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Evaluation of polymer micro parts produced by additive manufacturing processes by using vat photopolymerization method

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Abstract

Micro manufacturing scale feature production by Additive Manufacturing (AM) processes for the direct production of miniaturized polymer components is analysed in this work. The study characterizes the additive manufacturing processes for polymer micro parts productions using the vat photopolymerization method. A specifically designed vat photopolymerization AM machine suitable for precision printing has been developed, built and validated. In order to evaluate the AM machine capability a test part is designed having features with different sizes and aspect ratios. The printing parameters selected for the evaluation are considered as exposure time, light intensity and layer thickness. In order to have an initial optimal range of parameters values, a sensitivity analysis carried out prior to the final experimental plan. The print quality was assessed in terms of separation between the rows and columns of printed cubes, the number of printed features with square cross section and the surface roughness. The results declare the importance of different factors in micro additive manufacturing processes.

Keywords: Additive manufacturing; micro manufacturing; polymer components, precision.

1. Introduction

Additive Manufacturing (AM) technologies are suitable techniques for the fabrication of structures with a high geometric complexity and heavily undercut features, which cannot be fabricated easily with traditional manufacturing methods [1]. In order to take advantage of these capabilities, all factors influencing quality in the process should be monitored and optimized as far as possible. Process chain optimization deals with an early consideration and comparison of workpiece specifications and properties of manufacturing processes and the overall process chain configuration [2]. The minimum feature size and obtainable tolerances of additive manufacturing (AM) processes are represented by the smallest printable element. However, the hardware characteristics and settings used in commercial systems are not always known; there are always variations in machine construction, material quality, digital workflow, and post processing procedures. Furthermore, all manufacturing systems are subject to external disturbances such as vibrations and fluctuations in temperature and humidity. Thus, the true precision and resolution of a given machine can't be determined without producing, measuring, and characterizing parts with features near the voxel limit of the system [3].

This study analyses the accuracy of the printable features with vat photopolymerization method on a test part that designed with different sizes and aspect ratios in order to evaluate the additively manufactured parts.

2. Method

2.1. Part design

The test part was designed to cover various requirements in terms of the shape and size of the features. The shape was considered as a cube with a specific distance 250 µm between each other and 3:4 aspect ratio for the lateral size and 1:2 for the height. Figure 1 shows the part design. The base of the part was 12x12x2 mm^3. The features raised the maximum height of the test part to 2 mm.

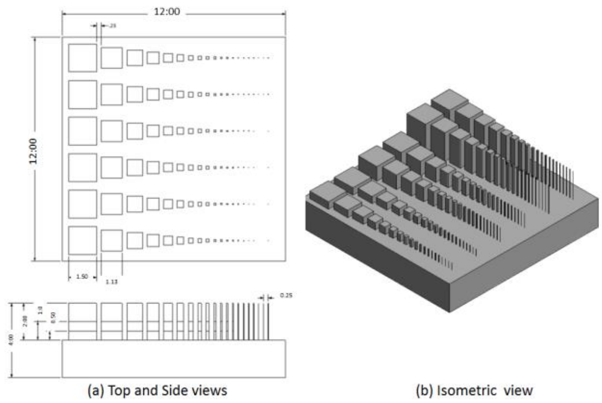


Figure 1. Drawing of the test part (a) Top& side views and (b) Isometric view (dimensions in mm)

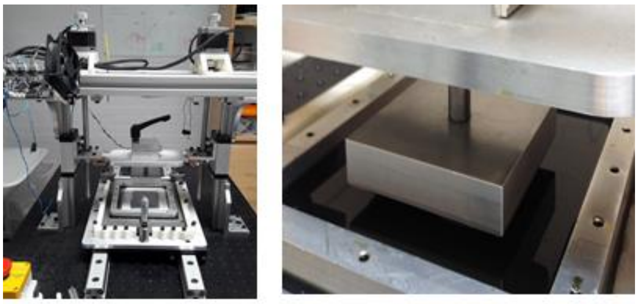
2.2. Printing and measurement procedure

Sample test parts were produced using a vat photopolymerization machine for precision printing with the level of accuracy down to 1 µm resolution in the z-stage that has been developed, built and validated at the Additive Manufacturing Laboratory at the Technical University of Denmark (DTU) (see Figure 2) [4]. A full factorial design of experiments (DOE) plan two levels with three different factors (2^3) were carried out. Two replicates were performed for each process parameter to investigate the consistency of the print. Eight parts were printed for the DOE and replicated twice for a total of sixteen manufactured parts.

Table 1 presents the experimental conditions. In order to select proper range of values for the different factors test runs, sensitivity analyses were carried out prior to the final experimental plan. Figure 3(a) shows the initial results of printing without proper printing parameters settings. The printing process for initial setup and post processing included some manual steps such as setting the built plate and reference points, adjusting the parameters, cleaning the printed part in an ultrasonic bath with isopropanol, drying the part, and finally a post-curing process with flashes of UV light.

The optical power and brightness produced by the projector were test by the manufacturer [5]. Each part was printed directly on the glass build plate. The parts were produced with industrial photopolymer that maintained its structural integrity while exposed to very low (-45°C) and high (225°C) temperatures. The post-processing procedure was carried out by cleaning the printed part from the liquid resin by isopropanol and placed in the ultrasonic bath. Then, in order to cure the photopolymer while not overheating the part in the UV-flashing chamber (causing cracks onto the surface or breakage of the ultra-small dimensioned surface features), pressurized air was blown onto the parts.

The test part features were measured using an Alicona Infinite Focus 3D microscope. The surface roughness evaluation was carried out using a 50X magnification lens and for geometrical measurements a 5X magnification lens was used.



(a) experimental set-up (b) Built plate

Figure 2. Experimental set-up 3D printing

Table 1 Experimental conditions

Parameters		Level 1	Level 2
Layer thickness	µm	21	24
Light intensity	-	16	18
Exposure time	s	2.3	2.6

3. Results

The features had a spacing distance of 250 µm (from the edge of each cube to the next one as shown in Figure 1). Therefore, by decreasing the feature size more blank space was left between the features with the smaller size. In order to evaluate the test part, the number of printed cubic features in the full height, the separation between features and the surface roughness quality of the print were determined. In terms of printed features by considering the relation between layer thicknesses, which was a significant factor for the number of all produced features, it was observed that the thinner layer leads to the higher amount of printed blocks. However, exposure time and light intensity indicate need to be increased for smaller square cross-section features. The separation between the features was depended mainly on the combination of two factors namely as exposure time and light intensity which in the lower values of these factors full height of the walls was separated between the cubes as shown in Figure 3(b) and (c). However, the leftover solidified polymer material observed mainly in the larger cubes where the space between features is very small. In terms of the surface roughness, the average of the five different cube was analysed as a response for each sample. Figure 4 shows the average value of the surface roughness for each printed sample. The best result obtained with lower layer thickness and higher light intensity and exposure time. The print quality is also affected by the transparent film between the resin and the light, which is directly in contact with the part. However, this effect was not considered in this study and to limit this factor in the printing process new film was used for the experimental plan.

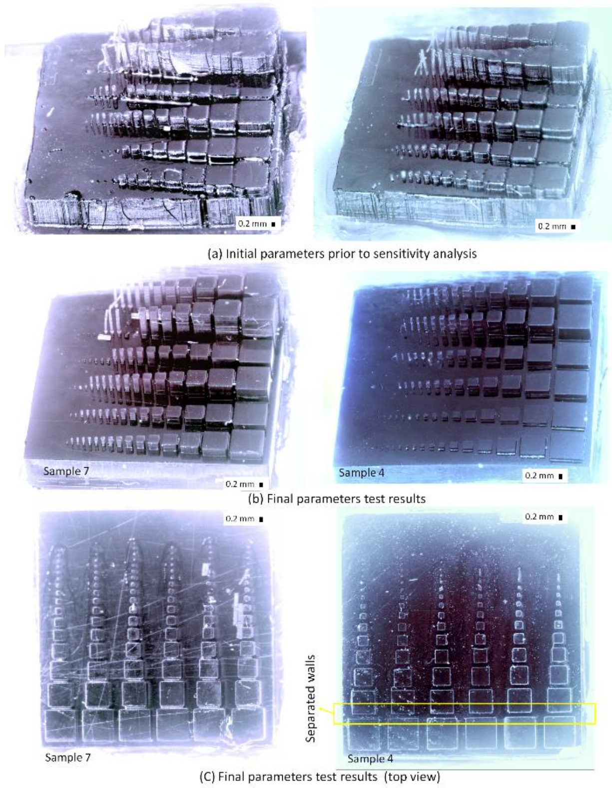


Figure 3. Test part sample prints (a) result with initial parameters (b) results after sensitivity analysis with final plan (c) top view

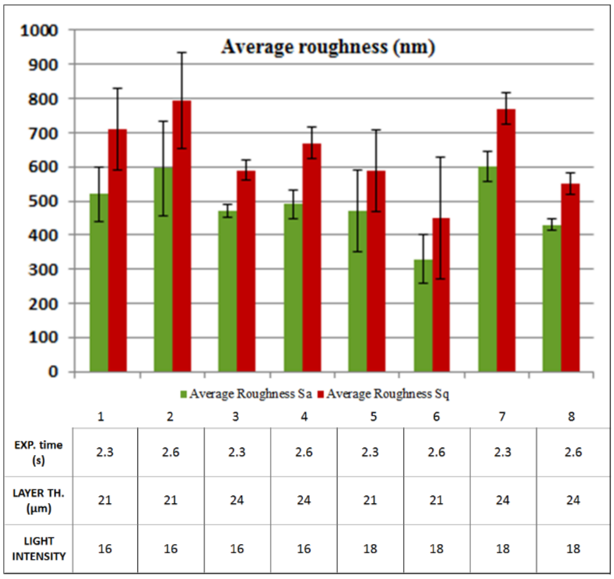


Figure 4. Average surface roughness S_a and S_q

4. Conclusion

This work presented the characterization of a vat photopolymerization AM machine for precision printing of a test part designed to evaluate 3D printing process capability at the micro scale. The number of printed cube features in the full height, separation between features and the surface roughness quality of the print were determined. The result reveals that print quality was affected by different factors. The smallest printed cube feature (about 100x100 μm^2) produced by the thinner layer 21µm thickness, which was also the important factor for the surface roughness quality. The wall thickness of the features was influenced by exposure time and light intensity.

References

[1] R. Liska *et al.*, "Photopolymers for rapid prototyping," *J. Coatings Technol. Res.*, vol. 4, no. 4, pp. 505–510, 2007.

[2] B. Denkena, H. Rudzio, and A. Brandes, "Methodology for dimensioning technological interfaces of manufacturing process chains," *CIRP Ann. - Manuf. Technol.*, vol. 55, no. 1, pp. 497–500, 2006.

[3] M. K. Thompson and M. Mischkot, "Design of Test Parts to Characterize Micro Additive Manufacturing Processes," *Procedia CIRP*, vol. 34, pp. 223–228, 2015.

[4] A. R. Jørgensen, "Design and development of an improved direct light processing (DLP) platform for precision additive manufacturing," Technical university of denmark (DTU), 2015.

[5] "visitech." [Online]. Available: https://visitech.no/products/luxbeam-rapid-system.