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TOWARDS PRODUCTION OF MICROFEATURES ON A CUSTOM-MADE STEREOLITOGRAPHIC DLP PRINTER

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Abstract: *Stereolithographic digital light processing (DLP) printing is a liquid-based additive manufacturing process, where 3D parts are made by curing a photosensitive polymer kept in vat. In this paper, the in-house DLP printer is presented. It uses two spindles for coarse and fine positioning in z-axis. A printer resolution is determined by printing inclined channels of different depths. At this development level the resolution is below 100 μm and it is to be further improved. Suitable process parameters are determined, a micromixer is manufactured and compared to the micromixer produced by casting. Better machining results are obtained by printing, but casting is more suitable for large scale production.*

Key words: *Additive manufacturing, DLP stereolithography, micromixer.*

1. INTRODUCTION

Additive manufacturing (AM) is a formal expression for what used to be called rapid prototyping technology (RP). This technology is used in a variety of industries for rapid creation of a prototype or basis model. The prototypes are intended to be used for quick functionality testing and improvement of part design.

Stereolithography (SLA) is a liquid-based AM process, from which 3D parts are made by curing a photosensitive polymer kept in vat, thus the term vat photopolymerization process is often used. Various light sources are used for photopolymerization, namely gamma rays, X-rays, electron beams, ultraviolet (UV) and visible light source [1]. Controlled light irradiation induces a curing reaction, forming a highly cross-linked polymer. Compared to other polymer-based AM technologies such as the extrusion or jetting based processes, the stereolithographic process can produce parts with fine features, good accuracy, and using various polymers [2].

In the last years, the resolutions of digital light processing (DLP) projectors have been significantly improved due to the use of new cost effective Digital Micromirror Devices (DMD). Some attempts to use DLP projector as a light source for photo-polymerization in SLA processes have already been performed. Compared to other light sources, the use of DLP projector enables building the whole layer at the same time, thus DLP stereolithography is a layer processing technology according to the naming proposed in [1].

DLP SLA is used in various fields including medical applications, where biocompatible and biodegradable materials ought to be used [3, 4], and oceanography [5] for a better understanding and restoration of fragile marine ecosystems.

A printing resolution that can be achieved by DLP SLA depends on the size of micromirrors in DMD and an optical system. In general, higher printing resolution requires smaller size of the printing layer. To achieve both, high resolution and larger layer, a dedicated hardware and software solutions are under development, e.g. DMD is moved continuously over the area of the medium while the projected image is updated accordingly [6]. Compared to other light sources used in SLA, DMD offers a relatively high resolution.

The control of the thickness of the layer that is cured is essential. For a given resin, the cure depth is determined by the energy of the light to which the resin is exposed. Therefore, the smallest feature that can be produced depends of the resin, too.

In this paper, the characterisation of in-house made stereolithographic DLP printer is presented. The emphasis is on control z-axis where two spindles are used: one for coarse and larger movements and micrometer spindle for precise but small movements. Further on, printing resolution is determined and finally, the characterisation of test workpiece, namely micromixer is performed and compared to micromixer manufactured by casting of polydimethylsiloxane (PDMS).

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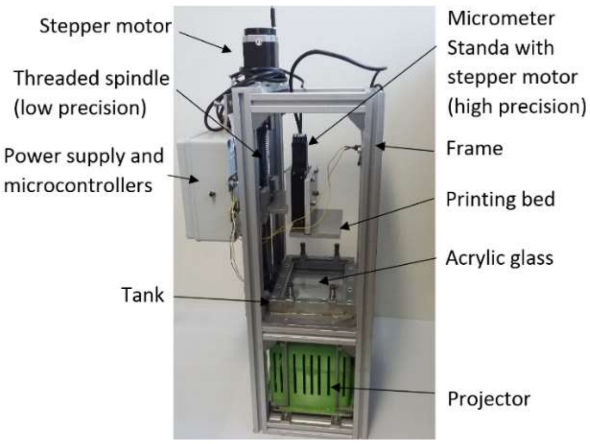


Fig. 1. Custom made stereolithographic DLP printer.

2. MATERIALS AND METHODS

For experiments we used a custom built stereolithographic DLP printer. The printer consists of optical system, printing bed, stepper motor, two threaded spindles and microcontrollers, as shown in Fig. 1.

2.1. Optical system

All experiments were performed on a custom made stereolithographic DLP printer (Fig. 1). Photopolymerisation was initiated by a Vialux STAR-065 EVM Type A monochromatic (UV) DLP-projector. Projector uses 405 nm wavelength light with power up to 25 W/cm^2 and resolution of 1920 × 1080 pixels. In order to increase the projector accuracy (reduce the pixel size) a 15 mm long spacer was mounted between light source and projector lens, as shown in Fig. 2. This reduced the printing distance from 340 mm to 80 mm and decreased pixel size from 80 µm to 19 µm. The projector was mounted in a custom made casing (Fig. 3) directly below the tank since a better printing precision is obtained when the photopolymer is illuminated through a transparent bottom of the vat (constrained-surface method) compared to illumination from the top (free-surface method) [7]. The photopolymer used in this research was Deep Black produced by FunToDo. 3D printer control software Creation Workshop was used.

2.2. Movement in z-axis

For large movements of printing bed with lower position accuracy a threaded spindle was used. To determine the position accuracy a set of experiments was designed. Printing bed was raised for 4 mm in 0.1 mm increments and then lowered back to starting position with the same increments. Bed height was measured at each increment using a dial gauge. Position accuracy and resolution are shown in Fig. 4. Measurements were done for print bed movement speed of 50 mm/min and 400 mm/min.

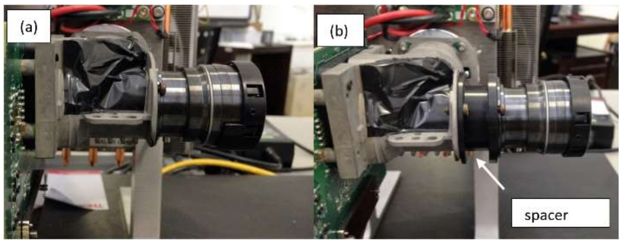


Fig. 2. Mounting of objective to reduce pixel size: *a* – pixel size is 80 µm without a spacer; *b* – pixel size is 19 µm with a spacer.

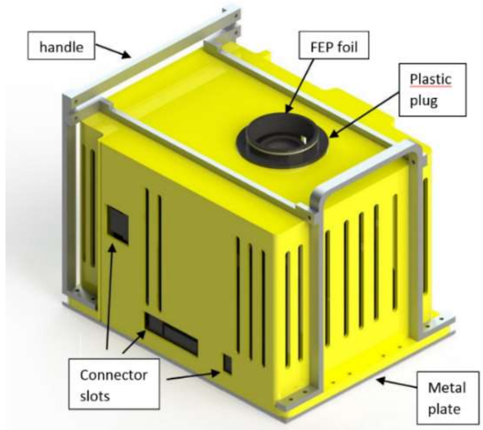


Fig. 3. Custom made casing for optical system.

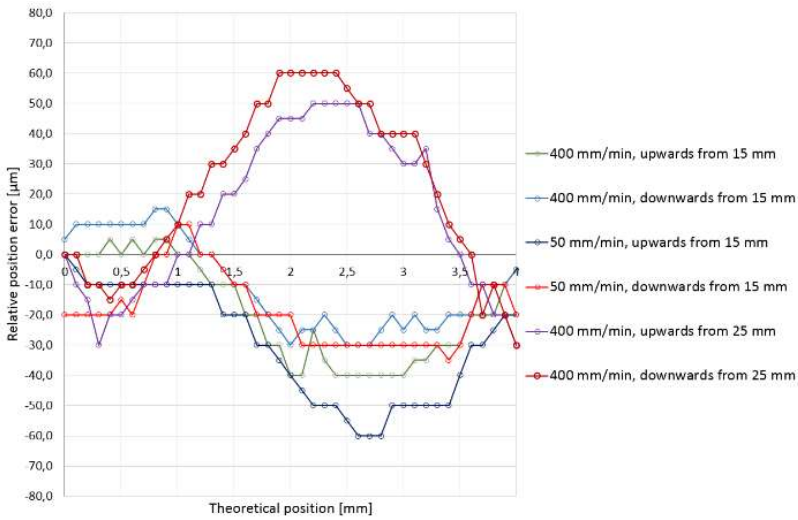


Fig. 4. Positional error at different bed movement velocities.

Repeatability was tested by raising the printing bed and then lowering it back down. Printing bed was raised by 4 mm and then lowered by 4 mm. At the end of each cycle the bed position was measured. Measurements were done for print bed movement speed of 50 mm/min, 100 mm/min, 200 mm/min and 400 mm/min.

To determine reasons for inconsistent results, additional experiments were performed with bed movement velocity of 400 mm/min, 0.1 mm increments and different starting positions. Bed position was measured only when lifting. First measurement was started at height of 15 mm and second at 17 mm. The motor was then disconnected from the printing bed, its axis rotated by 180°, reconnected and then the experiments repeated. Results show that both measurements done at starting height of 15 mm are consistent with each other, so the fault must be in a threaded spindle.

To obtain better precision of layer thickness on the given printer, the movement in z-axis was enhanced by an accurate actuator Standa 8MT167S-25LS (Lithuania). The actuator covers movements of maximum 25 mm with resolution of 1.25 µm. The new system allows speeds up to 6 mm/s. The load can be up to 30 kg in the horizontal direction and up to 7 kg in the vertical direction, which is more than enough for the given application. The feed system movement is controlled by 8SMC5-USB controller of the same manufacturer.

3. PRINTING RESOLUTION AND REPEATABILITY

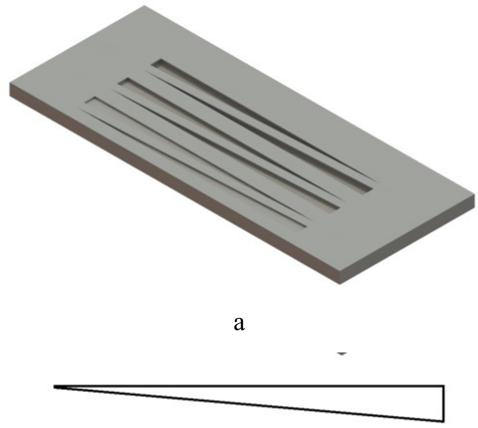
3.1. Methodology

To determine the printing resolution, special test pieces were designed as shown in Fig. 5.,*a*. In order to determine the minimum width that can still be printed at a given depth, channels as shown in Fig. 5.,*b* were printed. This type of channels appear in pairs in order to avoid the possible impact of the distance from the edge of the test piece. A single pair of channels has fixed depth and varying width. The width decreases from 1 mm to zero and are 100 µm, 200 µm and 300 µm deep.

In order to determine the printing resolution *x*, the length *a* was measured (Fig. 6) and *x* was calculated based on known angle *α*. The same procedure was repeated on both sides of the channels in pair and the mean value was calculated. Thus, the potential impact of different illumination on both sides of the test piece was eliminated. Five test samples were printed to estimate the printer repeatability (Fig. 7).

The measurements were performed on the Alicona Infinite FocusSL microscope, using 10× magnification, which allows a resolution of 100 nm and has a 2 mm by 2 mm square working area.

Suitable machining parameters were experimentally defined and are gathered in Table 1. In order to calibrate the printer, a few preliminary samples were manufactured and the width of the channel, which should be 0.5 mm, was measured using above mentioned microscope. The small discrepancy between the required and measured dimensions was compensated in the software Creation Wokshop that was used to control the printing process based on the 3D model.



a

b

Fig. 5. Test sample to determine printing resolution: *a* – model of the test piece; *b* – the ground plan of the channels.

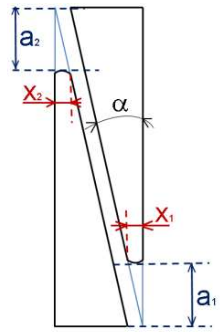


Fig. 6. Dimensions *x* are calculated from known angle and measured length *a*.

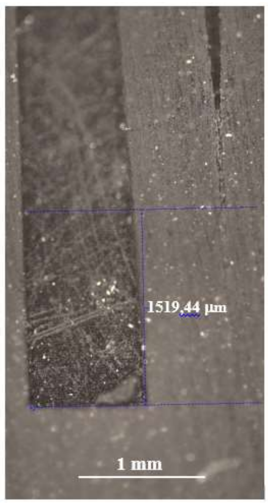


Fig. 7. An example of the measured length and hence the minimum width of the first test.

Table 1

Machining parameters used to print the test samples

Parameter	Value
Projector illumination power [%]	40
Thickness of the printed layer [mm]	0.01
Layer illumination time [ms]	100
Bottom layer illumination time [ms]	2200
Number of bottom layers [/]	2
Height of table lifting [mm]	4

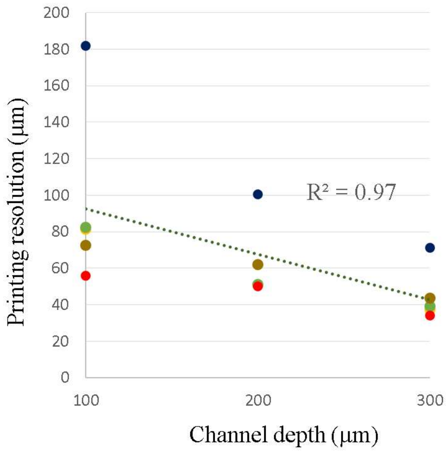


Fig. 8. Influence of feature depth to the printing resolution.

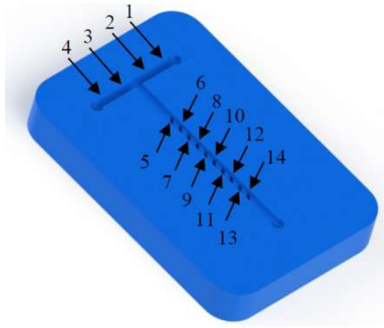


Fig. 9. Measuring positions on micromixer.

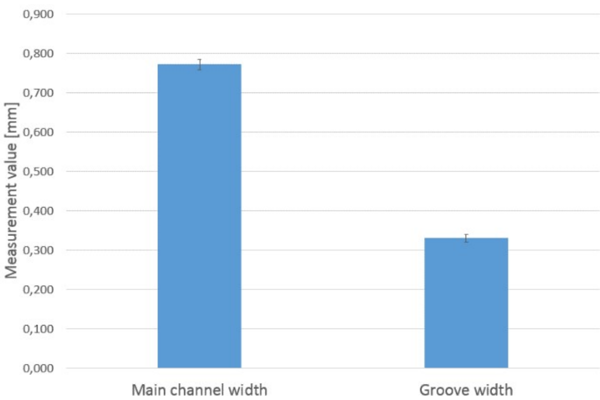


Fig. 10. Measurement results of main channel and grooves.

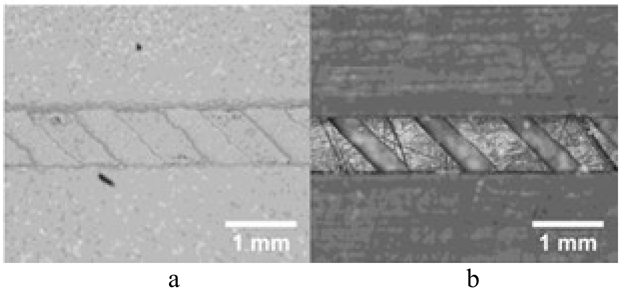


Fig. 11. Digital image of two micromixer channels: *a* – micromixer cast in PDMS [7]; *b* – printed micromixer.

3.2. Results

The results are gathered in Fig. 8. Printing resolution is actually the indirectly measured the smallest observable width of the channel at various channel depths. The lowest repeatability is observed when printing the shallowest channel and the printing resolution seems better at deeper channels. This could be related more to the measurement procedure than to the printing performances. Additional characterization of the printer is needed in order to make a confident statement. At this stage of printer development, the printing resolution is estimated between 50 and 100 µm.

4. MICROMIXER

Micromixers are important microfluidic functional units. Their main task is to mix different reactants in sub-millimetre channels where laminar flow regime is commonly present. One of the established design is bottom grooved micromixer. The grooves on the bottom of the channel laterally transport the fluids and consequently enhance fluid mixing. The design for the grooved micromixer was inspired from the literature [8].
A micromixer was manufactured by a stereolithographic DLP printer and compared with micromixer manufactured by casting of PDMS. The description of the process chain involved casting as well as detailed results of manufacturing are presented in [7]. Micromixer manufactured by DLP stereolithography was measured in several places using a digital camera. Measuring positions are shown in
Fig. 9. Positions from 1 to 4 are measurements of the main channel and positions 5 to 14 are measurements of the mixing channel and grooves inside. Measurement results are shown in Fig. 10.

Average channel width is 0.77 mm, which is 30 µm less than nominal dimension (80.8 mm). Average groove width is 0.33 mm, which is 30 µm more than nominal dimension (0.3 mm). Standard deviation is within 10 µm, which indicates stable printing process. Although dimension deviations are within photopolymer resolution, some could be attributed to part shrinkage during and after the printing process.

Fig. 11. shows two micromixer channels made by different technologies. Micromixer in Fig. 11.,*a* is made by a process chain involving Abrasive waterjet cutting (AWJ), die-sinking EDM and casting. Firstly, an EDM electrode is cut by AWJ and then the electrode is used to make a mould which is negative shape of the part. PDMS is then casted into the mould, solidifies and creates a micromixer. Fig. 11.*b* shows 3D printed micromixer. 3D printed part has much better edge quality and surface roughness when compared to casted micromixer.

5. CONCLUSIONS

According to the presented results, the following conclusions can be drawn:

- The movement in *z*-axis is significantly improved by implementing additional micrometer spindle (Standa, Lithuania). Therefore, a coarse spindle with larger movements in z axis can be used when making higher parts whereas micrometer spindle can be applied when part must be made by a small layer height and whole part is not higher than 25 mm.
- The in-house developed and produced stereolithographic DLP printer has printing resolution below 100 µm, which far high to be used for manufacturing of microproducts. Although, micromixer was successfully manufactured.
- Casting is one of the possible processes for large scale production of micromixers, but even a relatively poor performance stereolithographic printer can produce sharper edges and more accurate features.

There is still a lot of work in development of presented printer to be used for micromanufacturing. The obtained printing resolution (below 100 µm) is far greater than the resolution of optical system (19 µm). One of the next steps is to improve the transparency for UV light of the bottom of the vat as well as to improve the parallelism between the bottom of the vat and the printing bed.

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