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Published in:
Proceedings of the 18th International Conference of the European Society for Precision Engineering and Nanotechnology

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Evaluation of part consistency with photopolymer inserts in different injection moulding process parameters

Ali Davoudinejad, Alessandro Charalambis, Yang Zhang, David Bue Pedersen, Matteo Calaon, Guido Tosello and Hans Nørgaard Hansen

Department of Mechanical Engineering, Technical University of Denmark, Building 427A, Produktionstorvet, 2800 Kgs. Lyngby, Denmark

alidav@mek.dtu.dk

Abstract

Using additive manufacturing (AM) processes for direct fabrication of complex three-dimensional objects in a fewer time in comparison to the subtractive method is the advancement of this technology. This study connecting the AM with injection moulding (IM) process. AM inserts are directly manufactured by photopolymer material and used in IM process. Different combinations of IM parameters are used in order to find out the influence of various settings on the fabrication of the parts with soft inserts. The effects of injection moulding parameters are investigated by the use of a design of experiment (DOE) and optical metrology. DOE analysis concludes that the IM speed and cooling time are significant factors, for the geometry of the features. The height of bricks and knobs are also measured on the IM parts for assessment of different batches before any cracks appear on the inserts.

Additive manufacturing; Digital Light Processing; soft tooling lifetime; injection moulding

1. Introduction

AM method is very properly suited for single production of complex geometries and prototypes. Different AM technologies apply for fabrication of different components based on the manufacturing scale, material, and dimension precision needed for the products. Direct fabrication of micro features by Digital Light Processing (DLP) method was characterized with photopolymer material [1][2]. Different designs were fabricated in order to evaluate the AM machine capability. Even smaller scale method applied by using Two-photon polymerization (2PP) process to characterize the significance of process parameter in fabrication of features [3]. Beside direct fabrication AM was used for linking with other process such as injection moulding that used for the mass production in different industries.

This study investigate IM parts fabricated by AM inserts for sub-mm features. Various IM parameters were used in order to find out the effect of different settings on fabrication of parts.

2. Additively manufactured insert

Digital Light Processing (DLP) machine was used for fabrication of insert. DLP is known for high precision elements and temperature resistant materials. The material used in this project is a brand new prototype material and no data sheet, material property or chemical composition is available due to confidentiality agreements. The insert design selected from previous study [4] with different micro features. Figure 1 shows the detail geometry of the insert.

3. IM experimental procedure

The IM tests were carried out on an Arburg (370A 600-70), 60 tonne moulding machine. Acrylonitrile butadiene styrene (ABS) Terluran GP-35 is chosen for its ease of processing and injection temperature of 220-260°C. The material was dried for 4 hours at 80°C in a HELIOS WINsystem Micro D dryer. The IM is carried out with standard settings for ABS and varying parameters for injection temperature, injection speed, mould temperature and cooling time. The remaining parameters are kept constant at 200 bar packing pressure and 4 s packing time. Attention was used to not raise the packing pressure too much, which could damage the rather fragile polymer inserts.

A two-level half factorial design of experiments (DOE) with 4 factors was carried out to assess the effect of IM parameters on the lifetime of AM inserts. The tested IM parameters are listed in Table 1. The initial 5 moulded parts are collected in order to follow the changes during the lifetime of the insert.

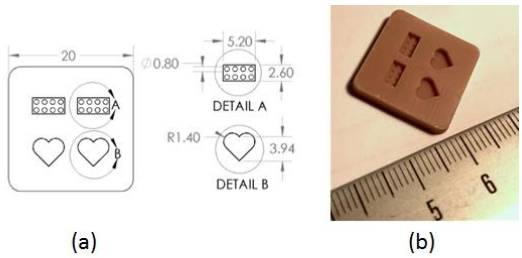


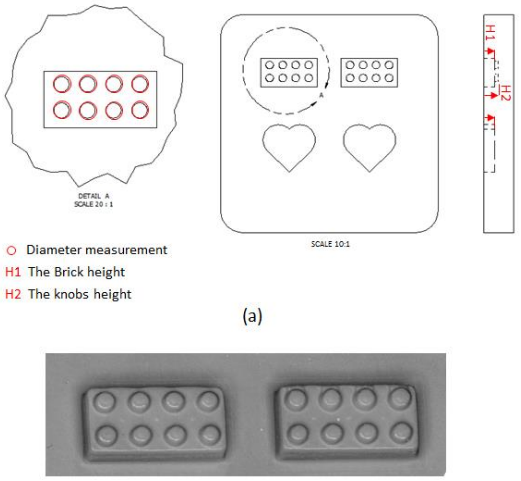
Figure 1. (a) insert drawing (dimensions in mm) (b) AM insert.

Table 1 Experimental factors and their levels

Factors	Low	High
Melt temperature	220 °C	260 °C
Injection speed	40 mm/s	80 mm/s
Mould temperature	25 °C	50 °C
Cooling time	0 s	5 s

4. Measurements

Injection moulding parts measurement were performed using an Olympus Lext OLS 4100 laser scanning digital microscope. As it is shown on Figure 2 the selected areas are marked in red. Heights of both the heart and the brick cavities are estimated by measuring from the mould surface to the bottom of the cavities. The bricks are measured according to, two heights, both from the mould insert surface to mid plane of the brick and to the knob surface. Diameters of the brick knobs are estimated as an important dimensional feature that may be affected during moulding hence the top-right and bottom-left are chosen as reference area. These places are chosen as they are expected to vary the most and also most effected by the IM process. In order to analyse the measurements data a scanning probe image-processing software was employed for the purpose (SPIP).



(a)

(b)

Figure 2 (a) insert analysis region (b) IM experiments part measurement area

5. Results and analysis

5.1. Influence of IM parameters

The parts were collected after all DOE runs and the average diameter of knobs was used for analysis as described in section 3. Figure 3 shows main effects plot for the combination of parameters for 8 tests. The influence of cooling time, IM speed, melt and mould temperatures were analyzed. The most influential factors were noticed as IM speed and cooling time. Therefore in a lower speed, 40 mm/s and more cooling time 5 s the diameter of the knobs were more uniform. This could be due to the small dimension of the features 800 µm that need more cooling time and lower speed to fill the shape properly during the IM process. However, the melt and mould temperature were not an influential factor to affect the diameter of the features.

The height of bricks and knobs are presented in Figure 4. The blue bar chart shows the bricks height and the line graph presents the height of knobs. IM parameters also affected the height of features. In batch A and D with 5 s cooling time, the highest features were observed with minimum standard deviation. The following measurement and analysis carried out on the IM parts before the crack appeared in the photopolymer inserts.

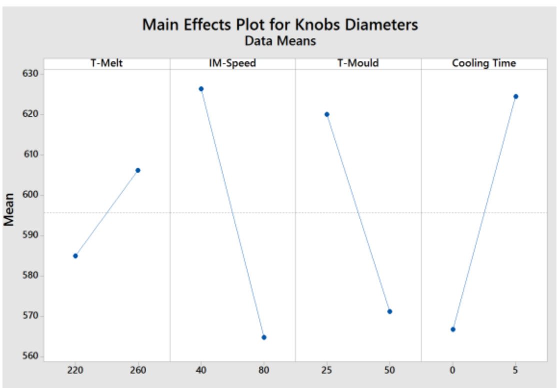


Figure 3. Main effect plot

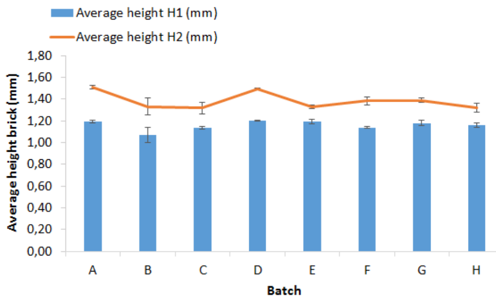


Figure 4 The height of the bricks and knobs

IM experiments were carried out up to the failure of the inserts. The failure criteria was selected in order to find out the tool life of the inserts in different conditions. The appearance of the cracks was considered as insert tool life. The cracks was observed in different regions of the insert. The longest insert tool life was observed at 115 shots.

4. Conclusion

This project aimed at evaluating the IM parts in different parameters with AM inserts. The main focus is on investigating which IM factor have the main effects on the parts accuracy. The influences of four main IM parameters were investigated. From the DOE analysis, it was possible to conclude that the IM speed and cooling time were significant factors, affect the diameters of the brick knobs. Besides, the height measurements also revealed the importance of factors in different batches. The higher cooling time 5 s influence the height of the features. The tool life of the insert was also evaluated for the number of shots before the first crack appeared to affect the IM parts. In the future study, the tool life and the crack propagation of the photopolymer inserts will be investigated.

Acknowledgments

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013) under REA grant agreement no. 609405 (COFUNDPostdocDTU).

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