IMPACT OF UV POST PROCESSING ON SIMPLE 3D PRINTED PARTS USING MASKED STEREOLITHOGRAPHY

Valentin-Serban Popescu[1] [0000-0002-0500-6650], Ionela-Mihaela Popescu [2][0000-0001-6013-3903]
[1]National Institute of Research and Development in Mechatronics and Measurement Technique Bucharest
[2]National University of Science and Technology Politehnica Bucharest
Email: ionela.baciu@upb.ro

Abstract - The main subject of this paper are the measurements done after the post-processing of 3D printed parts made using masked stereolithography (MSLA) 3D printing technology, after they have been previously detached from the construction platform and cleaned with isopropyl alcohol. This 3D printing technology requires resin, which mainly uses photopolymers, which are a type of plastic containing photoinitiators. This resin is hardened using a UV LED system and lenses to create the 3D part, layer by layer. The type of resin used can greatly influence the dimensional accuracy of the printed parts. Essential to this technology is the LCD screen that works like a mask, blocking the parts of the resin that doesn't need to be cured by UV light. This screen has a fixed resolution, a fixed pixel size, which affects the dimensional accuracy of the layers. Also, the post-processing time with additional UV light can affect the final dimensions of the printed parts and their resistance, too short exposure time having a negative effect, the parts are still soft, and too long exposure time, also having a negative effect, making the parts brittle.

Keywords: 3D Printing, Stereolithography, Post-processing, Masked Stereolithography.

1. Introduction

Polymer AM (additive manufacturing) of extrusion, known as soft tooling, enables a more rapid product development cycle and cost-effectiveness for small-scale production and highly customized parts. Lightweight, robust components with a great deal of design flexibility can be produced thanks to additive manufacturing. Up until now, the primary technique in the low-cost industry has been material extrusion, such as fused deposition modeling, or FDM. This makes it possible to employ affordable 3D materials (polymer filaments) and sturdy 3D printers. However, FDM printing takes a very long time, and the quality of the surfaces and dimensions are not very good. Among the different types of additive manufacturing, stereolithography (SLA) is one of the most versatile technologies, especially when it comes to creating prototypes with exceptionally high surface quality. Since its inception in the 1980s, SLA has had four generations of notable technology advancements during the last 40 years. These developments have subsequently resulted in a broad range of stereolithography systems with markedly improved resolution, throughput, and material selection for the production of complex 3D structures and devices. Combining polymer extrusion with additive manufacturing allows for design freedom and process chain flexibility. It lessens the need for trial-and-error and time-consuming iterations in the design process.

Even though the basic principles of this method haven't changed in almost thirty years, the recent expansion of the mask-based version of stereolithographic 3D printing technology (MSLA) has made it far more appealing and accessible to a wider range of the market. Because of its excellent quality and high resolution, resin 3D printing technology is renowned for producing intricate parts with fine details and precise dimensions. The challenges of the design are lessened by the ability of contemporary technologies to visualize the component before it is manufactured. Manufacturers can use 3D printing to directly make the components, but great attention to accuracy and precision is required [1,2,6,8,9].

According to [1] the dimensional evaluation, MSLA printed components deviate more from the nominal dimension than ones that are created conventionally with FDM. The study was conducted on acrylonitrile butadiene styrene (ABS) and polypropylene (PP) to evaluate the polymer extrusion line's integrated soft tooling.

In [2], the authors analyze the MSLA technology material market, and objectively compare the materials offered with those from reliable producers of materials for conventional SLA 3D laser printers. MSLA currently lacks the same selection of materials as 3D printers that use the laser version of stereolithography but MSLA technology is a viable alternative to laser stereolithography. The quality and scope of MSLA materials' technical standards are given particular attention because they are essential to their professional application.

In [3], it was investigated how post-curing ultra violet (UV) laser light affects the dimensional correctness of the 3D printed components made using the resin. The most frequent dimensional errors that occur in 3D printed parts are the linear variations dimensions and hole diameters. The results showed that dimensional errors are caused by changes in the size and shape of the part; frequently, the errors for internal and external diameters are bigger than those for liner dimensions.

Also, in [4] masked stereolithography (MSLA) technique was used to create functionally graded (FG) triply periodic minimum surfaces, Schoen-IWP (SIWP), and Schwarz primitive (SPrim) cellular structures using ABS-like gray resin. Experimental compression tests were used to examine the mechanical properties, energy absorption, deformation behavior, and sample morphology of graded and uniform structures.

In [5], printing tests were conducted on Digital Light Processing (DLP) 3D printing devices to investigate the impact of printing parameters configurations on the forming performance of DLP 3D printed samples. The authors conducted tests on printed samples with various thickness configurations to determine the mechanical characteristics and molding accuracy. According to the test results, the dimensional accuracy increases in the X-axis and Y-axis directions before decreasing in the Z-axis direction.

[7] is a comparative study between printouts from two distinct additive technologies, FDM and MSLA. The authors created eight models, resulting in sixteen printouts (eight for each printer), which were compared. Each cube-based model was symmetric in terms of plane, axis and point. The purpose of arranging each model symmetrically on the 3D printer's work table was to confirm that the machine's nozzle was working correctly in relation to all axes. The purpose of the study was to ascertain the FDM and MSLA technologies advantages and disadvantages as well as their applicability for industry and hobby manufacturing.

[8] proposes some design criteria in contribution to ascertain the potential and constraints of MSLA from a design perspective. In order to gather methodical information about crucial design elements including wall thickness, grooves, and holes, several test geometries were created and examined. Additionally, common issues in additive manufacturing are examined, like component hollowing or overhang and fit design. Authors concluded that the assessment of real-world 3D printing experiments yields crucial information that may be applied to design specifications for parts for MSLA additive manufacturing.

1.1 Technology

A generation ahead of traditional stereolithography (SLA), masked stereolithography (MSLA) printing technology is used for applications where high precision is required. Masked Stereolithography (MSLA) is a resin 3D printing technology that uses a UV light to cure the photopolymer resin, layer by layer until the part is finalized. Similar to stereolithography (SLA) or masked stereolithography (MSLA), DLP or "Digital Light Processing" has the same working principle as SLA or MSLA, but instead of a UV light source to cure the resin, DLP uses a light source to accomplish this.

What differentiates MSLA technology from the others is the way the UV light source works. In MSLA technology, an LCD screen that is used as a mask blocks the part of the resin that doesn't need to be treated. This process allows an entire layer to be cured at once, which makes the time needed to realize the 3D model drastically shorter compared to other 3D printing technologies such as FDM. This technology offers a high level of precision but also very detailed parts, as the "mask" screen can control the exposure area with very good accuracy.

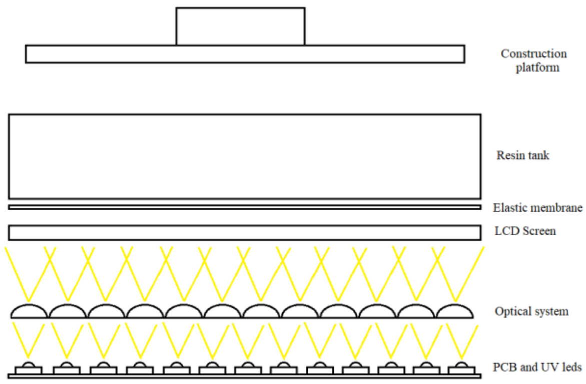

Figure 1. Working Principle of a 3D Printer using masked stereolithography (MSLA)

As can be seen from figure 1, between the LCD screen and the photopolymer resin, there is a special non-adherent elastic membrane. During the construction of each layer, the construction platform descends into the resin tank, leaving a layer-thick distance between the membrane and the platform. When the resin is exposed to UV radiation, the exposed resin will stick to the construction platform but also to the special membrane. When the exposure time necessary to realize the layer is over, the construction platform will rise to peel the layer from the elastic membrane, which remains attached to the platform. After the peel, the uncured resin rush in to take the place of the cured resin which is attached to the construction platform, untreated resin that is needed for a new layer, simultaneously allowing a short rest period for the UV light source, optical system and mask screen to cool down.

The cooling is essential to prevent rapid degradation of the mask screen, optical system and UV light source.

1.2 Materials

MSLA (Masked Stereolithography Apparatus) 3D printing uses photopolymer resins that are sensitive to UV light. When exposed to UV light from the printer, these resins harden, allowing for layer-by-layer creation of highly detailed objects. There are several types of resins available for MSLA 3D printing, each designed for specific applications and possessing different properties.

There are plenty of resins for 3D printing using masked stereolithography. These include standard, tough, flexible, castable, high-temperature, dental, medical, ceramic-filled, transparent and translucent resins.

1.2.1 General Details About Resins

1.2.1.1 Viscosity and Flow

Resin viscosity affects the flow and leveling in the resin vat. Higher viscosity resins might require longer exposure times and slower printing speeds.

1.2.1.2 Odor and Safety

Some resins emit strong odors during printing, requiring proper ventilation. Most resins are toxic when uncured and should be handled with gloves and protective gear.

1.2.1.3 Post-Processing Requirements

After printing, resin parts typically need to be washed with isopropyl alcohol (IPA) or an alternative cleaning solution to remove uncured resin. They also need additional UV curing to reach full strength and stability.

1.2.1.4 Shelf Life

Resins have a limited shelf life and should be stored in a cool, dark place to avoid premature curing or degradation.

1.2.1.5 Environmental Concerns

Uncured resins are harmful to the environment and should be disposed of properly, following local regulations for hazardous materials.

2. Equipment and Experimental Parts

2.1 The 3D Printer

The printer used to manufacture the experimental parts is an Anycubic Photon Mono 6Ks 3D printer, that uses masked stereolithography technology (MSLA), which has the parameters that can be seen in table 1.

Table 1. MSLA 3D Printer Parameters

Parameter	Value
Screen size	9.1 inch
Screen resolution	5760x3600
Pixel size	0.03403mm
Z-axis maximum error	± 0.01mm

2.2 MSLA 3D Printer Resin

The used resin is Anycubic ABS-like PRO 2 and belongs to the "tough" category and. This resin is formulated to mimic the properties of ABS plastic, offering better impact resistance and flexibility than standard resins. Its parameters are presented in table 2.

The resin's chemical formula contains: Poly(propylene glycol) diacrylate; 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14 dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate;(octahydro-4,7-methano-1H-indenediyl)bis(methylene) diacrylate

Table 2. MSLA 3D Printer Resin Parameters

Parameter	Value
Printable wavelength	365 ~ 405 [nm]
Density	1.05 ~ 1.25 [g/cm3]
Viscosity at 25C	300 ~ 400 [MPa*s]
Surface hardness	82 ~ 84D
Shrinkage	4.3 ~ 5.6 %
Flexural strength	35 ~ 40 [MPa]
Tensile strength	85 ~ 45 [MPa]
Modulus of elasticity	1000 ~ 1200 [MPa]
Heat deflection temperature (0.45MPa)	60 ~ 65°C

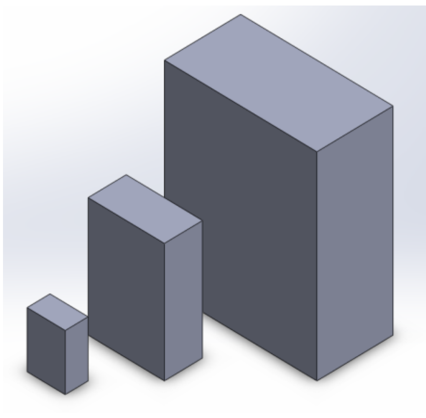

Figure 2: The experimental parts as seen in SolidWorks

The parts (figure 2) were exported from SolidWorks as format STL required by the 3D printer software. The tolerances were given by SolidWorks when saving as STL file. Those are presented in table 3.

Table 3. Experimental parts tolerances when exported as STL

Part Name	Deviation Tolerance	Angle Tolerance
3x5x7mm	0.00045191mm	0.5 degree
5x10x15mm	0.00092799mm	0.5 degree
10x20x25mm	0.00166374mm	0.5 degree

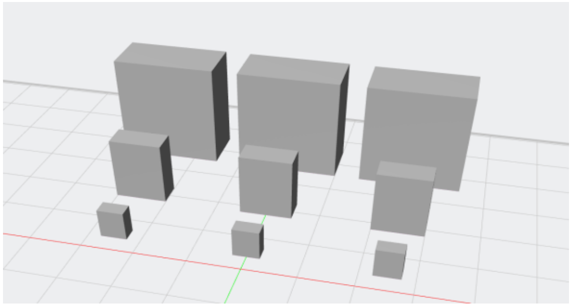

Figure 3: Experimental parts as seen in the slicer program

In figure 3 the experimental parts can be seen as shown in the printer slicer program.

Table 4. Slicer Parameters

Parameter	Value
Layers Thickness	0.05mm
Normal Exposure Time	*2.5 s
First Layers Exposure Time	*20 s
Number of First Layers	*5
Number of Transition Layers	*10
Z Lift Height	10 mm
Volume of Resin Used	25.138 ml
Price	0.7 $
Estimated Time	2 h 34 m 24 s

As can be seen in Table 4, the values with * are the values recommended by the manufacturer of the 3D printer and resin for the layer thickness of 0.05mm.

3. Results and Discussions

At the start of printing, the temperature in the printing chamber was 26.8°C and the humidity was 33%. At the end of the printing, the temperature was 31.5°C and the humidity was 25%.

All parts were printed at the same time, during the same printing job, with 100% infill.

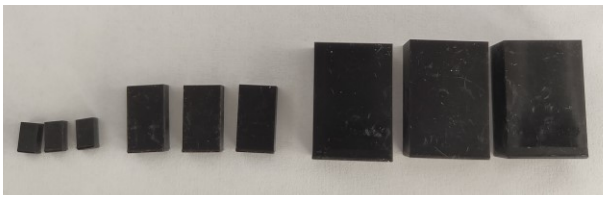

Figure 4: The experimental parts

Figure 4 shows the parts manufactured by 3D printing using masked stereolithography.

The measurements were performed using a micrometer with a resolution of 0.001mm and accuracy of ±0.002mm. A total of 513 measurements were performed for all 9 experimental parts. 45 measurements for the small parts, 156 measurements for the medium parts and 312 measurements for the large parts.

For each small part, one measurement was made on each side of the part, corresponding to the axes of the construction platform.

For each medium-sized part, 3 measurements were taken on the X-axis side, in the middle of the X-axis side, in the direction of construction of the part (Z-axis); 7 measurements were taken on the Y-axis side, in each corner and 3 measurements were taken in the middle of the side, in the direction of construction of the part (Z-axis); 3 measurements were taken on the Z-axis side, in the direction of the X-axis.

For each large part, 8 measurements were made on the X-axis side, 3 on each long edge and 2 on the middle of the side, in the direction of construction of the part (Z-axis); on the Y-axis side, 10 measurements were made, in each corner, on the middle of each long edge and 2 on the middle of the side, in the direction of construction of the part (Z-axis); on the Z-axis side, 8 measurements were made, 3 on each long edge and 2 on the middle of the side, in the X-axis direction.

The axes shown in each graph and table for each part type are the axes of the 3D printer's construction platform.

The temperature in the room in which the measurements were carried out had a constant temperature of 25°C, the measuring device was used using special gloves to prevent the transmission of substances/heat from the hands of the person who performed the measurements.

Table 5. Mean measurement values for the small parts on X-axis

Post Processing time [s]	Small Part 1 [mm]	Small Part 2 [mm]	Small Part 3 [mm]
0	5.027	5.009	5.024
15	5.026	5.016	5.024
30	5.031	5.009	5.022
60	5.028	5.008	5.021
120	5.022	5.009	5.021

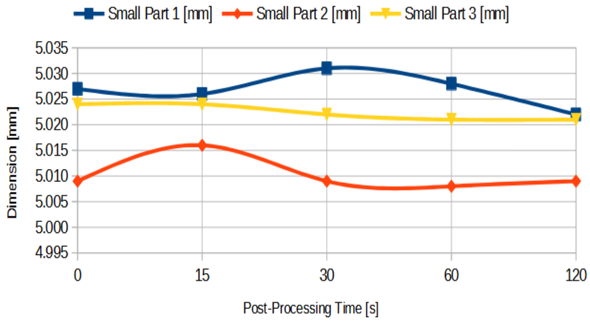

Figure 5: Dimensional deviation of the mean measurement values for the small parts on X-axis

Table 5 and Figure 5 shows a sharp increase in size at 30 seconds of additional post processing for small part 1 and a decrease in size at 15 seconds of additional post processing for small part 2. By 2 minutes post processing these increases will disappear returning to the initial dimensions, mostly within the margin of error of the measurement device.

Table 6. Mean measurement values for the small parts on Y-axis

Post Processing time[s]	Small Part 1 [mm]	Small Part 2 [mm]	Small Part 3 [mm]
0	3.030	3.017	3.021
15	3.023	3.017	3.034
30	3.020	3.020	3.034
60	3.019	3.019	3.022
120	3.018	3.016	3.021

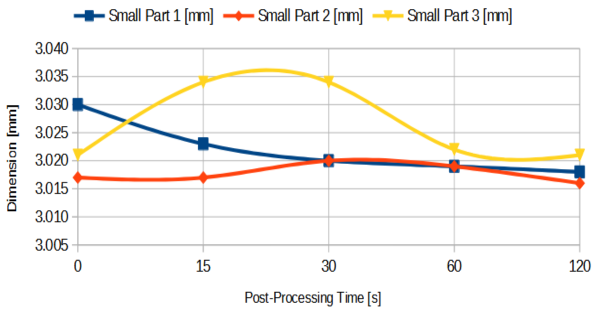

Figure 6: Dimensional deviation of the measurement values for the small parts on Y-axis

In Table 6 and Figure 6, it can be seen how the small part 3, increases significantly in size after 15 seconds of additional post-processing, after 30 seconds it starts to decrease slightly and by the end of the 2 minutes of additional post-processing it stabilizes, being close in size to the other 2 parts. Small part 1 has a decrease in size up to 30 seconds of additional post-processing, but after that it stabilizes up to 2 minutes of post processing.

Table 7. Mean measurement values for the small parts on Z-axis

Post Processing time [s]	Small Part 1 [mm]	Small Part 2 [mm]	Small Part 3 [mm]
0	6.857	6.781	6.797
15	6.801	6.791	6.862
30	6.802	6.789	6.863
60	6.799	6.788	6.860
120	6.796	6.788	6.860

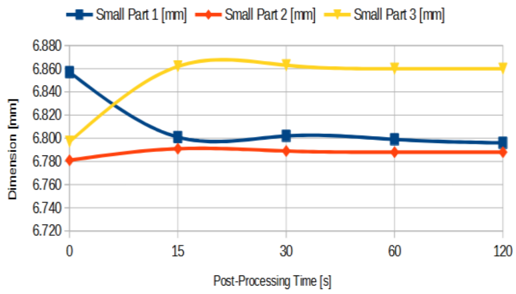

Figure 7: Dimensional deviation of the mean measurement values for the small parts on Z-axis

In Table 7 and Figure 7, it can be seen that the size of small part 1 decreases and the size of small part 3 increases, but after 15 seconds of additional post-processing, it stabilizes immediately afterwards.

Table 8. Mean measurement values for the medium parts on X-axis

PostProcessing time[s]	Medium Part 1 [mm]	Medium Part 2 [mm]	Medium Part 3 [mm]
0	10.002	10.025	10.003
30	10.000	10.026	9.992
60	9.999	10.021	9.997
120	10.000	10.026	9.995

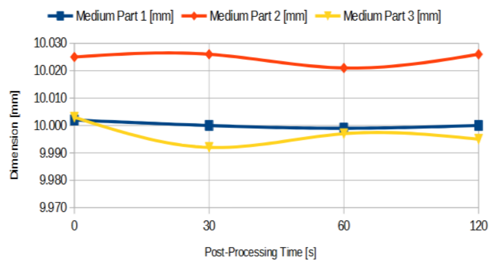

Figure 8: Dimensional deviation of the mean measurement values for the medium parts on X-axis

Table 9. Mean measurement values for the medium parts on Y-axis

Post Processing time [s]	Medium Part 1 [mm]	Medium Part 2 [mm]	Medium Part 3 [mm]
0	5.006	5.036	5.002
30	4.997	5.017	4.992
60	5.001	5.013	4,993
120	4.998	5.019	4.989

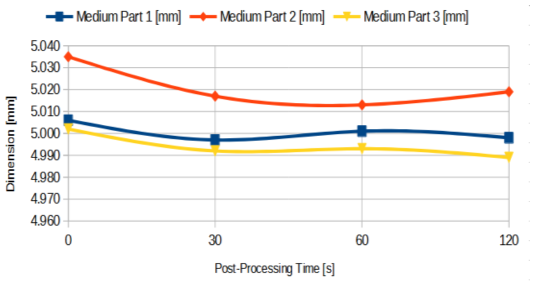

Figure 9: Dimensional deviation of the mean measurement values for the medium parts on Y-axis

In Table 9 and Figure 9, it can be observed that all the parts have a decrease in size at 15 seconds of additional post-processing, the largest decrease having the medium part 2, but by the end it stabilizes, without additional surprises.

Table 10. Mean measurement values for the medium parts on Z-axis

Post Processing time [s]	Medium Part 1 [mm]	Medium Part 2 [mm]	Medium Part 3 [mm]
0	14.813	14.877	14.885
30	14.808	14.875	14.886
60	14.807	14.871	14.885
120	14.806	14.870	14.881

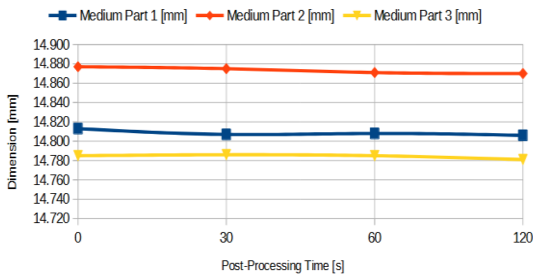

Figure 10: Dimensional deviation of the mean measurement values for the medium parts on Z-axis

Table 11. Mean measurement values for the large parts on X-axis

Post Processing time [s]	Large Part 1 [mm]	Large Part 2 [mm]	Large Part 3 [mm]
0	19.960	19.995	20.043
30	19.959	19.997	20.069
60	19.962	20.003	20.089
120	19.961	20.010	20.085

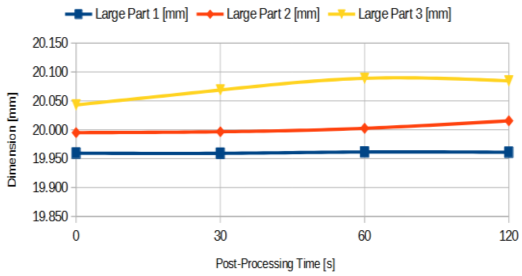

Figure 11: Dimensional deviation of the mean measurement values for the large parts on X-axis

In Table 11 and Figure 11, it can be seen that the large part 3 has a constant increase up to 60 seconds of additional post-processing, increasing by 0.046mm.

Table 12. Mean measurement values for the large parts on Y-axis

Post Processing time [s]	Large Part 1 [mm]	Large Part 2 [mm]	Large Part 3 [mm]
0	9.971	10.001	10.028
30	9.971	10.001	10.029
60	9.970	10.001	10.029
120	9.972	10.004	10.030

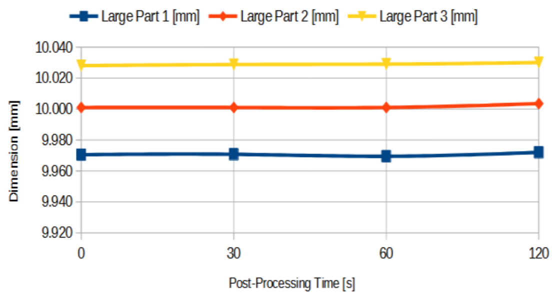

Figure 12: Dimensional deviation of the mean measurement values for the large parts on Y-axis

Table 13. Mean measurement values for the large parts on Z-axis

Post Processing time [s]	Large Part 1 [mm]	Large Part 2 [mm]	Large Part 3 [mm]
0	24,853	24,834	24,893
30	24,852	24,832	24,895
60	24,851	24,830	24,898
120	24,850	24,827	24,892

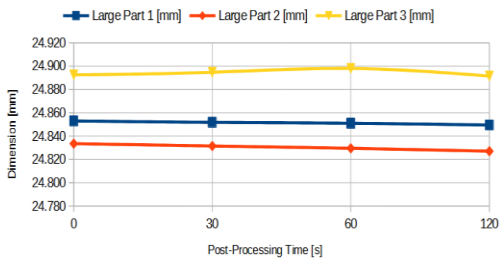

Figure 13: Dimensional deviation of the mean measurement values for the large parts on Z-axis

As can be seen from the figures and tables above, for some parts there are minor differences between no additional UV post-processing and UV post-processing for 2 minutes, and in others there is a difference of even more than 0.05mm.

The other parts that were not presented, including parts in Tables 8, 10, 12, 13 and Figures 8, 10, 12, 13, have a relatively identical behaviour.

4. Conclusions

All measurements that have a difference of 0.004mm fall within the margin of error of the measuring device, so these differences are practically negligible.

All values shown in the tables and graphs in section 3 (Results and Discussions) are the mean values of all measurements taken on the axis referred to in the graphs and tables.

In total 513 measurements were made, even if they were made on a small number of parts, most of these sets of measurement show a similar behaviour, the dimensions remaining within ±0.015mm from freshly removed from the building plate and cleaned with isopropyl alcohol until the end of the 2 minutes of additional UV post processing, the exception from this conclusion are those discussed in section 3 (Results and Discussions)

As can be seen from the measurements on the Z-axis, the difference compared to the nominal size is around -0.2mm. The reason for this would be that the parts were printed directly on the build platform without the use of support, the first layers being overexposed to ensure bonding to the build platform, but having the disadvantage that these layers will be compressed compared to the normal ones.

The size differences between the same type of parts can be attributed to the inconsistency of the resin, the temperature of the resin of about 26.8°C (the manufacturer recommends temperatures between 18°C and 35°C), the state of the attached elastic membrane that resides between the screen and the resin reservoir, the positioning of the parts on the printing platform (some in the middle of the platform where the elastic membrane has maximum flexibility, others closer to the metal part that fixes the membrane to the resin tank).

Acknowledgements

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