euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Investigation of process parameters influence on flash formation in injection moulding of polymer micro features through design of experiments

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Abstract
Micro injection moulding is one of the key technologies for micro manufacture due to its mass-production capability and relatively low component cost. Flash defects are among the most critical issues in the replication of micro features and constitute a manufacturing constrain in applying injection moulding in a range of micro engineering applications. In the present research the effects of four processing parameters on the amount of flash on a micro finger test structure were investigated using two different polymer materials and applying DOE approach. In particular, the following process parameters were considered: injection speed, holding pressure, melt temperature and mould temperature. The study revealed that for the materials with lower viscosity the injection speed, followed by barrel temperature, are the most influential parameters for increasing the amount of flash. On the other hand, barrel temperature, injection velocity, and mould temperature resulted as the most influential parameters for increasing the flash amount when moulding with high viscosity materials. Conversely, the holding pressure did not have a clear effect on the flash amount.

Micro injection moulding, Process parameters variability, Design of experiment, Flash

1. Introduction

Micro injection moulding is one of the most important mass micro production technologies because of its high productivity and many applications in different industries (communication, medical, bioanalytics, etc.). The importance of quality of the parts in combination with increasingly high production demand, implies a need for better understanding of the micro injection moulding process and the effect it has on the quality of the parts [1-5]. This study focuses on investigating the effect of process parameters on the quality of the replicated parts. Quality here is estimated by quantifying the flash amount. Flash is defined as additional unwanted material typically forming at the edge of the features. The aim is to study the effect of process parameters using the micro finger mould and DOE approach on flash amount created on the replicated part and determine which of the used parameters has the most effect on the quality of the part.

2. Experimentation

Injection moulding experiments were carried out on an Arburg (Allrounder 370 A) injection moulding machine which has maximum clamping force 60 tons with screw diameter of 18 mm. A commercially available unfilled material polypropilene (PP, trade name 400-GA05), manufactured by INEOS Olefins polymers Europe and acrylonitrile butadiene styrene (ABS, trade name Terluran GR35) manufacturing by BASF were applied as the polymer materials in this study. The investigated parameters were: injection speed (V_i), holding pressure (P_h), melt temperature (T_b) and mould temperature (T_m). These parameters were considered as the factors affecting the capability of the microinjection moulding process. By considering the injection moulding machine capability and the materials properties different injection process setting were selected for the statistical design of experiments, see table 1.

Table 1. Injection moulding process setting.

Injection moulding process parameters	Law level (-)	Law level (+)
Injection speed	140 mm/s	220 mm/s
Holding pressure PP	10 MPa	60 MPa
Holding pressure ABS	20 MPa	70 MPa
Melt temperature	240 ˚C	270 ˚C
Mould temperature	20 ˚C	60 ˚C

The part is a rectangular shape (20mm*10mm*1.5mm) with four fingers. The four fingers have the same length of 15 mm, the same width of 3 mm and different thicknesses 0.7 mm, 0.5 mm, 0.3 mm and 0.1 mm see figure 1.

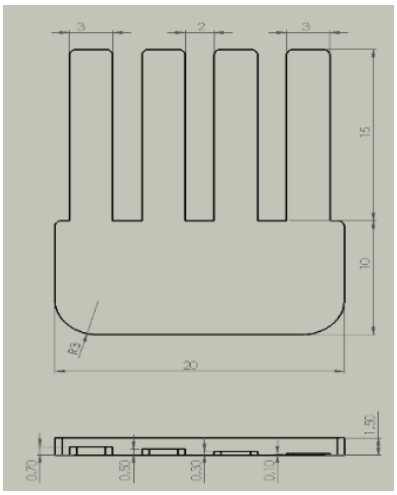

Figure 1. Dimensions of the micro finger test structures.

The Design of experiment (DoE) approach has been applied to assess the effects of the selected four parameters varying between a maximum and a minimum value. A two-level four-factor full-factorial design resolution V (2^4) was applied, scheduling 16 treatments that were carried out.

3. Result and discussion

A fixed position on the molded parts was selected for flash amount comparison. An optical quality control CNC measuring machine was used to take microscopic photographs for evaluating the flash amount formation in corresponding positions of moulded parts for each experimental run for both materials PP and ABS see Figure 2.

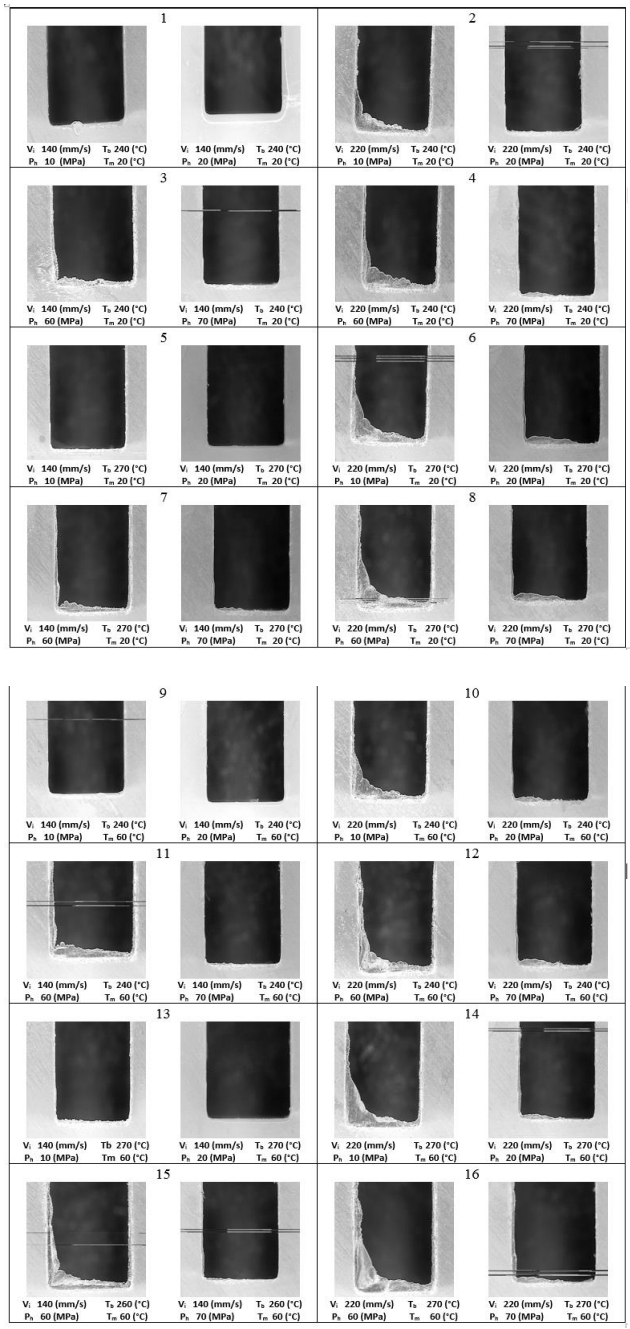

Figure 2. Images of PP (left) and ABS (right) flash formation in different process conditions at all the 16 DOE treatments.

For the first comparison we can see that the amount of flash formation for PP material is higher than ABS material for all the corresponding 16 DOE treatments leading due to the difference on viscosity where the PP is a material having a low viscosity, which is better for filling the micro features but on the other hand it favours for flash creating.

For PP material, as shown in Figure 2 at the left for all the 16 DOE treatments , the flash appears with the high level of injection velocity as shown in treatments number 2 and 4 which the melt and mould temperature are at the low level. At the high level of melt temperature with high level of injection velocity as shown in treatments number 6 and 8, the flash amount is large compared by treatments 2 and 4. For treatment number 10 and 12, which have mould temperature and injection velocity at the high level the flash amount is bigger than treatment 2 and 4 and less than treatments 6 and 8. At the high level of injection velocity, melt temperature and mould temperature the flash amount is very high as in treatment 14 and 16. The holding pressure has the smallest effect for flash amount as shown in treatments 3, 7, 11 and 15. From the above discussion the injection velocity, melt temperature and mould temperature respectively are the most influential parameters affect the magnitude of the flash amount formation.

For ABS, as shown in Figure 2 at the right for all the 16 DOE treatments, the flash appears with the high levels of melt temperature and injection velocity as shown in treatments number 6 and 8 where mould temperature are at the low level. At the high level of mould temperature with high level of injection velocity as shown in treatments number 10 and 12, the flash amount is small compared by treatment 6 and 8. At the high level of injection velocity, melt temperature and mould temperature and the flash amount is also high as in treatment 14 and 16. The holding pressure has no effect in the flash amount formation as shown in treatment 3, 7, 11 and 15. From the above discussion it results that the melt temperature, injection velocity and mould temperature respectively are the most influential parameters affect the magnitude of the flash amount.

5. Conclusion

This paper investigate the effect of four processing parameters injection velocity V_i, holding pressure P_h, melt temperature T_b and mould temperature T_m using flash amount as an experiment output response. Polypropylene (PP) and Acrylonitrile Butadiene Styrene (ABS) grade were used for the injection moulding process. The DoE approach has been applied to assess the effects of the selected four parameters, varying between a maximum and a minimum value. Experimental results and statistical analysis showed that the flash amount created when moulding the PP material is larger than the flash amount for the ABS material. For the PP material, the injection velocity followed by melt temperature are the most influential parameters on the flash amount formation. However, the melt temperature followed by injection velocity are the most influential parameters effect on the flash amount in ABS material moulding. In conclusion, in order to replicate high quality parts, the correct adjustment of the process parameters is crucial. In particular, an increase in injection velocity and melt temperature showed an increase in flash, choice of polymer also had a high effect on both the accuracy of the part and flash formation.

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