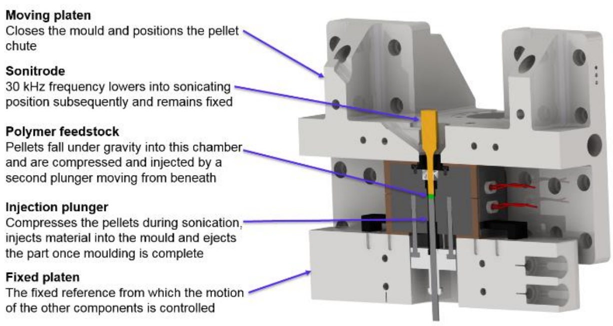

Figure 1. Schematic of the ultrasonic moulding machine

2.2. Visualisation system

A bespoke injection mould tool similar to that used in previous studies [2] was manufactured for this work. The tool incorporates a sapphire window and 45° first surface mirror which allows direct viewing of the mould cavity during filling, as shown in Figure 2. The mould cavity in this case was a simple circular disc of thickness 0.5 mm and diameter 20 mm which can hold a patterned insert for surface feature replication studies.

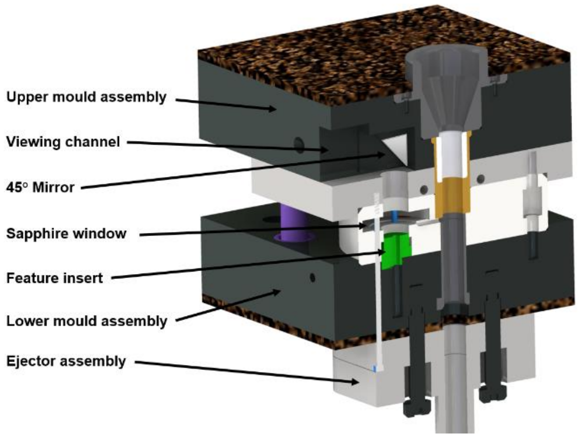

Figure 2. Flow visualisation mould configuration.

Thermal imaging of the filling behaviour was performed using an IRCam Equus 81k system which records in the 3-5 µm spectral range with a resolution of 320 x 256 pixels at a full frame rate of 487 Hz. Calibration of the optical system was performed by gradually raing the mould temperature, moulding a product, allowing the system to thermally stabilise then recording the resulting IR intensity.

3. Results and discussion

Time-dependant point measurements were recorded from the thermal data for applied ultrasonic energy durations of 2,4,6 and 8 s, the results of which are shown in Figure 3.

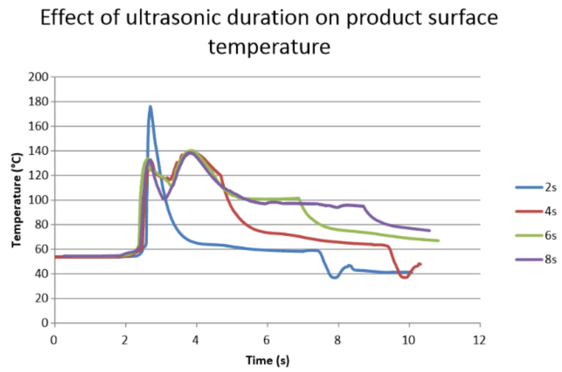

Figure 3. Component surface temperature results

These results showed a maximum temperature occurring after the cavity had completed filling, but when the ultrasonic energy was still sustained. This is a significant departure from conventional injection moulding where the maximum surface temperature always occurs as the part is filling, caused by the deposition of hot material onto the mould surface at the flow front due to the fountain flow effect.

Looking at the actual thermographs provided further insight into the filling behaviour where there were distinct temperature differences in the material convecting through the cavity during filling. This is illustrated in Figure 4 which shows thermograph sequences collected from 3 consecutive cavity filling events with identical process settings.

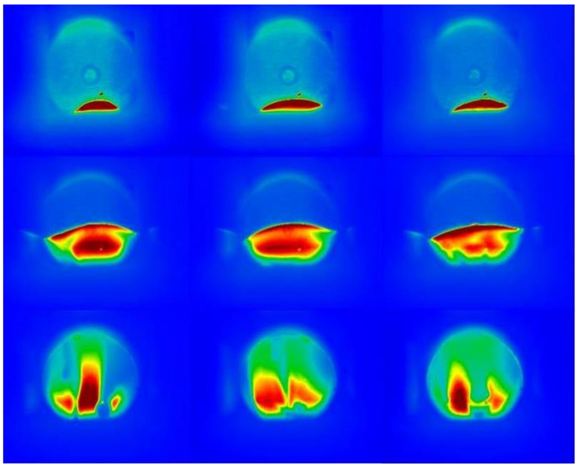

Figure 4. Thermographs of 3 consecutive filling events.

The large differences in surface temperatures observed are not repeatable, which suggests that they could originate from hot regions during melting caused by friction between pellet contact areas in the melting chamber. As the pellet configuration is essentially random at the beginning of the process, the distribution of such hot spots will be random too as they are convected through the mould cavity during the injection phase.

Despite the large variations in observed surface temperatures, the products resulting from the process appeared to be of good quality. In order to investigate the effect of such temperature distributions in the component, a cross polarised optical train was used to study the resulting birefringence in the ultrasonic moulded samples and a conventionally moulded specimen (Figure 5).

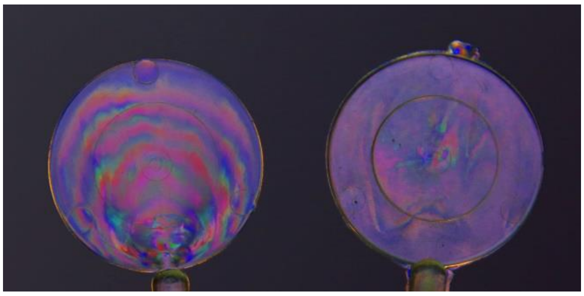

Figure 5. Polarised light imaging of birefringence in conventionally moulded sample (left) and ultrasonic moulded sample (right).

The images showed a lack of uniformity in the birefringence of the ultrasonic specimen, but it was noticable that the overall levels of birefringence, and therefore residual stresses were much lower than that seen in the conventioanl moulded disc.

5. Conclusions

Ultrasonic moulding techniques offer some clear benefits over conventional moulding processes but concerns remain over the ability of such systems to produce adequate melt homogeneity. The ability to continue to put energy into the material after filling has completed shows promise for reducing residual stresses and possibly improving surface feature replication.

References

[1] Whiteside BR; Martyn MT; Coates PD 2005, *International Polymer Processing* **20** 2

[2] Whiteside BR et al. *Plastics, Rubber and Composites* **37** 2-4