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Dimensional accuracy of Acrylonitrile Butadiene Styrene injection molded parts produced in a pilot production with an additively manufactured insert

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Abstract. Injection molding inserts manufactured additively by vat photopolymerization have become a serious option for significantly faster and more economical prototyping and pilot production due to technological progress and advancements in photopolymer materials in the recent years. 10 000 parts of a geometry including micro-features have been injection-molded in Acrylonitrile Butadiene Styrene (ABS) with a single 20x20x2.5 mm^3 injection molding insert manufactured in a photopolymer composite material. This research investigates the dimensional accuracy of the injection molded parts as a function of inserts wearing and deformation with increasing shot number.

Keywords: Additive manufacturing; Micro injection molding; Soft tooling
PACS: 06.20.-f Metrology

INTRODUCTION

In recent years, additive manufacturing soft tooling has become a considerable option for the manufacturing of injection molding inserts in prototyping and pilot production, as demonstrated in numerous publications, e.g., [1] and [2]. Its key advantages include low costs and fast manufacturing. Also, the process chain via injection molding enables a larger selection of polymer materials for the final part, thereby fulfilling a broader range of material requirements. Compared to conventional tooling, usually a low number of parts in the one to three-digit range can be produced with one insert. [3]

With technological progress, also longer tool lifetimes have become reality, as reported by [4], using a fiber-reinforced insert manufactured with vat photopolymerisaton for the production of more than 2 500 parts in polyethylene low-density. [5] presented the production of 2 800 parts injection molded in acrylonitrile butadiene styrene (ABS) as part of a long-term experiment. This research presents the continuation of that experiment.

MATERIALS AND METHODS

Insert Geometry

The test geometry consists of a plate containing two cuboid structures with 800 µm pillars attached as well as two heart-shaped elements. The consequent insert design is presented in Figure 1. A draft angle of 2° was added to the vertical walls to facilitate ejection of the injection molded parts.

Tooling

A stereolithography printer (3D Systems, SLA 3500, Solid State Nd:YVO_4 laser, 354.7 nm wavelength) was used to manufacture the injection molding insert in a ceramic composite photopolymer (SOMOS® Perform). A heat treatment was performed after the printing to increase the photopolymer's heat deflection temperature (268°C HDT @ 0.46 MPa, ASTM Method D648).

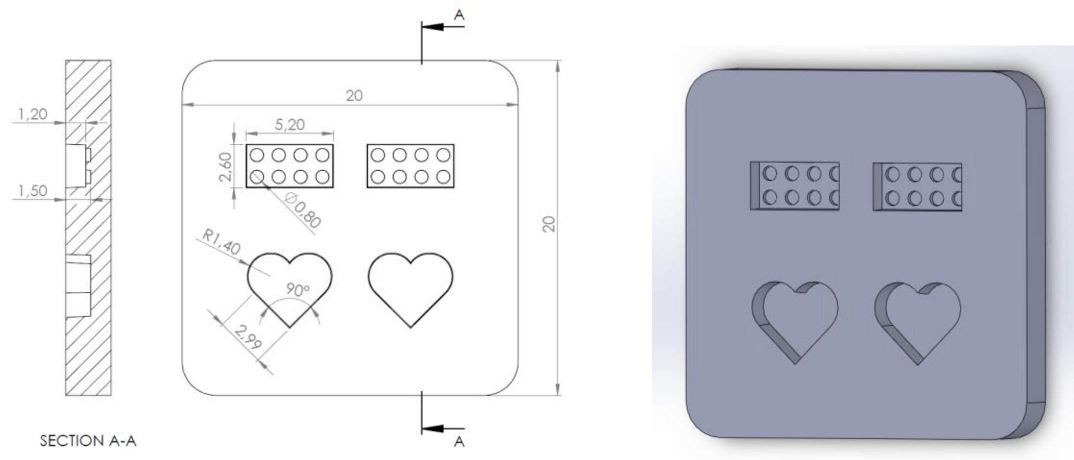

FIGURE 1. Sketch (a, left) of the insert geometry (20 x 20 x 2.5 mm^3) comprising two cuboid structures with pillars (diameter 800 µm, height 0.3 mm) and two heart-shaped elements as well the corresponding 3D-model (b, right).

Injection Molding

The injection molding was performed with a packing pressure of 950 bar using an Engel® e-motion 170/110 injection molding machine. The cycle time was 21 seconds with a cooling time of 10 seconds, the injection speed 15 mm/s, and the melt temperature 235°C.

Metrological Assessment

For the metrological assessment, a laser-scanning microscope (OLS4100 Lext from Olympus) was used to take images of selected samples of the injection molded parts. SPIP™ from Image Metrology was used to perform the dimensional analysis of the images.

RESULTS

Lifetime

More than 10 000 parts were injection molded successfully with one insert after which the experiment was stopped. This is significantly longer than other sources report [1-5]. A possible explanation for the long lifetime of the insert is the mold design. Only the part of the cavity on the injection side is manufactured in the photopolymer material. The cavity part on the ejector side is made of steel. Given the photopolymer's very low heat conductivity (0.178 – 0.187 W/mK, [6]) compared to steel, most of the heat is transported through the metal parts of the cavity, reducing the thermal energy load for the insert and, consequently, its thermal ageing.

Dimensional Accuracy

Pillar Diameter

Figure 2 shows the development of the pillar diameter. The diameters are deviating significantly from the nominal diameter (500-600 µm vs. 800 µm). This is a result of the printing process, which does not produce sharp edges (Figure 3).

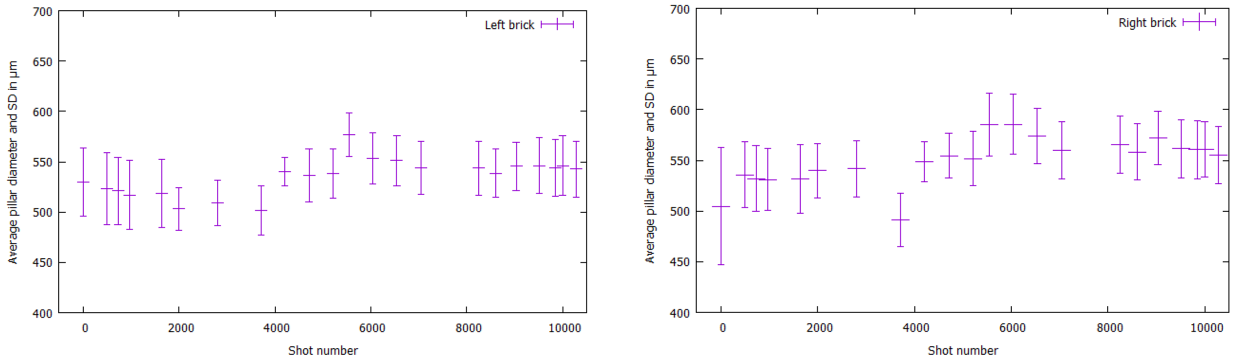

FIGURE 2. Average pillar diameter (left brick, right brick, in µm) and standard deviation over 10 000 shots.

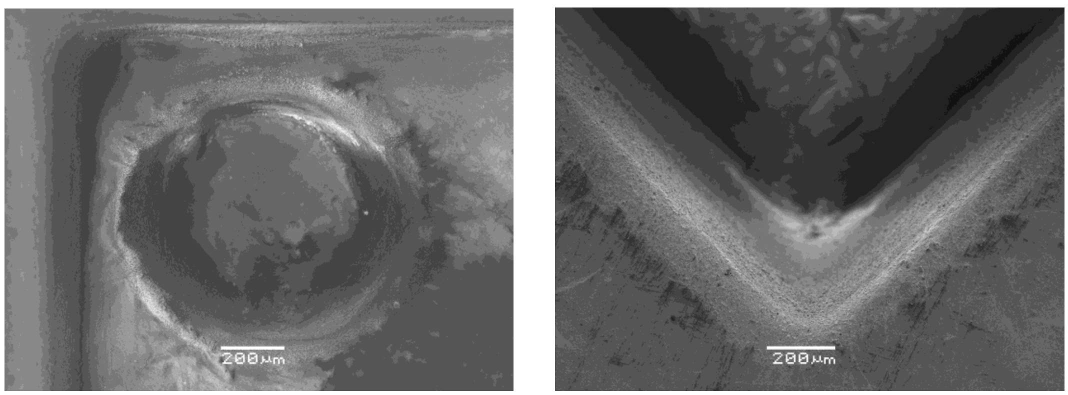

FIGURE 3. SEM images of the insert. Left: Top left pillar in the left cuboid. Right: Bottom of the bottom left heart.

Heart Corners

Figure 4 shows the angle of the 90° corners of the hearts. For the left heart, all values are between 88° and 92°, apart from three measurements between 500 and 1 000 shots at the left heart. For the right heart, all values are in the range 90±2°.

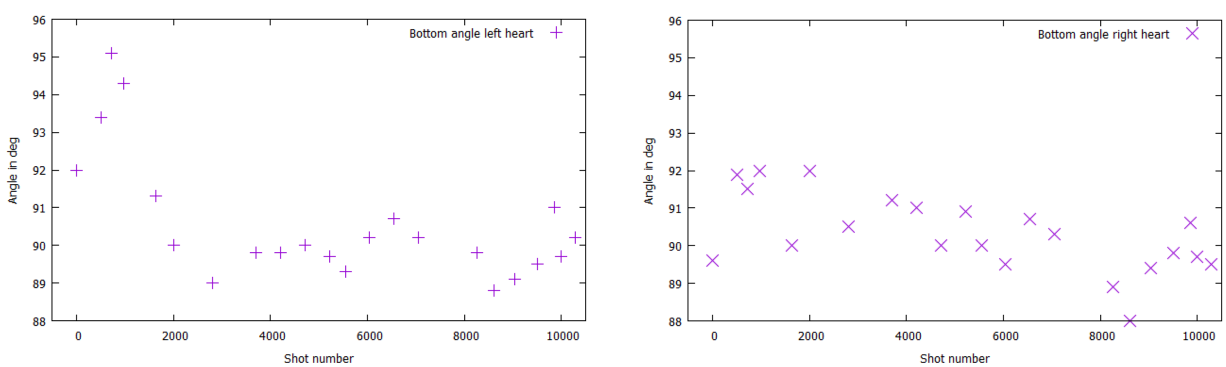

FIGURE 4. Angles at the bottom of the hearts (nominal value 90°) over 10 000 shots.

Depth of Cuboid Elements

The depth of the cuboids with and without the pillars (Section A-A in Figure 1, nominal values $h_1 = 1.2$ mm and $h_2 = 1.5$ mm, respectively) were constant within a range of ±20 µm throughout the experiment (Figure 5).

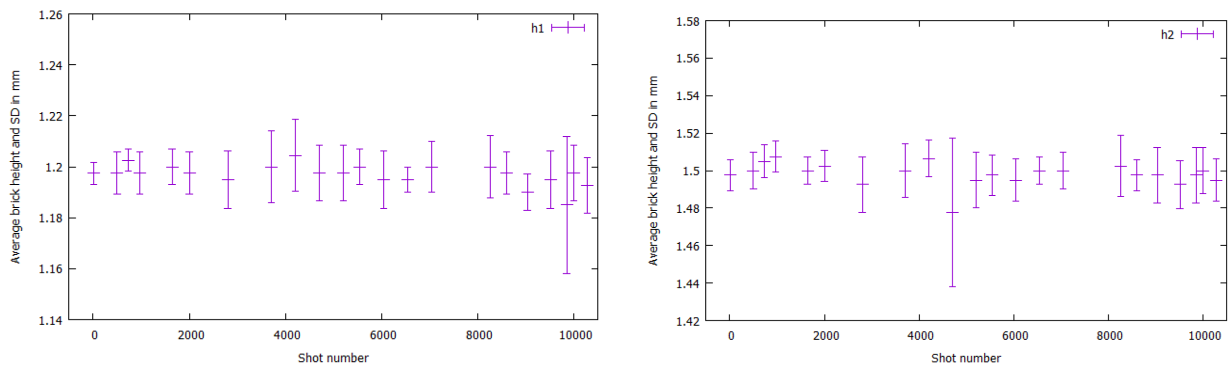

FIGURE 5. Average depth of cuboids and standard deviation over 10 000 shots (left: without pillars, right: with pillars).

CONCLUSIONS

With more than 10 000 parts being produced with a single insert, it has been shown that soft tooling based on vat photopolymerization can be used to injection mold five-digit part numbers, given appropriate conditions.

Concerning the dimensional accuracy, the measured diameters of the cylindrical elements attached to the cuboids were significantly smaller than the nominal values. An explanation for this phenomenon is the undesired curing of photopolymer material remaining in corners and edges after the printing process.

The measurements of the 90° corners at the bottoms of the hearts were within 90±2°, apart from three measurements between at the left heart 500 and 1 000 shots.

The depth of the cuboids remained constant within ±20 µm, showing the negligible insert wear during this long-term experiment.

Suggestions for Future Research

It is suggested to investigate the thermal aging process of the photopolymer material to determine the factors leading to the reported differences in insert lifetime. Further, the modification of the liquid photopolymer before printing (adding particles or fibers) or the printed part (coating) seems a promising direction for future investigations. Finally, thermal simulations have been found to be a useful and accurate tool for additive manufacturing soft tooling [5]. Consequently, the reader is encouraged to engage in in-depth simulations with both multiphysics as well as injection molding simulation software.

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REFERENCES

1. A.D. Lantada et al., "Toward mass production of microtextured microdevices: linking rapid prototyping with microinjection molding", *Int. J. Adv. Manufact. Technol.* **76**(5–8), 1011–1020 (2015).
2. J. Rajaguru et al., "Development of rapid tooling by rapid prototyping technology and electroless nickel plating for low-volume production of plastic parts", *Int. J. Adv. Manufact. Technol.* **78**(1–4), 31–40 (2015).
3. I. Gibson et al., "Additive Manufacturing Technologies", Springer, DOI 10.1007/978-1-4939-2113-3.
4. T. Hofstätter et al., "Evolution of surface texture and cracks during injection molding of fiber-reinforced, additively-manufactured, injection molding inserts", *Proceedings of ASPE Summer Topical Meeting 2016: Dimensional Accuracy and Surface Finish in Additive Manufacturing.*
5. M. Mischkot et al., "Performance Simulation and Verification of Vat Photopolymerization Based, Additively Manufactured Injection Molding Inserts with Micro-Features", *Industrializing Additive Manufacturing – Proceedings of Additive Manufacturing in Products and Applications – AMPA2017*, DOI 10.1007/978-3-319-66866-6_16.
6. J. G. Kovacs et al., „Evaluation of measured and calculated thermal parameters of a photopolymer", *International Communications in Heat and Mass Transfer* **38**(2011) 863-867.