OPTIMIZATION OF PROCESS PARAMETER FOR DIGITAL LIGHT PROCESSING (DLP) 3D PRINTING

[1]AFIZAH IBRAHIM, [2]N SA'UDE, [3]M IBRAHIM

[1,2]Faculty of Mechanical Engineering, Universiti Tun Hussein Onn (UTHM), Malaysia, 86400 Batu Pahat, Johor, Malaysia
Email: [1]afizahibrahim92@gmail.com, [2]nasuha@uthm.edu.my, [3]mustaffa@uthm.edu.my,

Abstract: Digital Light Processing (DLP) 3D printer which have similar process as SLA currently become a promising printing method among toolmakers for its ability to create objects faster than SLA. Process parameter is one of significant element used to enhance the quality of printed part. This paper attempt to investigate the influence of process parameter which are layer thickness and exposure time on physical and mechanical properties of DLP structure. The physical properties include surface finish and dimension accuracy whereas the mechanical properties covers ultimate tensile strength and the flexural properties of printed parts. The study is conducted on test sample of B9R-1-Red built using B9 Creators machine. All the samples are tested under specific ASTM test conditions. The finding results shows that layer thickness of 50 µm with exposure time of 9 sec have tensile and flexural strength of 8.98 N/mm^2 and 18.39 N/mm^2 respectively. As for dimensional accuracy, the percentage difference across dimension of B9R-1-Red is found to be 3.8%. It was found that for B9R-1-Red, the layer thickness of 50 µm with exposure time of 9 sec would provide the best mechanical properties along with minimum dimensional error.

Keywords: Digital Light Processing, Process Parameter, Layer Thickness, Exposure Time, Mechanical Properties.

I. INTRODUCTION

Stereolithography Apparatus (SLA) machine invented by Charles Hull in 1984 is one of the earliest 3D printer used in Additive Manufacturing (AM) sector. SLA is known for its ability to produce detailed and highly accurate polymer parts [1] .As 3D Printing is moving progressively from prototyping to manufacturing, the technology began to diverse into two major sector. The first sector attempt to produce highly engineered and complex 3D parts. Some of industries that gain benefits from these technologies are automotive, medical and jewelry sector [2]. The second sector aim to improve the concept development and functional of 3D printing. Currently, many commercial 3D printer were developed as user-friendly which can be operated in non-industrial setting. This sector is where today's commercial 3D printers are emerged from[3].Although there are various types of commercial 3D printers available in market, most of them lack of functional development which limit the performance of machine to operate at optimum condition [4]. As the expectation of 3D printing performance are running high, huge effort is required to satisfy the technical constraints so that the final product produced by using 3D printing are high in quality. Digital Light Processing (DLP) 3D printer currently become one of the promising printing method among toolmakers for its ability to create object faster than SLA [5]. There are various types of DLP 3D printers available commercially.

However, the application of some commercial DLP 3D printers not yet being optimized which reflects on the quality of final part product that not fully meet with requirement from industries. The quality of final part is analyzed based on their physical and mechanical properties. There are many factor that reflect on the quality of DLP part and one of them is process parameter [6] specifically focusing on layer thickness and exposure time. Thus, this research attempt to study the influence of selected process parameter on physical and mechanical properties of DLP. At the same time, the study also intend to optimize the properties of commercial resin B9R-1-Red so that the fabricated part of B9R-1-Red are able to function with best mechanical properties and dimensional accuracy.

II. DETAILS EXPERIMENTAL

2.1. Machine and Material

B9 Creators is a commercial DLP 3D printer that have similar process with SLA where the printing process work with liquid photopolymers. The major different between both technologies is the source of light. SLA using laser as the source of light while DLP using the projector light. DLP 3D printer used liquid-based processes where the light source is used to harden and solidify a container filled with photopolymer resin [7].

DLP 3D printer employ a vat of photosensitive resin and UV light to build the layer of the object one at a time. The projector light will project profile on the surface of the liquid layer. The part that expose to projector's light will cure and solidifies the pattern trace on the resin and join it to the next layer below. The DLP 3D printer used for this research is shown in Figure 1. The printing material used for this study is B9R-1-Red. B9R-1-Red is a customized resin for B9 Creators machine that usually used to create silicone or RTV molds.

Figure 1: B9 Creators

2.2. Process Parameter

B9Creators machine have both software and hardware parameters that can influence surface finishing and mechanical strength of printed parts. Process parameter is one of the process variable that may influence the quality of printed part [8]. For this study, the focus process parameter are layer thickness and exposure time. Layer thickness is layer height of each successive addition of material in Additive Manufacturing (AM) in which layer are stacked [9]. Commonly, layer thickness for 3D printer are between 16 μm and 150 μm depend on setting and compatibility of printed material and printing machine. The required printing time also greatly determined by layer thickness. Table 1 shows the varied layer thickness used for this research.

Table 1: Control Process Parameter of B9 Creators

Control Factor	
Parameter	Level
Layer Thickness (Z axis)	50μm
	70μm
	100μm
	150 μm

The second process parameter is exposure time. Exposure time is the duration where the resin is exposed under light source for each layer. Exposure time plays a crucial role in influencing the number of photon received by material to initiate and propagate reactions in cross-linking process.

Exposure time play a role in adhesion between layers. If the exposure time is too high, it will lose the definition of the build. When the exposure time is too low, the builds will not stick together [10]. Table 2 shows the varied exposure time used to fabricate DLP structure. The following Table 3 shows the setting for other fixed parameter.

Table 2: Control Process Parameter of B9 Creators

Control Factor	
Parameter	Level
Exposure Time	3seconds
	6seconds
	9seconds
	12seconds

Table 3: Fixed Process Parameter of B9 Creators

Fixed Factor		
Factor	Value	Unit
Resolution	1920×1080	-
Shutter open speed	70.0	milliseconds
Shutter close speed	60.0	milliseconds
Horizontal Resolution	50	μm
Base exposure time	4.0	seconds
Attach over cure	2.0	seconds

2.3. Experimental Description

The sample were model first by using 3D CAD software-AutoCAD and then were converted into stereolithography (STL) format which generalized the input setting of B9 Creators machine. The STL file then were proceed to slicing process where prefatory software is used to slice the model based on required layer thickness. By using the machine's software, the exposure time were adjusted and began the printing process. Figure 2 show the stages to construct 3D model.

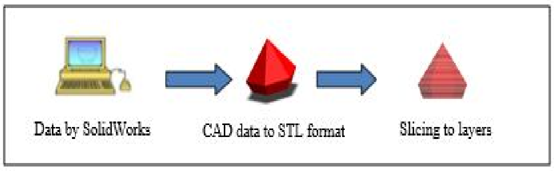

Figure 2: Constructing 3D Model

All the sample were printed using different layer thickness and exposure time. The test part were fabricated based on conducted testing which are tensile testing, flexural testing and dimensional accuracy as shown in Figure 3.

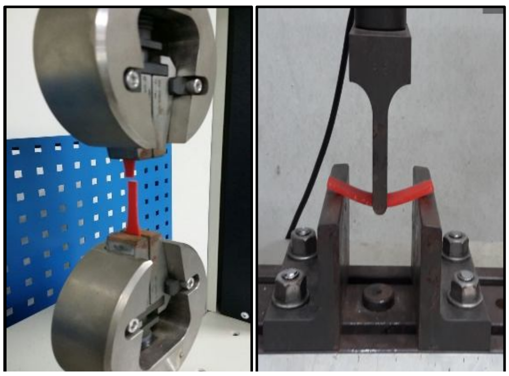

Figure 3: Mechanical Testing set-up

III. RESULTS AND DISCUSSION

3.1. Tensile Results

The influence of layer thickness and exposure time over the tensile strength is tabulate in Table 4 and graph of tensile strength with reference to layer thickness and exposure time was shown in Figure 4.

Table 4: Tensile strength result for varied layer thickness and exposure time

Exposure Time (sec)	Layer Thickness			
	50 μm	70 μm	100 μm	150 μm
	Tensile Strength (N/mm^2)			
3	8.51	8.01	6.44	5.55
6	8.63	8.26	6.76	5.88
9	8.98	8.43	7.01	5.96
12	7.68	7.52	5.99	4.75

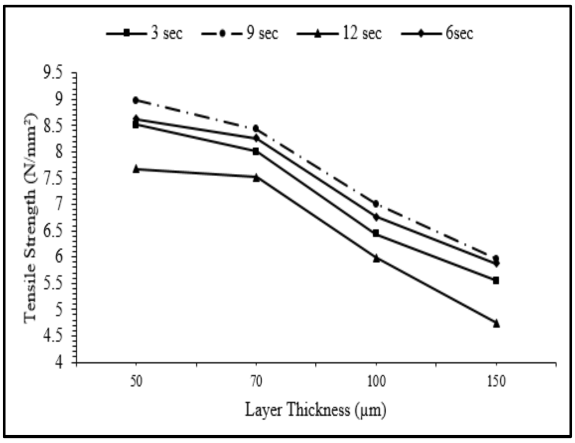

Figure 4: Graph of tensile strength

Based on result from Figure 4, it shows that layer thickness of 50 μm with exposure time of 9 sec have the highest tensile strength which is 8.98N/mm^2. The graph also shows that exposure time have little influenced in enhancing the strength of DLP structure. It was found that at layer thickness of 50 μmhave higher tensile strength due to stronger interlayer bonding between layers created during printing process. The interlayer bonding become stronger with the increase number of layer when creating one complete structure. Due to that, higher stress is required to break all the attached layer until it reach failure [11].

3.2. Flexural Results

The influenced of layer thickness and exposure time over flexural strength were tabulated as in Table 5 and the graph of flexural strength at fracture shown in Figure 5.

Table 5: Flexural strength result for varied layer thickness and exposure time

Exposure Time (sec)	Layer Thickness			
	50 μm	70 μm	100 μm	150 μm
	Flexural Strength (N/mm^2)			
3	16.10	10.87	5.72	5.21
6	16.47	10.92	5.99	5.30
9	18.39	11.03	6.46	5.61
12	15.42	7.26	4.80	4.57

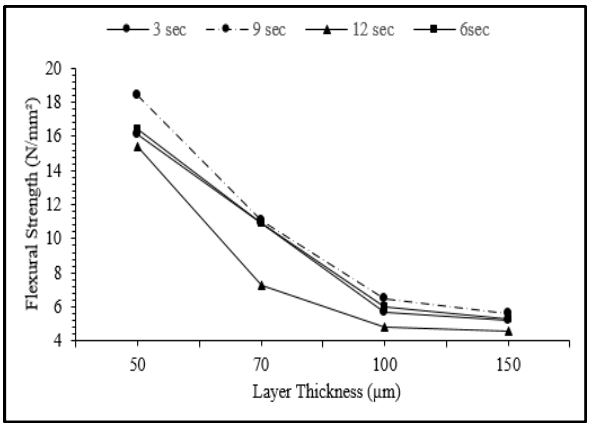

Figure 5: Graph of flexural strength

The graphs shows the layer thickness have a control over flexural strength of the sample. Based on the graph, the flexural strength is decrease linearly as the layer thickness increase. Layer thickness of 50 μm have the maximum flexural strength which is 18.39N/mm^2 compare to other layer thickness. It was discovered that exposure time also have little influence on the flexural strength. At layer thickness of 50 μm, exposure time of 9 sec have the highest value of flexural strength compared to other exposure time.

3.3. Dimensional Accuracy

For dimensional accuracy, the dimension of the specimen is measured by Vernier caliper. Table 6 show the data measurement for DLP structure includes percentage difference for length and Table 7 shows the percentage difference for width.

Table 6: Percentage error for length

Length				
Exposure Time (sec)	Layer Thickness			
	50 μm	70 μm	100 μm	150 μm
	Percentage Difference (%)			
3	1.2	1.6	2.3	3.4
6	1.3	2.0	1.1	2.6
9	0.8	1.9	2.1	2.1
12	2.3	2.4	3.8	3.6
12	9.0	11.0	15.0	21.0

Table 7: Percentage error for width

Width				
Exposure Time (sec)	Exposure Time (sec)			
	50 µm	70 µm	100 µm	150 µm
	Percentage Difference (%)			
3	7.0	9.0	14.0	17.0
6	4.0	5.0	11.0	9.0
9	3.0	4.0	11.0	13.0

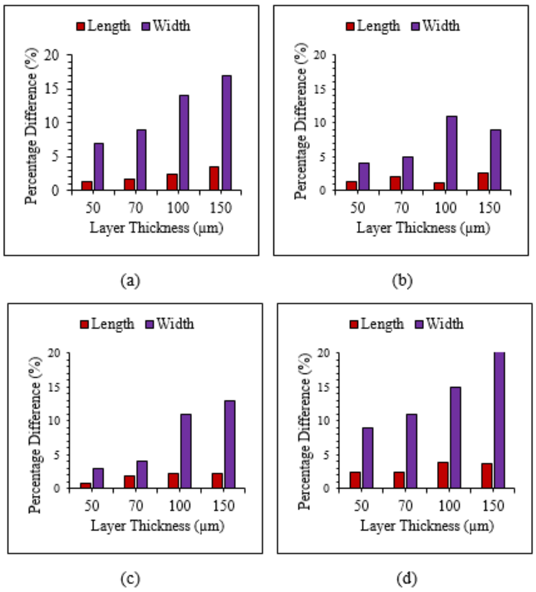

Figure 6: Percentage difference across dimension for different layer thickness at exposure time of (a) 3 sec (b) 6 sec (c) 9 sec (d) 12 sec.

Figure 6 shows the percentage difference between the actual dimensions with measured dimension of the sample. From the graph, it can be observed that layer thickness of 50 µm with exposure time of 9 sec have the smallest percentage difference between actual and measured dimension which is 3.8% compared to other layer thickness and exposure time.

CONCLUSION

It was successfully proved that layer thickness and exposure time have significant influence on physical and mechanical properties of B9R-1-Red. For layer thickness, it discovered that part fabricated from layer thickness of 50 µm have better mechanical properties compared to other studied layer thickness as it have highest tensile and flexural strength which is 8.98 N/mm^2 and 18.39 N/mm^2 respectively. As for exposure time, it was successfully claimed that 9 sec is the optimal exposure time for B9R-1-Red as the strength of DLP part are at the highest compared to other exposure time. The photopolymer need to be exposed under optimal exposure time so that the adhesion bonding between layers become stronger. From overall finding, it can be summarized that layer thickness of 50 µm with exposure time of 9 sec have better mechanical properties for B9R-1-Red along with low dimensional stability compared to other studied layer thickness and exposure time.

REFERENCES

1. Melchels, F. P. (2010). This is the accepted version of this journal article : Melchels , Ferry P . W . and Feijen , Jan and Grijpma , Dirk applications in biomedical engineering . Biomaterials , A review on stereolithography and its applications in biomedical engineering, *31*. http://doi.org/10.1080/01972240903562753
2. Szulżyk-Cieplak, J., Duda, A., & Sidor, B. (2014). 3D Printers – New Possibilities in Education. *Advances in Science and Technology Research Journal*, *8*(24), 96–101. http://doi.org/10.12913/22998624/575
3. Berman, B. (2012). 3-D printing: The new industrial revolution. *Business Horizons*, *55*(2), 155–162. http://doi.org/10.1016/j.bushor.2011.11.003. *Journal of Science and Technology 2012, 12(6), 54-67*
4. Matias, E., & Rao, B. (2015). 3D printing: On its historical evolution and the implications for business. *2015 Portland International Conference on Management of Engineering and Technology (PICMET)*, *2015-Septe*, 551–558. http://doi.org/10.1109/PICMET.2015.7273052
5. Bhatia, U. (2015). 3D printing technology. *International Journal of Engineering and Technical Research*, *3*(2), 327–330
6. Bangalore & Narendra, D. D. (2014). Studies on the Process Parameters of Rapid Prototyping Technique (Stereolithography) for the Betterment of Part Quality. *International Journal of Manufacturing Engineering*, *2014*, 11
7. Reddy, N., Murthy, A., & Rani, D. (2014). International Journal of Advances in Computer Science and Technology. *International Journal*, *3*(2), 161–165. Retrieved from http://warse.org/pdfs/2014/ijacst03342014.pdf
8. Raju, B. S., Chandrashekar, U., Drakshayani, D. N., & Chockalingam, K. (2010). Determining the Influence of Layer Thickness for Rapid Prototyping With Stereolithography (Sla) Process. *International Journal of Engineering Science and Technology*, *2*(7), 3199–3205.
9. Ghazy, M., (2016). Effect of SLA Process Parameters on Part Build- Time Effect of SLA Process Parameters on Part Build-Time, (October 2015).*Journal of Rapid Prototyping , 31(4), 322-336*
10. Richmond, G., Araujo, M., & Guvench, M. G. (n.d.). A DLP Stereolithographic 3D Printer for Experimentation and Research in High Resolution Additive Manufacturing, (2006), 3601.*Journal of Rapid Prototyping, 24(3), 24-32*
11. Farzadi, A., Solati-Hashjin, M., Asadi-Eydivand, M., & Osman, N. A. A. (2014). Effect of layer thickness and printing orientation on mechanical properties and dimensional accuracy of 3D printed porous samples for bone tissue engineering. *PLoS ONE*, *9*(9), 1–14. http://doi.org/10.1371/journal.pone.0108252

★★★