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Rapid tooling for micro injection molding of micro medical devices via digital light processing

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Abstract: High-resolution additive manufacturing methods such as digital light processing (DLP) offer promising opportunities for rapid tooling for micro injection molding (µIM). There are possible savings in time and costs for µIM of small and micro plastic parts for sensors, electronics and (bio)medical products. Here we present the rapid tooling of polymeric molds via DLP 3D printing for the µIM of convex chips (Ø3.5 x 1.16 mm) of polypropylene (PP) as exemplarily chosen geometry and medical relevant material. Five molds (one mold has a total size of 8 x 22 x 10 mm, height x length x width, made of 2 pieces) were 3D printed simultaneously in t ~ 30 min (plus t = 10 min post-curing) with a layer height of z = 50 µm and a photopolymer consumption of m ~ 2 g per mold. The micro-injection-molded PP chips show a significant staircase-effect as a result of 3D printing of the molds. Nevertheless, the molds perform well (no cracks, adequate demolding) when used for a relatively low number of µIM cycles (n ~ 20, T_{mold} = 30 °C, T_{PP} = 205 °C).

I. Introduction

High-resolution, photopolymerizing additive manufacturing methods such as stereolithography (SLA) and digital light processing (DLP) offer promising opportunities for rapid tooling for micro injection molding (µIM) [1]. There are possible savings in time and costs for µIM of especially small series of micro plastic parts for sensors, electronics and (bio)medical products. Moreover, the advantages of both technologies are combined, which are the accuracy of DLP 3D printing and the wide material range of µIM.

Precise medical imaging methods such as cone beam computed tomography (CBCT) enable the generation of high-resolution standard triangle language (STL) files for 3D printing. As a result, there are accurate digital models of micro-sized implants, for example, for round window niche as well as frontal ostium (for frontal sinus drainage), which enable modern methods for the therapy of inner ear disorders [2] or chronic rhinosinusitis (CRS) [3] to be used. Here we investigate rapid tooling for µIM of convex chips (Ø3.5 x 1.16 mm) of the medical relevant thermoplastic material polypropylene (PP).

II. Material and methods

Five molds (8 x 22 x 10 mm, height x length x width, 2 pieces, Fig. 1 B) for µIM of convex chips (Ø3.5 x 1.16 mm, Fig. 1 A) are 3D printed simultaneously using VIDA DLP device (EnvisionTEC GmbH, Gladberg, Germany). The VIDA device features a printing platform of 140 x 79 mm and a high-resolution projector (1920 x 1080 pixel). An EnvisionTEC UV light curing box is used for t = 10 min of post-curing. For materials, the acrylate-based photopolymer EnvisionTEC E-Model light is used. It has a relatively low heat deflection temperature (HDT) of 60.5 °C (at 1.82 MPa), though, it is affordable (~220 €/kg) and features a layer height of z = 50 µm for adequate, high-detailed modelling. For µIM investigations the 3D printed mold is installed in µIM device "formicaPlast" [4] using a tight-fitting metal mold holder. As a µIM material the thermoplast PP H357 09RSB (Braskem Europe GmbH, Frankfurt a. M., Germany) is used. The following µIM parameters are applied:

- Mold temperature T_{mold} = 30 °C
- Temperature of material PP T_{PP} = 205 °C
- Pressure after injection of p = 400 bar for t = 4 s
- Injection volume flow rate of Q = 35 mm³/s

3D printed mold is used for multiple cycles of µIM (up to n = 50). Shape accuracy of chips manufactured using a DLP 3D printed mold and chips manufactured using a milled steel mold are compared. Furthermore, the condition of mold and quality of PP chips over the number of µIM cycles is investigated. Investigations are done via macro lens photography (Alpha 5100 with Minolta MC 50/3.5 Macro Rokkor, Sony Europe B.V., Berlin, Germany). The mold and the PP chips are checked for signs of wear or quality loss as e. g. cracks, deformation or discolouration.

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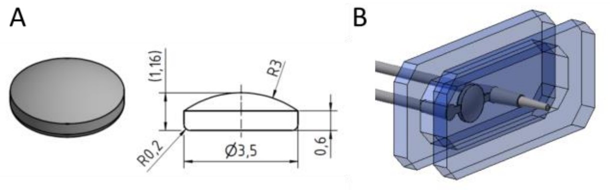

Figure 1: (A) digital model of the convex chip (B) µIM scheme: chip with sprue and runner (grey) inside the mold (blue, 2 parts)

III. Results and discussion

Five two-pieced molds were DLP 3D printed simultaneously in a time of t ~ 30 min using a layer height of z = 50 µm. Fig. 2 shows one DLP printed mold (yellow) in comparison with one milled steel mold. There are an additional two minutes for cleaning after 3D printing and t = 10 min for post-curing in the curing box. There was a photopolymer consumption of m ~ 2 g per mold. Because of the exposure principle of DLP and the size of the VIDA printing platform, there could be a maximum of 21 molds to be printed simultaneously with no increase of 3D printing time.

Figure 2:Milled steel mold (left) and DLP printed mold (right)

The 3D printed molds were successfully used for µIM of convex chips. Fig. 3 shows a comparison between chips from a 3D printed polymer mold and chips from a milled steel mold. The chip from the 3D printed mold shows significant staircase-effect due to the layer height of z = 50 µm used for 3D printing of the mold. As a result, round shapes and very fine details (R0.2, bottom) are affected. The chip from the milled mold has a much more accurate convex shaped surface. Staircasing is a typical effect when using 3D printing methods. Nevertheless, commercially available DLP devices and photopolymer materials enable lower z-heights of, e.g. z ~ 25 µm and even lower. Another option is to finish the surface via e.g. sandblasting. The 3D printed molds have been successfully used for multiple µIM cycles. They perform well when used for a relatively low number of µIM cycles (n ~ 20). There is significant wear of mold, when used for more µIM cycles (Fig. 4 A, B). Most likely, thermal stress is the reason. Because of the tight-fitting metal mold holder there can't be significant mechanical stress and there was no residual material left in the molds. As a result, there is a significant loss of shape-accuracy of PP chips (Fig. 4 C-F).

IV. Conclusions

In conclusion, we demonstrate rapid tooling based µIM process promising for time and cost-saving injection molding of small and micro-sized medical devices and implants. Prospectively, we can combine high-accurate 3D printing with a wide range of medical relevant and biocompatible materials, enable µIM manufacturing of patient-individualised (micro)implants, e.g. for round window niche as well as for frontal sinus drainage. The accuracy of our process is expected to be suitable for such implants. Further investigations will focus on the µIM processing of drug-loaded materials.

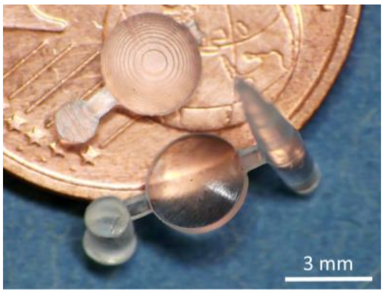

Figure 3: Top: Chip from µIM using DLP 3D printed mold. Surface shows staircase-effect. Bottom: Chip from µIM using milled steel mold. No staircase-effect, smoother surface.

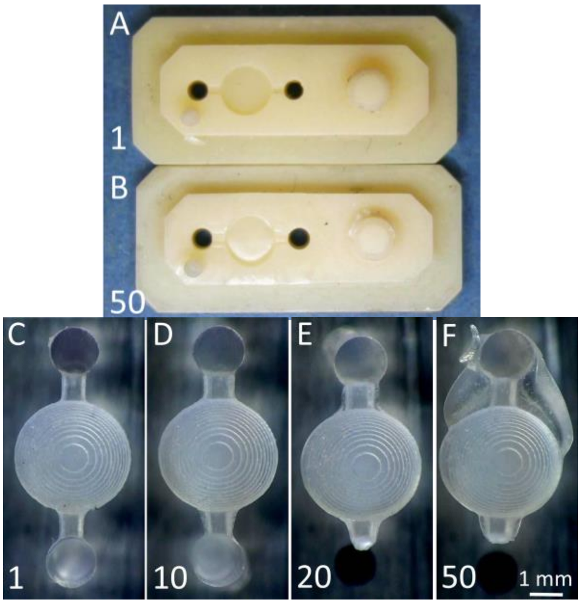

Figure 4: (A) DLP 3D printed mold after 1 µIM cycle and (B) after 50 µIM cycles with bulging of surface. (C)-(F) Series of µIM chips over n of µIM cycles. Significant errors in material injection and chip deforming show up when n ≥ 20.

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AUTHOR'S STATEMENT

Authors state no conflict of interest. Informed consent has been obtained from all individuals included in this study.

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