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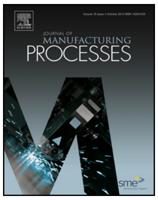

Technical Paper

A Soft Tooling process chain employing Additive Manufacturing for injection molding of a 3D component with micro pillars

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ABSTRACT

The purpose of the research presented in this paper is to investigate the capability of a soft tooling process chain employing Additive Manufacturing (AM) for preproduction of an insert with micro features by injection molding. The Soft Tooling insert was manufactured in a high temperature photopolymer by Digital Light Processing (vat photopolymerization). The mold cavity was formed by two insert halves, by design; both inserts have four angled tines, with micro holes (Ø200 μm, 200 μm deep) on the surface. Injection molding with polyethylene was used with the soft tool inserts to manufacture the final production components. The diameter and height of the pillars that were replicated on the molded components were characterized by means of a 3D profilometer. The influence of the injection molding parameters on the replication was evaluated using a 2-levels DOE of three factors. The uniformity of the pillars are also evaluated regarding the diameter and height.

1. Introduction

Functionalities realized by micro-structured surfaces are applied in many areas, for example in the field of cell biology [1,2], optical elements [3], etc. The micro structured surface considered in this work is of special interest due to the fact that it can promote cell proliferation and enhance the bonding between the proliferated tissues and the molded surface, provided the micro-features are arranged according to a certain pattern [4,5].

Replication of micro features onto polymer can be achieved by different molding process precisely [6]. One of the latest research is from Metwally et al., who reported their work on replication of micro and sub-micro features on flat surface and high fidelity between the molded parts and the mold was obtained [7]. Most of the research focus on flat surface or surface with single curvature. For instance, S. Bruening et al. implemented a cylinder processing system [8]. Nian et al. showed in [9] that micro features could be replicated by hot embossing on a curved surface. However, the process chain for producing complex parts with microstructures on surface is rarely reported, although most of the real-life devices that demand that the micro structuring on the surface has a three-dimensional (3D) geometry. The challenges lie in the fabrication of a 3D mold cavity with micro features on the surface, and in the replication process from the mold. For instance, demolding may fail for features with high aspect ratio on a complex surface, e.g. non-perpendicular to the demolding direction. Bissacco et. al have reported their work of replication of nano pattern on a 3D mold insert by injection molding. The results shows that the specific nano pattern was successfully generated on polymer parts using the 3D mold inserts [10]. In the author's previous work, It was demonstrated that when the aspect ratio is 0.5, it was possible to obtain Ø4 μm PEEK pillars on a wall parallel to demolding direction by injection molding [11]. In this paper, the investigated product is a ring with four tines, each characterized by having an angle of 60°. This geometry has been studied in [12], where micro features were introduced by implementing pre-fabricated nickel plates, and micro pillars (Ø4 μm) with aspect ratio of 0.5 was obtained by silicone rubber injection molding on the tines.

This paper focuses on the replication of microstructures on complex surface created by a soft tooling process chain. This method replaces the steel mold cavities in the injection molding machine with a set of inserts made by vat photopolymerization based AM. Compared to metal AM, the photopolymer based AM technologies can achieve higher precision. In the case of Image mask projection systems, the resolution can be as high as 6 μm [13]. Among technologies that are able to create microstructures on the surface of a 3D cavity, additive manufacturing has the advantage in computer-aided design for surface topography. Moreover, the machining time

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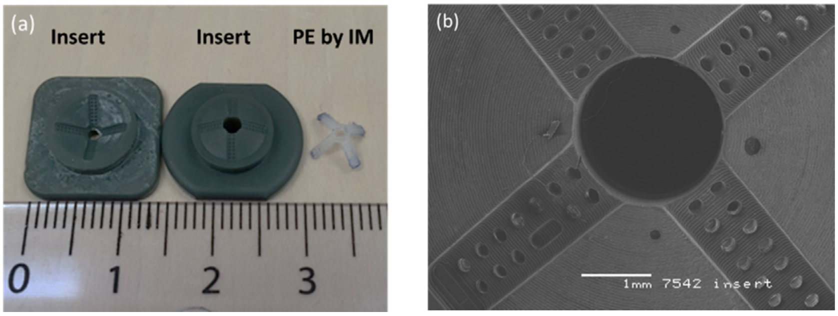

Fig. 1. (a) Inserts produced by additive manufacturing process and one polyethylene (PE) replica produced by injection molding using the two inserts which forms the mold cavity. (b) The surface of the insert: individual layers from the AM process are visible. Ø200 µm holes were printed on the four tines.

and cost is reduced significantly compared to conventional tooling processes based on CNC machining. Processes involving AM is suitable for products requiring a high flexibility in design freedom. Lantada et al. has described a process chain that starts from AM prototypes in order to obtain designed surface texture, and then coating techniques was employed for obtaining metallic mold inserts for injection molding [14]. Polymer parts produced by AM has been proved directly applicable as mold inserts. For example as reported in [15] and [16]. Inserts manufactured from carbon fiber reinforced photopolymer has withstood up to 2500 injection molding cycles for polyethylene before noticeable mold deterioration was observed [17]. This soft tooling process chain is suitable for production in intermediate production volumes (e.g. from 1000 to 10.000 cycles by injection molding).

2. Experiments

2.1. Inserts fabrication by additive manufacturing (AM)

Two inserts are required to form the cavity. An EnvitionTEC perfactory® 3 MML with an enhanced resolution module (ERM) was used in order to produce the parts. The Perfactory 3 MML is with a f–85 mm lens capable of delivering a voxel-size of down to 16 µm [18]. The photopolymer used was a proprietary methyl methacrylate and acrylamide monomer/oligomer blend, photo initiated by a titanium dioxide based photoinitiator. The resin has a tensile strength of 56 MPa, elongation at break of 3.5%, a flexural strength of 115 MPa, flexural Modulus of 3350 MPa and a heat deflection temperature of 140 °C [19].

Fig. 1(a) shows the inserts fabricated by AM and the PE parts produced by injection molding. Two rows of circular holes were vertical to the surface on the tines (Fig. 1(b)). The nominal dimensions has been chosen so that when the holes are resolved into the 16 µm voxel-size of the AM machine tool, it will yield a roundness of 0.8 which correlates to nominal geometry that is 200 µm in diameter and 200 µm in depth. These features were spaced with a center- to-center distance 400 µm. A mark was designed on both the inserts, which is an elongated hole on both sides, so that the same tine can be tracked for investigation. The layers structure that was formed in the AM process are clearly visible.

2.2. Injection molding (IM)

Injection molding tests were operated by an Arburg (370 A 600–70) equipped with a micro unit. The screw diameter was 8 mm and the clamping force was 100 kn. Polyethylene (PE Purell 1840) was chosen as the material for injection molding mainly due to its low processing temperature. Fig. 2 illustrates how the inserts was mounted on the mold. Fig. 3 illustrates the demolding step. The pillars were not parallel to the demolding direction, they may risk breaking during demolding.

Table 1
The tested injection molding parameters in the design of experiments (DOE).

#	Injection molding parameters		
	Control Factors	Low	High
1	Mold temperature [°C]	30	60
2	Melt temperature [°C]	175	185
3	Injection speed [mm/s]	38	65

A two-level full factorial design of experiments (DOE) with 3factors were operated in order to evaluate the influence from the injection molding (IM) parameters on the replication. The tested IM parameters are listed in Table 1. For all the $2^3 = 8$ runs, the injection molding was operated until one insert cracked or otherwise stopped at 100 cycles. For each run, a new pair of inserts were used. Most of the runs reached more than 80 cycles. After a limited amount of runs, the injection side insert cracked due to the very thin area in the center. The replication degree was calculated by dividing the dimensions from the pillars by the dimensions of hole on the corresponding insert.

2.3. Dimension measurements

The micro features on the inserts and the IM parts were measured using an Olympus Lext OLS 4100 laser scanning digital microscope with assistance of the SPIP® software for post-processing of data. The detailed method was described in [12]. The obtained PE parts were grouped into batches of 10 pieces in each run, i.e. 1–10 was the 1st batch, 11–20 was the 2nd batch, until the last piece in the run. One random sample in each batch was measured on the top and back sides; two areas with different distance to the gate "near the gate" and "far from the gate" on both sides of the tine were measured for comparison. Fig. 4 illustrates the measured sides (on the inserts) and the areas. Four holes/pillars on each area were measured. The average dimensions of the four hole/pillars were used to characterize the measured area. Both the depth/height and the diameter of the features were analyzed. The measurement repeatability for the pillars using this instrument is 8.1 µm for the diameter measurements and 1.6 µm for the height measurements.

3. Analysis

3.1. Replication propagation over 100 shots

The demolding was successful, in the sense that no pillar breaking was observed in all the studied samples. Most of the runs reached more than 80 cycles.