

Assessment of sub-mm features replication capability in injection moulding using a multi-cavity tool produced by additive manufacturing

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

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

alidav@mek.dtu.dk

Abstract

This research investigates the effect of injection moulding process parameters on photopolymer mould inserts produced with the Digital Light Processing (DLP) additive manufacturing (AM) method. The main motivation of applying AM to produce mould inserts, is the potential of reducing lead time and manufacturing cost, as well as achieving a more flexible manufacturing method in case of non-mass produced products such as prototypes. In this research moulds inserts of 20 x 20 x 2.7 mm with mould cavities as small as 5 x 4 mm in dimensions are tested. The parts are analyzed and evaluated by the measurements of different features and the influence of the IM process.

Keywords: additive manufacturing; digital light processing; soft tooling; injection moulding

1. Introduction

With additive manufacturing (AM) as an emerging technology, there has been an increased interest in combining this technology with well-known traditional technologies, such as injection moulding (IM). By combining the two technologies it is possible to utilize the advantages of both, while simultaneously circumventing the main limitations of them. The main advantage of AM is the rapid iterations between design and product, while it is limited by material choice, surface quality and mechanical properties. The advantages of IM lies in the high quality part with good replication and the ability for mass production.

This research is based on combining the technologies by using AM to produce inserts that directly will be used in IM for moulding the final parts. This concept relies on the AM inserts being able to handle the typical IM parameters for an extended period without degradation of quality or damage.

2. Experiments

2.1. Mould Inserts design and fabrication

The investigated AM mould inserts have been manufactured with DLP method that was applied for different micro AM features fabrication[1][2][3]. A high precision industrial 3D-printing system was used with a 50 μm pixel detail in X and Y directions and the precision of $\pm 50 \mu\text{m}$ in X, Y, and Z directions. Due to the rather larger build, envelop of the printing 96x54x150 mm (X/Y/Z) most of the inserts were printed in the same batch. This method is well known for high precision elements and temperature resistant materials. The insert was fabricated with photopolymer material. The insert design is based on the previous research [4] and designed with two different micro features: two hearts and two bricks with eight knobs each. The features are intended to induce cracks in specified positions as well as evaluate the ability to reproduce

specific geometries. A technical drawing of the insert with important dimensions and features can be seen in Figure 1.

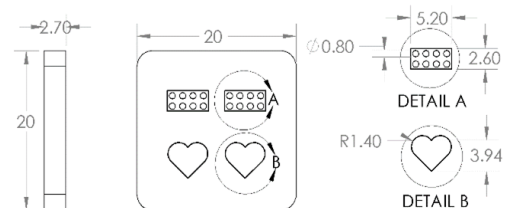


Figure 1. Drawing of the insert (dimensions in mm).

2.2. Injection Moulding

The IM tests were carried out on an Arburg (370A 600-70), 60 tonne moulding machine. In the literature the main goal is to extend the tool lifetime as much as possible and therefore low temperature materials are used, such as PE and PP [5]. However, in this study a material with a higher melting point is used. 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.

A two-level half factorial design of experiments (DOE) with 4 factors was carried out. The tested IM parameters are listed in Table 1. The moulded parts are collected in batches of 10 in order to follow the changes during the lifetime of the insert, as well as exactly identifying when the first crack appears, as the insert itself cannot be monitored during the IM.

The levels for the melt and mould temperature is based on the data sheet for ABS Terluran GP-35. The mould temperature levels are adjusted because the mould is not insulated. The mould is set to the theory values for the temperature, but due

to heat loss from the mould sides, the actual measured mould temperatures were lower.

Table 1 Chosen experimental factors

| Insert | T melt (°C) | Injection speed (mm/s) | T mold (°C) |
|--------|-------------|------------------------|-------------|
| A | 220 | 80 | 25 |
| B | 260 | 40 | 50 |
| C | 220 | 80 | 50 |
| D | 220 | 40 | 25 |

The melt temperature levels were not adjusted as the inserts did not show initial damage. The levels for injection speed are based on the literature [5] but from initial test shots, which did not damage the inserts the high level was raised to 80 mm/s.

It was not possible to find comparable values for the cooling time as this depends on the insert geometry, the workshop environment, the chosen temperature levels, the mould insulation and the conductivity of the insert material. Therefore, the values for the cooling time were found from testing. The cooling time described here comes in addition to the cooling time, when the mould is closed. Therefore, it is added as a delay of the mould closing.

2.3 Dimensional measurements

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. The five initial injected parts were evaluated to find out the repeatability and the influence of the process without considering the wear of the inserts. The investigation was carried out with a focus variation microscope (Alicona Infinite Focus), using a 5x magnification lens for visual inspection and a 20x magnification lens (pixel width 883 nm x 883 nm) for the measurements. In order to analyse the measurements data a scanning probe image-processing software was employed for the purpose (SPIP). Figure 2 shows the acquisition of the lower part of the heart in the SPIP for angle measurement. Additionally the inserts were inspected for the initiation of the cracks which visually identified in a certain batch.

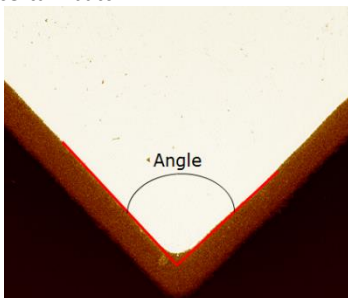


Figure 2. The acquisition of lower angle shape of the heart in SPIP for the IM part

4. Results and analysis

In order to evaluate the manufactured parts with soft tooling insert, the measurement results of the first five parts for each batch is presented in following graphs. Figure 3 shows the angle measurement of the hearts in both sides of the parts and Figure 4 illustrates the average diameter of the pillars. The results reveals variation between the right and left side of the parts mainly for the angle measurements. Batch A had minimum variation on the left and right side of the part in comparison to other setting. Regarding the diameter of the pillars in all conditions smaller size observed in comparison to

the nominal geometry. The variation of the dimensional features of parts are mainly due to the IM setting parameters and also might be due to the shrinkage of ABS material, and the crack of the insert that affect the feeding of the mould.

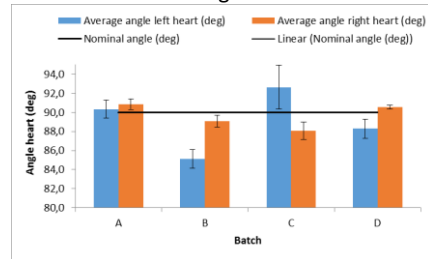


Figure 3. The lower angle shape variation of the hearts in IM parts

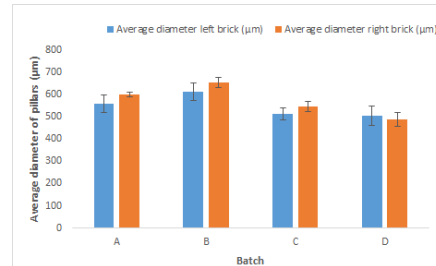


Figure 4. The average diameter of the pillars

5. Conclusion

This work presented the capability of the soft tooling insert manufactured by digital light processing AM method for injection moulding. Inserts of 20 x 20 x 2.7 mm with mould cavities as small as 5 x 4 mm in dimensions were tested. Different feature of size was designed and evaluated for this experiments with various IM parameters setting. The measurements carried out for different features to evaluate the effect of the IM parameters. The five initial parts were investigated to eliminate the other effects. The influence of the IM parameters were observed in different batches of parts.

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).

References

- [1] Davoudinejad A, Ribo MM, Pedersen DB, Islam A, Tosello G. Direct fabrication of bio-inspired gecko-like geometries with vat polymerization additive manufacturing method. J Micromechanics Microengineering 2018.
- [2] Davoudinejad A, Pedersen DB, Tosello G. Characterization of additive manufacturing processes for polymer micro parts productions using direct light processing (DLP) method. 33rd Conf. Polym. Process. Soc. Cancun, Mex., 2017.
- [3] Davoudinejad A, Pedersen DB, Tosello G. Evaluation of polymer micro parts produced by additive manufacturing processes by using vat photopolymerization method. Jt. Spec. Interes. Gr. Meet. between euspen ASPE Dimens. Accuracy Surf. Finish Addit. Manuf., 2017.
- [4] Mischkot M, Davoudinejad A, Charalambis A, Tosello G, Pedersen DB, Nørgaard H. Dimensional accuracy of Acrylonitrile Butadiene Styrene injection molded parts produced in a pilot production with an additively manufactured insert. 33rd Conf. Polym. Process. Soc. Cancun, Mex., 2017.
- [5] Zhang Y, Pedersen DB, Gøtje AS, Mischkot M, Tosello G. A Soft Tooling process chain employing Additive Manufacturing for injection molding of a 3D component with micro pillars. J Manuf Process n.d.;27:138–44. doi:10.1016/j.jmapro.2017.04.027.