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Evaluation of surface roughness and geometrical characteristic of additive manufacturing inserts for precision injection moulding

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Abstract. In order to use additive manufacturing (AM) processes for producing complex feature geometries and benefiting from the possibility of manufacturing large series by using medium/high production techniques, the repeatability of the AM process and accuracy assessments is a critical aspect to be considered in the polymer insert printing and it's integration into the injection moulding process chains. This study investigates the AM tool inserts and injection moulded parts in terms of surface roughness and geometrical accuracy prior and after injection moulding. The vat photopolymerization method was used to produce additively manufactured tool inserts. The insert was designed in a way to involve several miniaturized features with different shapes in order to evaluate the process repeatability over a large variety of geometries, dimensions and aspect ratios.

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INTRODUCTION

Different processes are applied for manufacturing microinjection moulding tool inserts depending on the number of parts needed. The tool fabrication for injection molding can be categorized in four main different manufacturing schemes which two use silicon substrates and two use other materials as the substrate (polymers or metals). Two schemes utilize subtractive micromachining (reactive ion etching, mechanical micromachining or laser micromachining) and two schemes involve additive micromachining (UV-lithography combined with electroforming) [1].

Additive manufacturing (AM) processes with fundamental abilities to fabricate three dimensional parts with high aspect ratio is thus becoming a standard method in part production and rapid tooling applications [2]. Polymer materials with low melting point or with liquid state are widely used in AM industry because of low weight, low cost and processing flexibility. Different AM methods have been employed for printing the polymers composite materials which some of the well-recognized techniques to fabricate polymer parts are as follow; Stereolithography (SL) [3], Selective laser sintering (SLS®) [4], Direct Laser Writing (DLW) [5], Vat photopolymerization [6] and etc. The selection of proper AM processes is depend on different factors such as the ease of manufacturing, speed, fabrication cost, part design, material, processes limitations, surface finish and dimensional accuracy of the part.

This study will focus on the AM process of the IM inserts to evaluate the injected parts with different printed inserts. The inserts were directly printed with vat photopolymerization process then the inserts were used for IM process and the repeatability of the parts were evaluated.

EXPERIMENTAL PROCEDURE

Mold inserts fabrication

The mould inserts were produced in the photopolymer by vat photopolymerization method in which liquid photopolymer in a vat is selectively cured by light activated polymerization layer by layer [7]. A high precision industrial 3D-printing system Digital Light Processing DLP-LED Stereolithography was used with a 50 µm pixel detail in X and Y directions and the precision of ± 50 µm in X, Y, and Z directions. Due to the rather larger build, envelop of the printing 96×54×150 mm (X/Y/Z) most of the inserts were printed in the same batch. The test part is designed in a way to evaluate the ability to reproduce specific geometries. It is a flat cuboid (19 x 19 x 3 mm3) with rounded corners and includes both micro and macro features: On top of the cuboid, there are two heart-shaped artefacts and two more cuboids (5.30x 2.67x1.17 mm3) with eight cylinders (0.83 mm diameter) on the top surface of each as shown in Fig. 1.

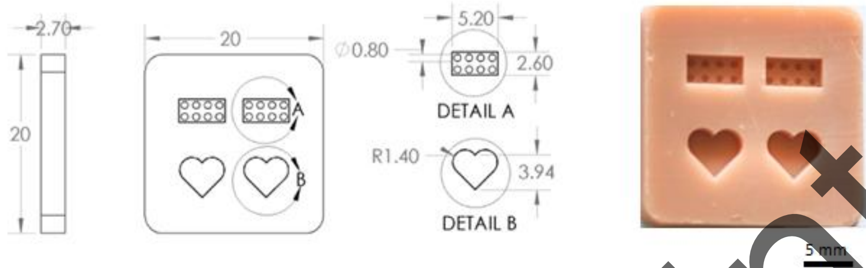

FIGURE 1. (a) Drawing of insert and details (dimensions in mm) (b) printed insert

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Injection Moulding

The IM was carried out on an Arburg (370A 600-70), 60 tonne moulding machine. Injection moulding material with a higher melting point was used. Acrylonitrile butadiene styrene (ABS) Terluran GP-35 was 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 the ABS. The 200 bar packing pressure and 4 s packing time were kept constant in different conditions. In order to collect the exact manufactured parts in the initial of the moulding process for each insert only one cavity with AM insert was used for each moulding out of four cavities. Table 1 shows the IM parameters applied for each insert.

TABLE 1 MIM experimental parameters

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

Measurements and Analysis

The inserts were measured prior to the IM experiments in selected positions within the focus areas are systematically considered, to carry out similar measurements on all inserts as show in if Figure 2. The measurement results of the heart shape is presented in this paper. The inserts measurements were conducted with infinite focus Alicona (3D optical microscope). The areal roughness (Sa) measurements were conducted under 100x magnification with exposure time about 1-2 ms. Roughness of the insert cavity surfaces are measured at specific points. Each heart cavity is measured at three locations. Regarding the IM parts, similar measurements were carried out on the five initial injected parts to find out the repeatability of the process without considering the wear of the inserts.

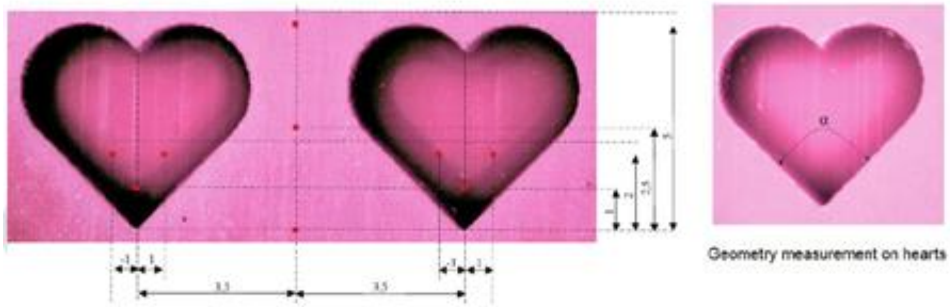

FIGURE 2. Diameters of the brick knobs (Indicated with withe circles) and roughness measurements zone of bricks (top) and heart (bottom, left, on outer surface between and inside holes); angle measurement on hearts (bottom, right).

RESULTS

The replication of the injection moulding parts were continued until the AM inserts were broken. The inserts tool life were different, the cracks were appeared at various area of the inserts. The inserts after number of shots started with a crack and then the crack propagated and resulted in the total breakage. Most of the runs reached at least 30 cycles. Figure 3 shows insert crack and final damage for one of the insert with lowest number of shots. The crack resulted in the damage of the top left corner of the left brick and the experiment was stopped as total failure prevents further use of the insert.

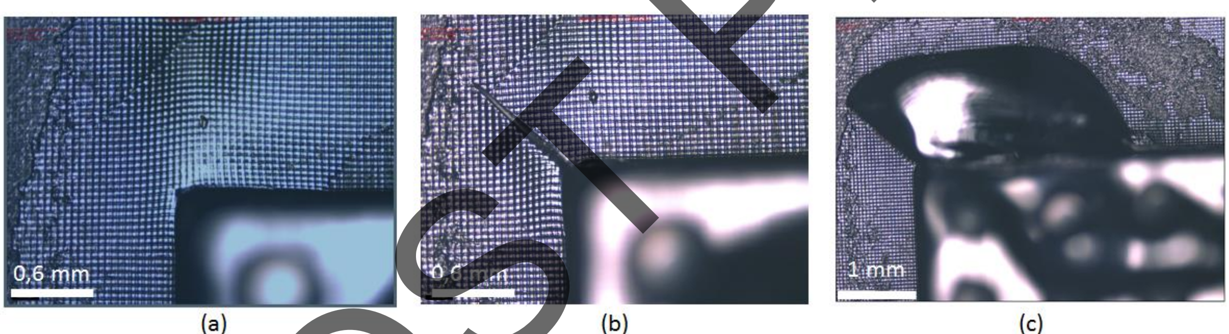

FIGURE 3 Crack propagation and final damage (a) new insert (b) after 30 shots (c) after 38 shots.

Figure 4 presents the surface roughness results obtained at the bottom of hearts on the inserts (Figure 2) prior to the IM experiments and the five initial injection moulded parts on the top of the hearts. The results reveals slight difference surface roughness at the left and right hearts in both 3D printed inserts and IM parts. The variation in terms of inserts might be due to the non-uniform quality of the 3D printer vat that replicate the insert with the same un-even quality. Concerning the IM parts, the final quality was affected by the surface of the insert and the IM parameters as well. The best surface was achieved with the first batch of the IM parts that shows the lowest surface roughness of the insert and the combination of the IM parameters. Figure 5 shows the height variation of the inserts and the IM parts. The height differences reveals a comparable variation between the inserts and the parts. There is a decreasing tendency in the IM parts with the same inserts, which is due to the shrinkage in the IM process, affected by material and IM parameters.

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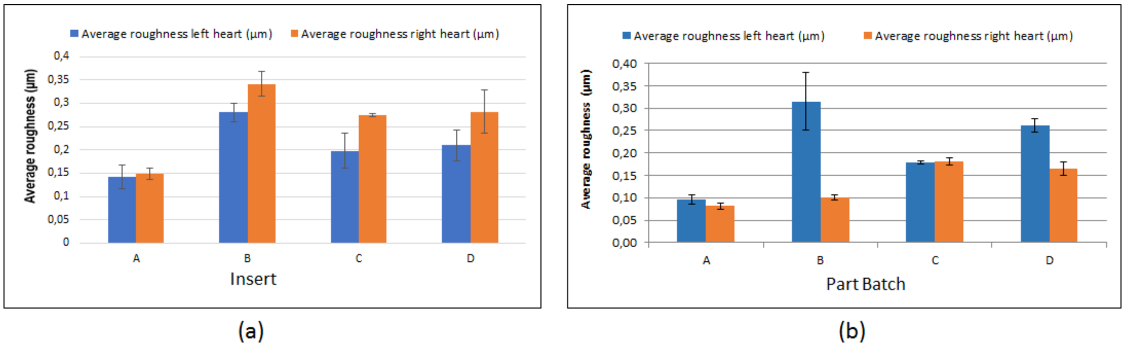

FIGURE 4 Areal surface roughness in the hearts (a) 3D printed inserts (b) IM parts

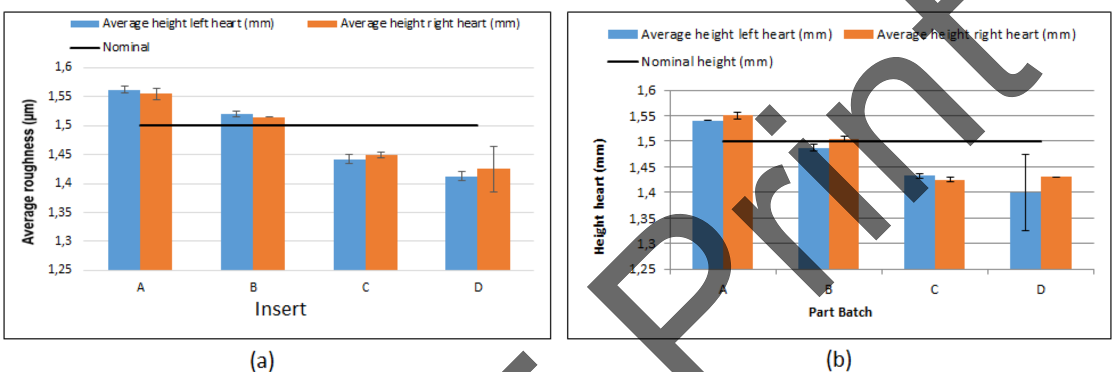

FIGURE 5 the height variation of the hearts (a) 3D printed inserts (b) IM parts

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CONCLUSION

This study investigated the capability of the soft tooling insert produced by AM method for injection moulding components. The inserts were manufactured with vat photopolymerization method. The defect was appeared as a crack on the inserts and then the crack propagated to break the insert. The surface roughness was slightly difference on each side of the inserts and IM parts. The variation of the parts affected by IM parameters as well. In terms of height, similar trend was observed with a little variation due to the shrinkage and IM parameters.

ACKNOWLEDGMENTS

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