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Effect of process parameters on the geometrical quality of ABS polymer lattice structure

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ABSTRACT – This research investigated on the effect of processing parameters of fused deposition modelling (FDM) technique on the geometrical quality of an ABS polymer lattice structure. Variations of layer thickness of the FDM machine in this study were 70 µm, 200 µm and 300 µm. Examinations on the diameter circularity of the printed lattice blocks were conducted with direct measurement and formulation from a previous study. It was found that, the layer thickness of 200 µm produced more accurate strut diameter with a reliable mechanical response.

1. INTRODUCTION

Cellular structure material has been used in various applications, most commonly as a core material in sandwich structure because of their good energy absorption performance and lightweight property. Honeycomb and foam are the most studied core material [1-2]. They possess high stiffness and strength-to-weight ratio [3]. Besides, there has been an increasing interest in a new type of cellular material, namely lattice structure material.

Lattice structure material is a periodic open cell structure which was established from the approximation procedure of microstructure models for foam. Lattice structure is found to be stiffer and stronger than metal foam with same material and weight [4]. The industry, particularly aerospace and automotive develop strong interest in material with high performance but lower in energy and cost consumption. Therefore, more studies on lattice structures have been conducted to find its best properties that can be used in lightweight, high performance applications [3-5]. In order for this lattice structure to be successful, the relationships between the geometry and mechanical properties should be determined. Hence, this study utilized additive manufacturing technique to investigate the effect of the process parameters on the diameter circularity of the printed part and the relationship with the mechanical response of the produced lattice block.

2. METHODOLOGY

In this work, lattice structure composed of cells from body-centred-cubic (BCC) arrangement was designed with 1.6 mm strut diameter. Figure 1 shows a BCC single unit cell and one complete lattice structure block designed in SolidWorks.

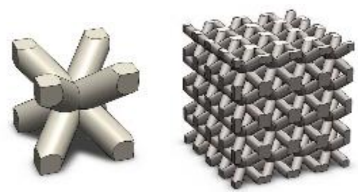

Figure 1 BCC single unit cell and one complete lattice structure block

The lattice structure was manufactured using FDM method. Figure 2 shows the schematic diagram of FDM printer machine. CubePro 3D printer machine by 3D Systems Inc. was used to fabricate the lattice structure blocks with the size of 20×20×20 mm made from acrylonitrile-butadiene-styrene (ABS) material. Combination of parameters used are provided in Table 1. In this study, the studied process parameter was the layer thickness.

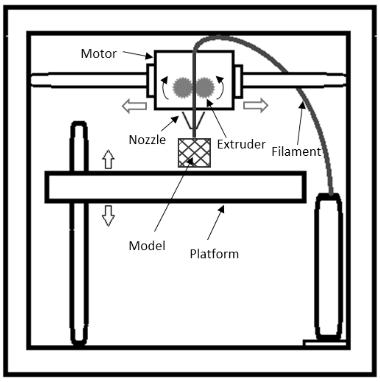

Figure 2 Schematic representation of FDM printer machine

Table 1 Samples ID and process parameters

Sample ID	Print pattern	Print strength	Layer thick-ness (μm)	Dia-meter (mm)
As/Hc/70/1.6	Honey-comb	Almost Solid	70	1.6
As/Hc/200/1.6	Honey-comb	Almost Solid	200	1.6
As/Hc/300/1.6	Honey-comb	Almost Solid	300	1.6

Lattice structure blocks in this study were tested under compression test at a rate of 1.3 mm/min in compliance to ASTM D695-15 standard test procedure using Instron 5585 compression test machine. The lattice structures produced by FDM technique were defined in terms of its diameter. The objective was to study the most promising parameters combination of this particular machine to produce the most accurate product according to the designed drawing. In this study, measurement of strut diameters was done by using optical microscope. The measured strut diameters were compared with estimated diameter by formulation from Tsopanos as well as Kude and Khainar similar as done in [5].

3. RESULTS AND DISCUSSION

Table 2 compares the results of the differences between all methods. By taking the direct measurement as reference, the results give a percentage of error less than 20%. Considering all methods, it can be concluded that the layer thickness of 200 μm produced lattice structure with strut diameters closest to the designed lattice structure.

Table 2 Diameter of struts for different layer thickness from various method

Method	Diameter of strut (mm)		
	70 μm	200 μm	300 μm
Direct measurement (mm)	2.036	1.655	1.373
Tsopanos formula (mm)	1.721	1.458	1.163
Percentage of difference for Tsopanos formula	0.820 %	6.944 %	0.539 %
Kude and Khainar formula (mm)	2.052	1.780	1.365
Percentage of difference for Kude and Khainar formula	15.425%	11.894%	15.282%

Figure 3 shows the relationship between the layer thickness to the relative density where it is discovered that lower layer thickness increased the relative density. Figure 4 is the closed up view of the strut by using the optical microscope which shows the differences between each layer thickness. As observed in Figure 4, the 70 μm layer thickness possessed greater interlayer bonding which makes the staircase effect less visible as compared to 200 μm and 300 μm layer thickness. The schematic diagrams of staircase effect between each layer thickness are shown in Figure 5. Smaller layer thickness resulted to more material deposition and hence caused increment in mass. Consequently, the density and relative density of the lattice structures were also increased.

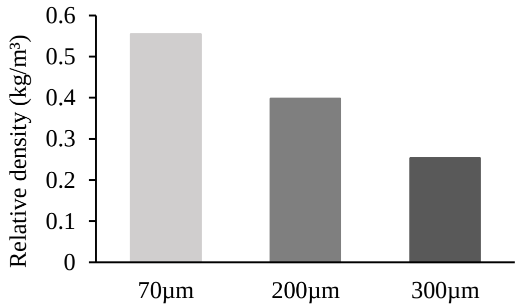

Figure 3 Effect of layer thickness to relative density

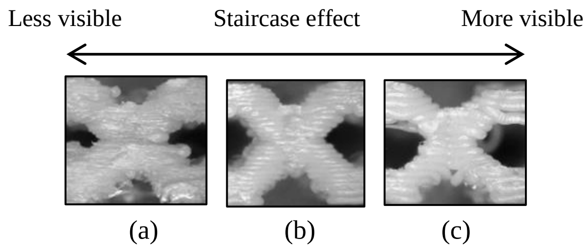

Figure 4 Closed-up view of strut with layer thickness of (a) 70 μm, (b) 200 μm and (c) 300 μm

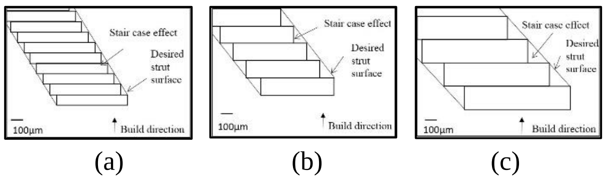

Figure 5 Schematic diagram of staircase effect with layer thickness of (a) 70 μm, (b) 200 μm and (c) 300 μm

Figure 6 provides the typical stress-strain curves of the lattice structures with three different layer thicknesses. As observed, there is a significant rise in the elastic regions, to steady plateau regions, then grow into densification regions. Comparison between layer thicknesses showed that smaller layer thickness resulted in higher compressive strength. From the graph, it can be concluded that larger layer thickness possessed longer flat plateau. In this case, the 200 μm layer thickness resulted in better response than 70 μm layer thickness as it showed longer plateau region.

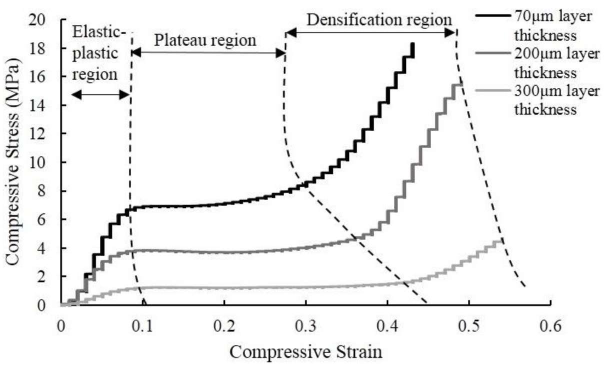

Figure 6 Stress-strain graph of different layer thickness

4. CONCLUSION

In this research, the investigation on the effect of process parameters to the produced lattice blocks was done by studying the quality of strut. It showed that variations in strut diameter affected the deformation behaviour and mechanical properties of lattice structure. Although the 70 µm layer thickness showed greater interlayer bonding, the layer thickness of 200 µm produced better quality of struts. The 200 µm layer thickness lattice produced reasonable mechanical response where it possessed long flat plateau at a good strength.

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