THE ENGINEER STORY

e-ISSN: 3009 - 0792 Volume 6, 2023, 1-6

MANUFACTURABILITY ANALYSIS OF COMPLEX PARTS PRODUCED USING STEREOLITHOGRAPHY (SLA) TECHNIQUE

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ABSTRACT

3D printing has been recognized as the future manufacturing technique by different industries. Stereolithography (SLA) technology demonstrates the potential for manufacturing parts with complex structures for various engineering applications. The properties of products manufactured using this technique depend upon a large number of factors. The purpose of this study is to perform the manufacturability of the SLA complex part which is a Gyroid lattice based on different UV laser exposure times and layer thickness and to analyze the quality of the printed part in terms of mechanical strength and dimensional accuracy. Multilevel Categoric Design of Experiments (DOE) was conducted to generate an experimental plan and assess the influence of the printing parameters on the dimensional accuracy and compressive strength. Analysis of Variance (ANOVA) revealed that exposure time and layer thickness had a significant influence on the compressive strength of the Gyroid lattice. While only exposure time influences the dimensional accuracy of Gyroid lattice. The tested resin showed strengthening with a combination of high-level UV exposure time and low-level layer thickness.

KEYWORD

SLA 3D Printer, Gyroid Lattice, Dimensional Accuracy, Compression Test

INTRODUCTION

Since its invention 50 years ago, 3D printing technology has progressed at a rapid pace, with significant impact in both the industrial and commercial world. Stereolithography, selective laser sintering, and fused deposition modelling were among the first widely successful methods of 3D printing, initially used for industrial prototyping. 3D printing technology was soon developed for use in a variety of fields, for large-scale manufacturing, engineering of highly complex parts, and even for personal use (Su & al'Aref, 2018). The advantages of the AM are less material wastage, freedom of design, and automation. In the few past years, additive manufacturing has developed in industries from prototypes to products. This technology has gained attention in the medical field due to the ability of freedom in design (Ngo et al., 2018).

With the development of AM technology, the cellular structure becomes more attention owing to the possibility of producing complex designs (Kang et al., 2019). The cellular structure is a representative complex design and lightweight product. The cellular structure is divided into a two-dimensional and three-dimensional lattice structure. In the early stage, cellular structure is not familiar to fabricate because of the limitation of design freedom for conventional manufacturing. By using a conventional manufacturing process, the fabrication of cellular structure is difficult and high cost, due to it requires undergoing many manufacturing processes such as punching, roll forming, and welding.

Stereolithography (SLA) is one of the earliest additive manufacturing processes to be used (Vaezi et al., 2013). The method is based on printing using special photocurable resin. The resin is cross-linked under ultraviolet (UV) light exposure, called photopolymerization. According to Cosmi & Maso (2019), the mechanical properties of SLA-printed parts highly depend on several parameters that differ case by case, such as layer height and post-curing settings. This research is carried out to determine the manufacturability analysis of complex parts produced using the Stereolithography (SLA) technique.

The objective of this research is to perform the parameter optimization of the SLA complex part on UV laser exposure time and layer thickness and to analyze the mechanical strength after optimization mainly on compressive strength and dimensional accuracy.

MATERIAL AND METHODOLOGY

In this study, stereolithography (SLA) 3D printer was used to fabricate a gyroid lattice with the dimension of 25mm x 25mm x 25mm as shown in Figure 1. Gyroid lattice is manufactured using varying exposure times and layer thicknesses, including 6s, 9s, and 12s and 0.025mm, 0.05mm, and 0.1mm respectively. Gyroid lattice dimension readings were taken and compared to design dimensions. ANOVA was used to determine the variables that influence dimensional accuracy. At loading rates of 2.5 mm/min, compression tests were performed using a 10kN Shimadzu universal testing machine according to the ASTM D 1621 – 00 (Standard Test Method for Compressive Properties Of Rigid Cellular Plastics1) as shown in Figure 2. ANOVA was used to analyze the compressive strength data and identify the variables that influence compressive strength.

Figure 1: Complete printed Gyroid lattice

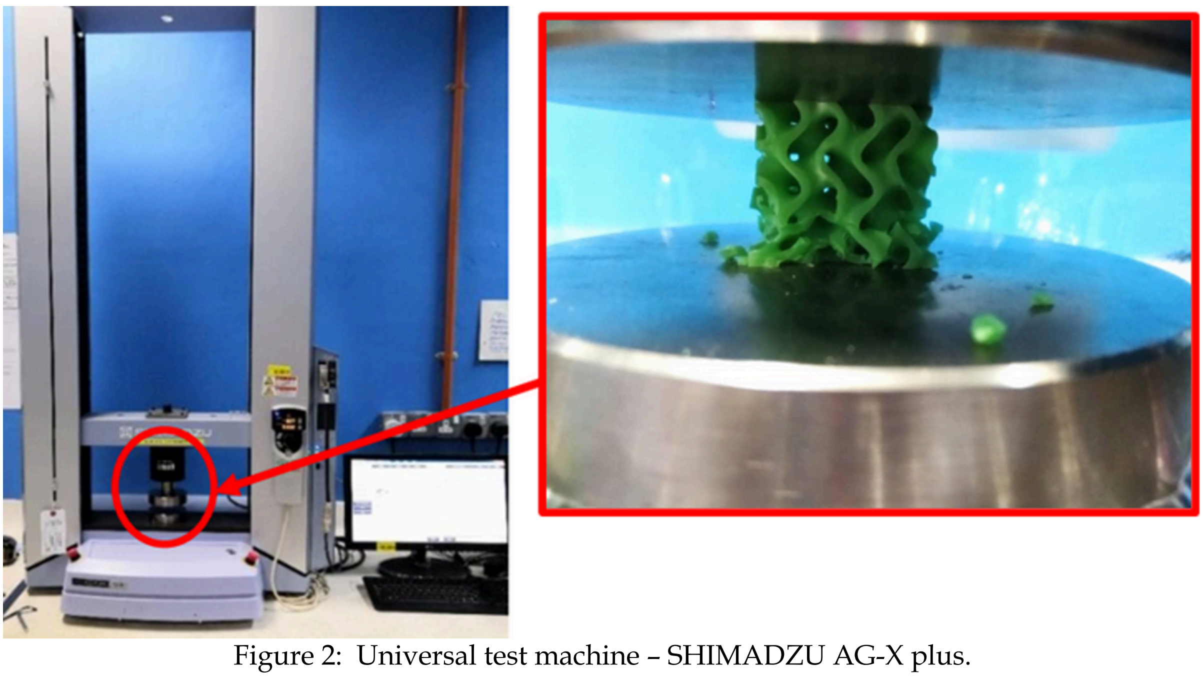

Figure 2: Universal test machine – SHIMADZU AG-X plus.

DIMENSIONAL ACCURACY ANALYSIS

In this research, a dimensional accuracy experiment is done by measuring the height of the specimen which is the dimension on the z-axis. The design value for the height of the printed part is 25mm. From the measurement result, the dimensional error can be calculated by using equation (1). The calculation of dimensional error is shown below by taking the result of the standard order 1 as an example.

Dimensional error (mm) = Measured value (mm) – Design value (mm) (1)

where in standard order 1, Design value = 25.00 mm
Measured value = 25.04 mm

Therefore,
Dimensional error (mm) = 25.04 mm – 25 mm
= 0.04 mm

The data obtained are tabulated in Table 1. The run order is the sequence of the experiment is generated randomly by Design-Expert software.

Table 1: Dimensional error for each printed part from Design Expert

		Factor 1	Factor 2	Response 1
Std	Run	A: Exposure time	B: Layer thickness	Dimensional accuracy
		s	mm	mm
1	9	6	0.025	0.04
2	3	9	0.025	0.09
3	11	12	0.025	0.1
4	15	6	0.05	-0.01
5	14	9	0.05	0.09
6	17	12	0.05	0.08
7	10	6	0.1	0
8	13	9	0.1	0.06
9	6	12	0.1	0.12
10	4	6	0.025	0.07
11	12	9	0.025	0.16
12	8	12	0.025	0.12
13	16	6	0.05	0.03
14	7	9	0.05	0.08
15	1	12	0.05	0.04
16	5	6	0.1	0.07
17	18	9	0.1	0.06
18	2	12	0.1	0.08

Table 2: Result of ANOVA for dimensional error from Design Expert

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.022	8	0.0027	3.09	0.0564	not significant
A-Exposure time	0.0128	2	0.0064	7.22	0.0134	
B-Layer thickness	0.0064	2	0.0032	3.61	0.0708	
AB	0.0027	4	0.0007	0.7656	0.5735	
Pure Error	0.008	9	0.0009			
Cor Total	0.03	17				

Based on the results of ANOVA, the p-value for A-Exposure time and B-Layer Thickness are 0.0134 and 0.0708 respectively as shown in Table 2. Since the p-value is less than 0.05, the H0 is rejected due to there exists a significant difference at the 0.05 level of significance. Therefore, it can be concluded that the exposure time is the most significant process parameter that influences the dimensional accuracy of the printed part

MECHANICAL PROPERTIES ANALYSIS

For this analysis, a compression test is carried out to determine the compressive strength of the printed part. After obtaining the value of stress and strain, the stress-strain curve is plotted in Microsoft Excel for each set of data as shown in Figure 1. The result of the compressive strength is shown in Table 3. Figure 1 shows the highest maximum stress for the specimen gyroid is the parameter (12s) exposure time and (0.025mm) layer thickness with a maximum stress value of 7.43 Mpa. While the lowest maximum stress for gyroid is a specimen with (6s) exposure time and (0.1mm) layerthickness with a maximum stress value of 4.29 Mpa. Based on the results of ANOVA, the p-value for A-Exposure Time, B-Layer Thickness and AB are < 0.0001, < 0.0001and 0.1620 respectively. The p-value of A-Exposure time and layer thickness is less than 0.05, thus H0 is rejected due to there exists a significant difference at the 0.05 level of significance. The result can be concluded that exposure time and layer thickness significantly influence the compressive strength of the printed part. However, AB-Interaction between exposure time and layer thickness does not significant in affecting the compressive strength of the printed part due to the p-value of the layer thickness being greater than 0.05. The results of the analysis of variance for the compressive strength are shown in Table 4.

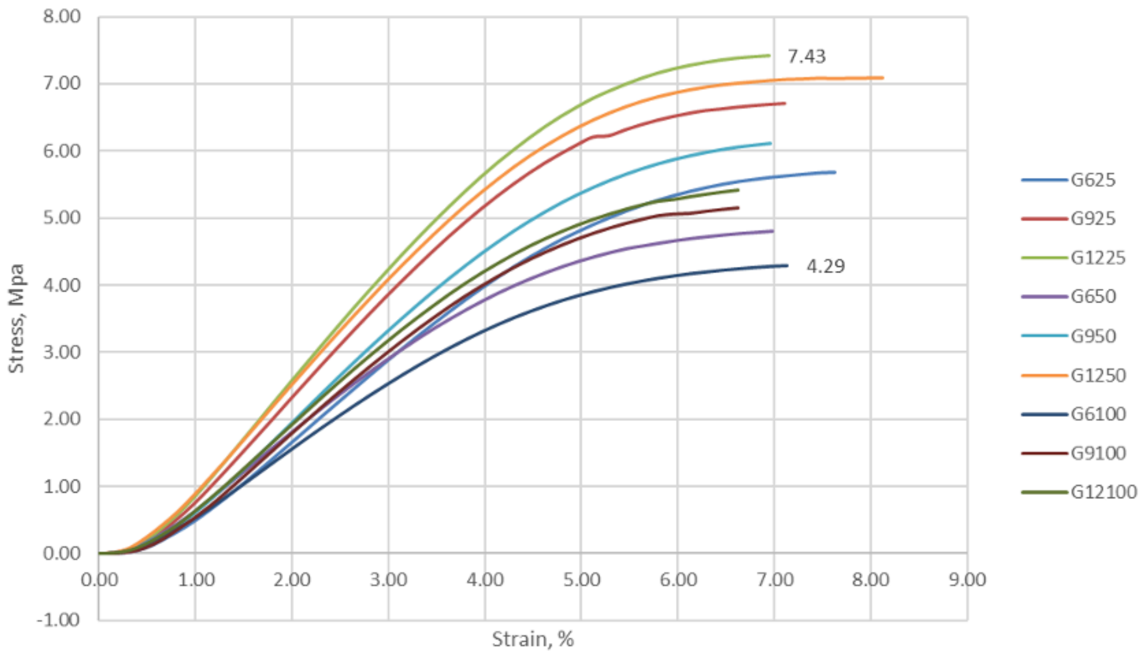

Figure 1: Graph Stress vs Strain for Gyroid.

Table 3: Compressive Strength for each printed part from Design Expert

No	Name Parameter Unit	Mean Max_Stress Calc. at Entire Areas (N/mm2)
1	G625	5.68
2	G925	6.71
3	G1225	7.43
4	G650	4.81
5	G950	6.12
6	G1250	7.09
7	G6100	4.29
8	G9100	5.16
9	G12100	5.41

Table 4: Result of ANOVA for compressive strength from Design Expert.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	18.23	8	2.28	28.91	< 0.0001	Significant
A-Exposure time	8.96	2	4.48	56.83	< 0.0001	
B-Layer thickness	8.61	2	4.3	54.61	< 0.0001	
AB	0.6647	4	0.1662	2.11	0.162	
Pure Error	0.7092	9	0.0788			
Cor Total	18.93	17				

CONCLUSION

The result was shown that the dimensional accuracy is significantly affected by exposure time. Dimensional accuracy increase as the exposure time decrease. Generally, to improve the dimensional accuracy of the printed lattice structure, the ideal settings for process parameter is low exposure time and thin layer. Furthermore, exposure time and layer thickness have a significant impact on compressive strength, however, an ANOVA analysis revealed that interaction between exposure time and layer thickness has a minor impact on the mechanical properties. The previous study suggested that a longer exposure time might improve the mechanical characteristics. High exposure times, however, will increase dimensional error, leading to printed items that are imprecise.

ACKNOWLEDGEMENT

All test specimens are prepared as per ASTM Standard. The authors express special thanks to UTM Malaysia and the reviewers for their thoughtful review and comments

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