Geometrical shape assessment of additively manufactured features by Continuous Liquid Interface Production, vat photopolymerization method


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Abstract

Additive Manufacturing (AM) is a notable procedure for direct production of miniaturized polymer components, mainly due to the ability of the process to produce complex geometries with time and cost effective iteration cycles in the development of new plastic products. This study evaluate the capability of the vat photopolymerization in terms of geometry, when printing features of different sizes and shape. Continuous Liquid Interface Production (CLIP) technology was used for printing the features which is a new method to produce monolithic polymer parts at high speed. For this purpose, two test artifact specimens designed with micro features of different geometries and printed in different batches and evaluated the variability of the results in a single and in various prints.

Keywords: Additive Manufacturing; Vat Photopolymerization; Micro Manufacturing; Polymer;

1. Introduction

Additive Manufacturing technologies are growing in different industries with capabilities of manufacturing final component in a less time in comparison to traditional manufacturing methods. In order to achieve the best precision when printing micro features in a final product, it is important to know and understand the performance and capability of the AM machine [1][2]. In this work, the performance of a VP AM machine is studied. For this purpose, two test artifact specimens designed with micro features of different geometries and printed in the dead zone above the window has been printed, it is necessary to clean the liquid resin that has been left on it, using isopropyl alcohol (IPA). Once the sample is clean, it is left dry afterwards thermally cured for 4 hours at 120 °C in a dedicated convection oven. Rigid polyurethane (RPU) 70 is a two-component resin containing a part A, with the photopolymer and photo initiator activated during printing and a part B, which contains a thermoset-polymer that polymerize during subsequent thermal curing. During printing, the exposure time is adjusted based on the cross-sectional area of the specific slice.

Table 1. Experimental Conditions

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Fine</th>
<th>Super Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer thickness/µm</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Light intensity mW/cm²²</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Resin</td>
<td>Rigid polyurethane (RPU) 70</td>
<td></td>
</tr>
</tbody>
</table>

2. Method and Materials

2.1. Continuous Liquid Interface Production (CLIP) Technology

Vat photopolymerization process, the liquid photopolymer resin is placed in a vat, where an Ultraviolet (UV) light is radiated, curing the liquid resin, layer by layer. CLIP relies on the inhibition of free radical photopolymerization in the presence of atmospheric oxygen. The dead zone created above the window maintains a liquid interface below the advancing part. Consequently, an oxygen-permeable build window results in the formation of a dead zone, or a region of uncured liquid resin which cause continuous fabrication of features. The continuity of the reduction of the dead zone effect without affecting build time and results in a printed part [3]. In this experiments two different setting were chosen in order to evaluate the print geometries. The selected parameters for this work are listed in Table 1. After the sample has been printed, it is necessary to clean the liquid resin that has been left on it, using isopropyl alcohol (IPA). Once the sample is clean, it is left dry afterwards thermally cured for 4 hours at 120 °C in a dedicated convection oven. Rigid polyurethane (RPU) 70 is a two-component resin containing a part A, with the photopolymer and photo initiator activated during printing and a part B, which contains a thermoset-polymer that polymerize during subsequent thermal curing. During printing, the exposure time is adjusted based on the cross-sectional area of the specific slice.

2.2. Test Parts

Different test parts that have been designed with the shape of Box and cylinder considering two geometries: circular and square, as shown in Figure 2. The features have a total height of 500 µm. The first feature start with 1.5 mm diameter/width and a decreasing aspect ratio applied. The base of the part is 10×10×2.5 mm³.

2.3. Measurement Procedure
The Alicona Infinite Focus 3D Microscope has been used to performed the measurements. The magnification lens of 10x for the smaller geometries 840 µm third row and of 5x for the bigger geometry 1.5 mm were chosen. The measurements have a vertical and lateral resolution of 200 nm and 3 µm for 5x and 410 nm and 7 µm for 10x, respectively. The software SPIP was used for analyzing the obtained data.

The roundness was evaluated for the cylindrical geometry, from 0 to 1, being 1 a perfect circle [4]. The average value of the roundness, considering the 5 batches, has been represented in Figure 5 for the nominal diameters of 1.5 mm and 840 µm. The error bars represent the standard deviation of the roundness for each diameter, considering the 5 batches. As it can be observed, the roundness result improves when the size of the circles increases, similarly to the squareness. For the batches printed with super fine slicing, the cylinders are closer to have perfect circularity when the cross-sectional area is 1.5 mm compared to the batch printed with fine slicing thickness. Opposite is the roundness for the cylinders printed with fine slicing closer to the nominal when considering the smaller 840 µm cross-section.

3. Results

The printable feature geometry of the sample were evaluated in comparison to the CAD model. Figure 3 shows the image of the printed features. In terms of geometry, the squareness was evaluated for the square stepped pyramid as the deviation of the edges from the right angle. It has been observed less squareness for all the batches in the smaller features (840 µm). In Figure 4, the standard deviations of the square edges from the right angle have been represented in the error bars for the steps with nominal widths of 1.5 mm, 840 µm, considering the five batches. It must be noted that the average value of the 4 angles of each step is always 90°, for being a parallelogram. It is noticeable that the deviation in squareness is slightly smaller for the batch printed with fine slicing thickness (50 µm), compared to the batch with super fine slicing thickness (25 µm), when considering the boxes with the smaller 840 µm nominal width.

In this work, the performance of a proprietary CLIP AM machine has been characterized, using two test parts: a box and a cylinder. Five batches of each test part were printed. The features were evaluated in terms of geometry and with two different slicing options during printing. The obtained results for both test parts present the similar trend, being that the deviation from the nominal geometry increases with a smaller cross-sectional area for the selected feature-of-size. In both the squared and the cylindrical geometries slightly better results obtained with a cross-sectional area of 840 µm to the nominal printed with 50 µm slicing thickness compared to 25 µm. This indicates that the slicing thickness is not significantly affect printing within the selected geometry.

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