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Davoudinejad, Ali; Pedersen, David Bue; Tosello, Guido

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Characterization of additive manufacturing processes for polymer micro parts productions using direct light processing (DLP) method

A. Davoudinejad, D. B. Pedersen, G. Tosello

Department of Mechanical Engineering, Technical University of Denmark, Building 427A, Produktionstorvet, 2800 Kgs. Lyngby, Denmark

Abstract. The process capability of additive manufacturing (AM) for direct production of miniaturized polymer components with micro features is analyzed in this work. The consideration of the minimum printable feature size and obtainable tolerances of AM process is a critical step to establish a process chains for the production of parts with micro scale features. A specifically designed direct light processing (DLP) AM machine suitable for precision printing has been used. A test part is designed having features with different sizes and aspect ratios in order to evaluate the DLP AM machine capability to fabricate polymer micro scale features geometries. Four different factors are evaluated for the AM process analysis: printing layer thickness, exposure time, film thickness and geometry. The process optimization of the workpiece quality features is carried out to highlight potential and challenges of the micro AM process.

INTRODUCTION

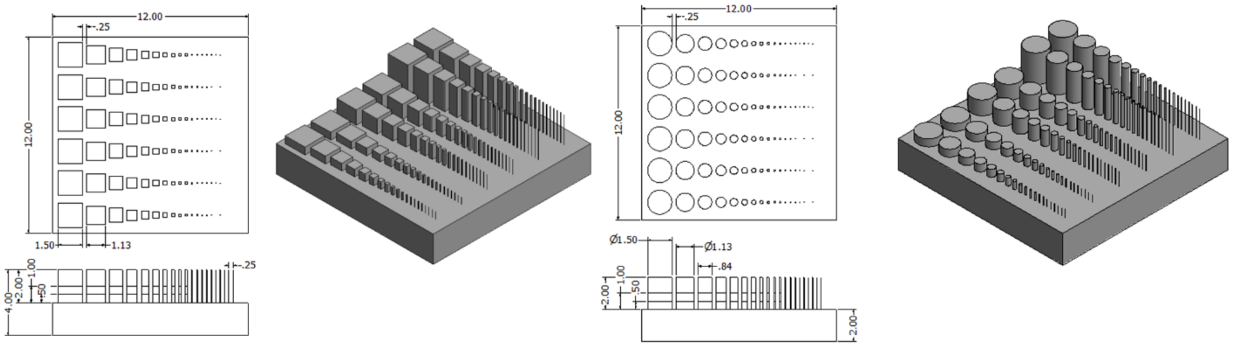
Direct AM of components is significant for different industrial applications to produce the end components having all the properties of marketable products. AM processes are thus characterized by a complex parameter optimization that must be done individually depending on the complexity or feature size of the parts [1]. In order to evaluate the performance of AM machines different test parts were used to investigate how accurate parts were printed with different complexity [2] in the macro scale. Another study investigated the resolution and repeatability of AM processes with voxel sizes at the micro scale to provide clear information about the resolution of the 3D printer that produced them [3].

This study evaluate the experimental printing parameters with two different test parts are designed having features with different sizes and aspect ratios. The results reveals the number of printed feature and the smallest printable size for parts and the height variation with this AM method.

METHOD

Part Design

The test part was designed in a way to cover various requirements in terms of the shape and size of the features. Two different shape was considered as a box and cylinder with a specific distance of 250 µm between each other and 3:4 aspect ratio for the lateral size and 1:2 for the height. Figure 1 shows the parts design in two different geometries. The base of the part was 12x12x2 mm2. The features raised the maximum height of the test part to 2 mm. The geometries were designed to observe the accuracy of micro print features in different shapes.



(a) Top and Side views (b) Isometric view (a) Top and Side views (b) Isometric view

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

Printing and Measurement Procedure

In vat photopolymerization method liquid photopolymer in a vat is selectively cured by light activated polymerization [4]. In this study, Direct Light Processing (DLP) was applied by using a light projector to solidify liquid photopolymer. By changing the light pattern and vertical position of the workpiece, the favorite geometry is build up layer by layer. The 3D printing 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 AM laboratory at the Technical University of Denmark (DTU) as shown in Figure 2 [5].

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

FIGURE 2. Experimental set-up 3D printing

In order to design the experimental plan, and decide on the significant factors to evaluate and values of the different levels some preliminary experiments were carried out to certain optimal values [6][7]. The printing parameters were selected as film thickness, layer thickness, exposure time and the sample geometries. A full factorial experiment 24 was applied to optimize an array of important printing parameters in order to improve the expected printing quality. Table 1 shows the experimental conditions, four different factors and two levels. The total number 16 samples were printed and printing time for each sample takes about45 minutes.

TABLE (1) Experimental conditions

Experiment number	**Layer Thickness**	**Film Thickness**	**Exposure Time**	**Geometry**
	µm	µm	s	
1	16	100	4	Square
2	18	100	4	Square
3	16	100	4.5	Square
4	18	100	4.5	Square
5	16	100	4	Circle
6	18	100	4	Circle
7	16	100	4.5	Circle
8	18	100	4.5	Circle
9	16	254	4	Square
10	18	254	4	Square
11	16	254	4.5	Square
12	18	254	4.5	Square
13	16	254	4	Circle
14	18	254	4	Circle
15	16	254	4.5	Circle
16	18	254	4.5	Circle

Printing included some manual steps such as setting the built plate and reference points, adjusting the parameters, afterwards post processing cleaning the printed sample with isopropanol in order to remove residual resin. The last step is to place the sample for curing in the UV oven, where it is exposed to UV light for 60 minutes.

Regarding the measurement different area on the samples were measured and investigated in order compare and measure the results in an effective way. Consequently, the height of pillars for both geometries, the width of the square in both *X* and *Y* directions and diameter of the cylinder were evaluated. For the measurements, the Olympus LEXT electronic microscope, and for analysis a scanning probe image-processing software was employed for the purpose (SPIP). For observing, the total printed intact pillars the Zeiss microscope was used for inspection of the samples.

RESULTS

The initial inspection in terms of the samples distortion reveals that the high aspect ratio printed features tended to collapse at 2 mm height. Figure 3 shows the printed samples with different geometries. The higher magnification of the parts in the red box area shows how height variation affect the sample with similar size. At 0.5 mm height, all printed features were in the correct shape (perpendicular to the base) however, they tend to be distorted at 1 mm height. Then more features were printed in the lower height (0.5 mm) about eleven features with the smallest size of 84 µm. However, at 2 mm height about 8-7 features were printed with the smallest size of 266 µm and 200 µm. Figure 4 presents the number of printed features in different geometries at various parameters at 0.5 mm height. The sloid fill graph are the square and the gradient fill are the cylinder. In terms of the geometry, it was reveals higher number of features were printed with cylindrical shape due to the limitation of the pixel at the corner of the square.

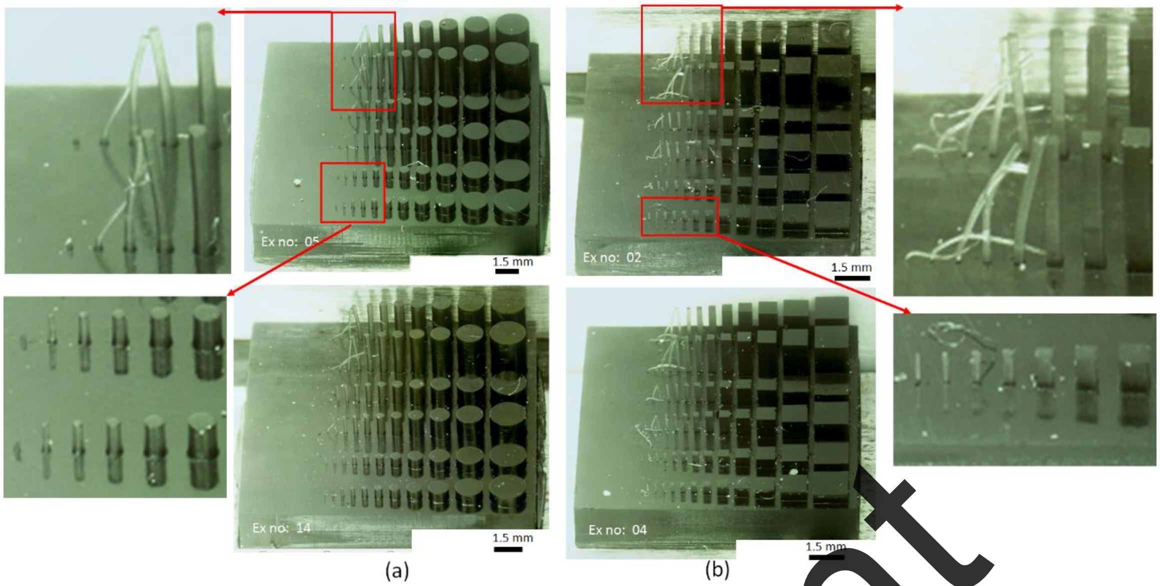


FIGURE 3 the printed samples (a) cylindrical (b) cube.

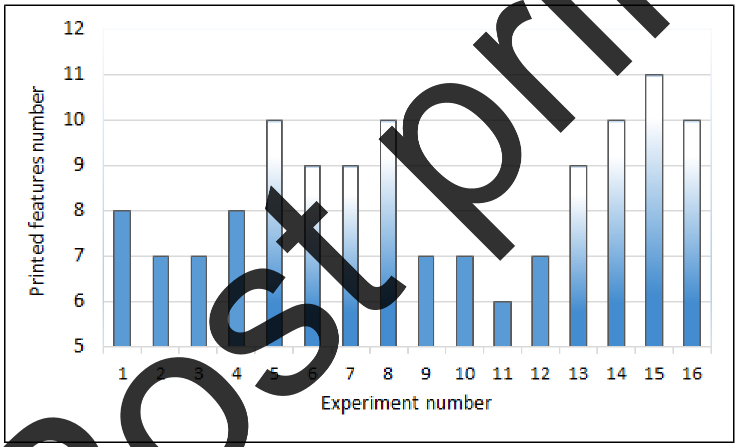


FIGURE 4 Number of printed features, sloid fill square and the gradient fill cylinder

Regarding the height measurement, design of experiments (DOE) analysis was carried out to illustrate the printing parameters contribution. Figure 5 shows the main effect plot and the height measurement at 500 µm features. The main effect plot (Figure 5 (a)) shows the influence of the factors on the height variation. The film thickness significantly affect the height variation and printed features with the thicker film tends to have higher size. This might be due to the less distortion of the thicker film in the vat for solidification of each layer. Then the geometry of the printed features and the layer thickness influenced the height of the features.

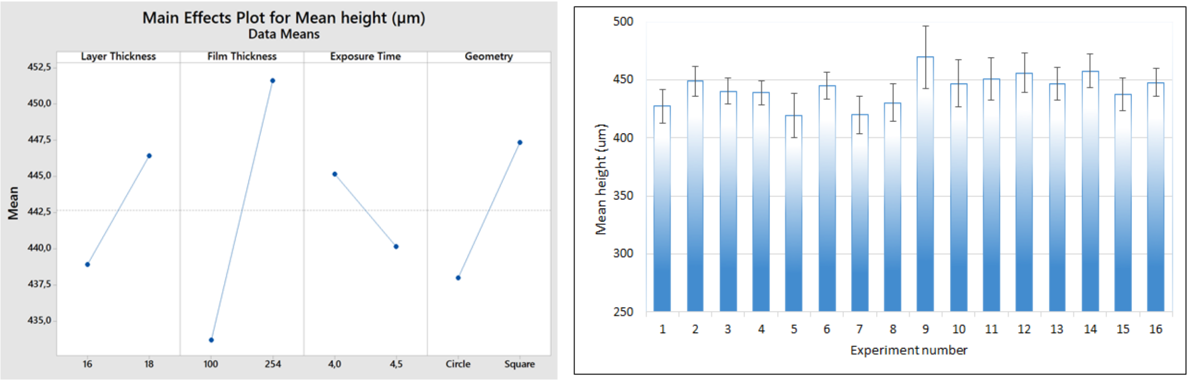


FIGURE 5 (a) main effects plot (b) height measurements.

CONCLUSION

The paper presents the evaluation of AM vat photopolymerization method in production of miniaturized polymer components. Two test parts were designed with different geometry, sizes and aspect ratios. Four different printing parameters as layer thickness, film thickness, exposure time and geometry were selected. The most significant factor for the printed features height was the film thickness and with thicker film 254 µm higher features printed. In terms of the smallest printable feature, the geometry affect the results, with the cylindrical shape more features were printed than square shape. It was observed that features with high aspect ratios tend to be distorted with 200-150 µm at 2 mm height however, at 05 mm 84 µm features size was printed.

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