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3D PRINTER'S PARAMETER OPTIMIZATION FOR POTENTIAL PATIENT SPECIFIC IMPLANT FABRICATION

Abdul Manaf Abdullah[a], Dasmawati Mohamad[a]*, Tuan Noraihan Azila Tuan Rahim[b], Hazizan Md Akil[b], Zainul Ahmad Rajion[a]

[a]School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, Kelantan
[b]School of Material and Mineral Resources Engineering, Universiti Sains Malaysia, Penang

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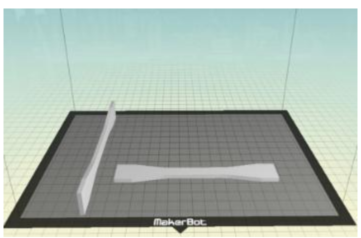
*Corresponding author
dasmawati@usm.my

Graphical abstract



Abstract

This study attempted to investigate the effect of printing orientation and layer height on mechanical and topological properties of printed ABS specimens. 2 printing orientations (xy and yz) with 3 different layer heights (0.1, 0.2 and 0.3mm) were chosen and specimens were printed utilizing a 3D printer. Tensile, morphological and topological properties were evaluated utilizing Universal Testing Machine (Shimadzu AGX-2plus), FESEM and surface profilometer respectively. Statistical analysis of two-way Anova was carried out to investigate the relationship of layer height and printing orientation on the tensile strength and surface roughness of the specimens

Keywords: 3D printer, layer height, printing orientation, tensile strength, surface roughness.

1.0 INTRODUCTION

Additive manufacturing is currently an emerging technology that usually being used to produce prototypes for design review. The enhancement of this technology has also benefited medical and health practitioners as the aim to produce patient specific implant (PSI) with reasonable cost is one step ahead to become reality.

An affordable additive manufacturing segment that currently available is an extrusion base 3d printer that uses fused filament fabrication (FFF) technology. As it is inexpensive, drawbacks such as small build plate and limited heater capability affect the build size and variety of materials that could be tried on.

The commercial 3D printer comes with their own software that controls the printer. Makerbot Corporation, United States based company introduced Makerbot, a 3D printer that utilizes software named Makerware. Though open source software offers more control, Makerware provides adequate function that could be enhanced. Many researchers have started to investigate the 3D printer's existing parameter. The properties of ABS printed using various open source filament based RepRap 3D printer in combination with angular pattern orientation and various layer heights were found to be comparable to the commercial 3D printer [1]. Other than ABS, mechanical properties of calcium sulphate semihydrate scaffold printed using commercial powder based 3D printer in combination with various layer heights and orientations has also been investigated [2].

Material for implantation need to be biocompatible, easy to fabricate, osseointegrative and have sufficient mechanical integrity [3]. Equipped with build plate size of 25cm x16 cm, among the biggest in its segment with robust technology, implant fabrication via 3D printer (Makerbot Replicator 2X) could be achieved. However the material property needs to be well defined and must be suited with the application and processing techniques. Besides, 3D printer's existing parameter could be optimized in order to achieve good quality of build in term of strength and aesthetic.

This study attempted to optimize the 3D printer's parameter of Makerbot Replicator 2X, in order to discover the potential implant fabrication for this device. Layer height and printing orientation were chosen as variables to evaluate the effect on strength and surface roughness of the printed specimens.

2.0 MATERIALS AND METHODS

Material used for this study was commercial ABS filament, Lot No 62757 (Makerbot Corporation, USA). The filament was fitted at 3D printer (Replicator 2X, Makerbot) and it was used to print the tensile specimens. Tensile specimen was designed using CAD software (SolidWorks, USA) following ASTM D638 and was converted to standard tessellation language(STL), 3D printer's readable format. The file was then sliced utilizing Makerbot slicing programme (Makerware), and was sent to the printer for printing. Specimens were placed at two different orientations, which were xy and yz as in Figure 1 following [4] with layer heights of 0.1, 0.2 and 0.3mm, ended up of 6 systems with 7 specimens (n=7) in a system. Design of experiment of this particular study was summarized in Table 1. Extruder temperature was set at 230°C with 110°C heated build plate. Printed tensile specimens were used to check the surface roughness using surface texture measuring instrument (SURFCOM FLEX, Accretech Japan). The parameter setting such as cut off value, evaluation length and measure speed were set at 0.80mm, 5.00mm and 0.60mm/s respectively. The tensile properties were tested utilizing Universal Testing Machine (Shimadzu AGX-2 plus) fitted with 20kN load cell with cross head speed of 5mm/min. The fracture surfaces of tensile specimens were evaluated using FESEM. Statistical analysis was performed using IBM SPSS Statistics version 22. Two-way Analysis of Variance (ANOVA) was carried out to observe the relationship of layer height and orientation on the tensile strength and surface roughness of the specimens. The interactions were considered as significant when $p< 0.05$.

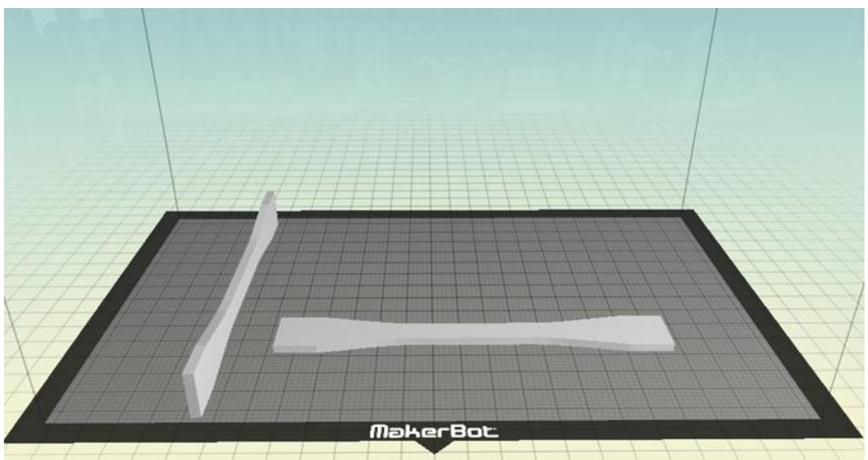


Figure 1 Orientation of specimens visualized in Makerware

Table 1 Design of experiment of this particular study

	Layer height	Orientation
System 1	0.1	xy
System 2	0.1	yz
System 3	0.2	xy
System 4	0.2	yz
System 5	0.3	xy
System 6	0.3	yz

3.0 RESULTS AND DISCUSSION

3.1 Statistical Analysis

The result of two-way ANOVA are shown in tables below. Printing orientation (xy and yz direction) and layer height (0.1, 0.2 and 0.3mm) interaction was statistically significant on the dependent variable of surface roughness(p = .027). Although printing orientation showed no statistically significant on tensile strength but the interaction between printing orientation and layer height showed statistically significant on tensile strength ($p < .05$).

Table 2 Result of two-way ANOVA for surface roughness.

Dependent Variable: Surface roughness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1214.556[a]	5	242.911	51.883	.000
Intercept	1904.389	1	1904.389	406.757	.000
Orientation	1125.790	1	1125.790	240.457	.000
Layer	51.282	2	25.641	5.477	.008
Orientation * layer	37.484	2	18.742	4.003	.027
Error	168.548	36	4.682		
Total	3287.493	42			
Corrected Total	1383.104	41			

a. R Squared = .878 (Adjusted R Squared = .861)

Table 3 : Result of two-way Anova for tensile strength.

Dependent Variable: Tensile strength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	200.954[a]	5	40.191	51.319	.000
Intercept	43558.007	1	43558.007	55618.525	.000
Orientation	1.972	1	1.972	2.519	.122
Layer	191.578	2	95.789	122.312	.000
Orientation * Layer	7.190	2	3.595	4.591	.017
Error	26.627	34	.783		
Total	44483.544	40			
Corrected Total	227.581	39			

a. R Squared = .883 (Adjusted R Squared = .866)

3.2 Surface Roughness

Figure 2(a) shows the effect of layer height and printing orientation on surface roughness of ABS specimens. Higher layer setting in combination with xy orientation resulted in rougher surfaces, where 0.3mm of layer setting showed the highest surface roughness value. This result was in agreement with a study conducted by [4], where higher layer setting resulted in rougher surface.

Being an essential factor for successful implant, several studies reported that osseointegration critically depends on the surface roughness of the material. Nowadays, calcium phosphate based implant such as β-TCP and HA augmented material is widely used due to bioactive surface characteristic. Study showed that human bone marrow cell adhesion and proliferation were increased as surface roughness of HA increased [5]. A study conducted on mouse MC3T3-E1 osteoblast cells seeded on β-TCP/chitosan surface also proved that rougher surface cultivated cell attachment [6]. Thus, natural roughness created via 3D printing could be manipulated to produce implant that would induce osseointegration.

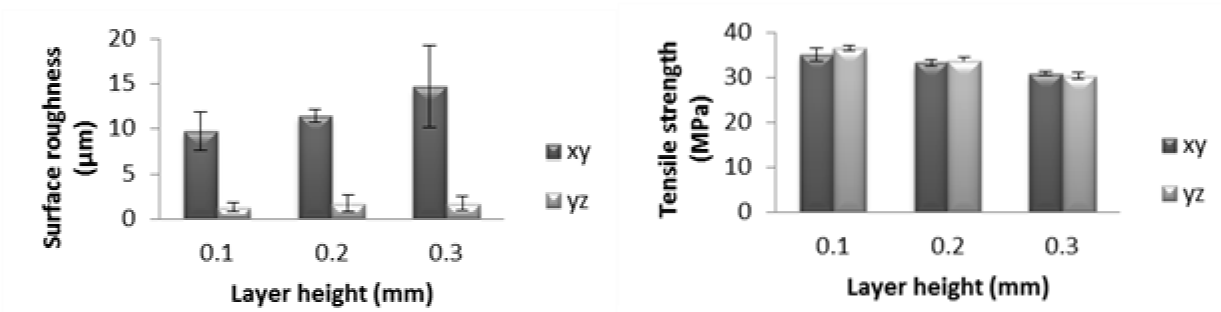
3.3 Tensile Strength

Figure 2(b) shows the effect of layer height and printing orientation on tensile strength of ABS specimens. Thinner layer height in combination with yz orientation resulted in higher tensile strength, where 0.1mm of layer height showed the highest tensile strength.

Specimens fabricated via thinner layer setting ended up with more layer filled,therefore higher stress was needed to break the structure. Printing utilizing yz orientation contributed to the higher tensile strength as the printing orientation was parallel with the testing mechanism. The printed specimens tended to elongate more during testing compared to others before the structure broke.

3.4 Fracture Surface

Fracture surfaces of selected systems are shown in Figure 3. Compact layering structure can be seen in Figure 3(a). The surface was also homogenous with very small air gap and this morphological properties led to a higher tensile strength. In contrast, layering gap was obviously visible in Figure 3(b) due to thicker layer setting. Air gap was also detected at certain areas and this led to a lower tensile properties.



(a) (b)

Figure 2 Effect of layer height and printing orientation on (a) surface roughness, (b) tensile strength.

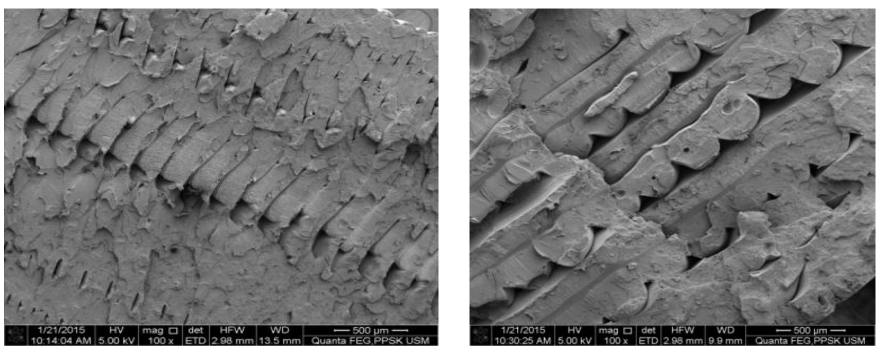


Figure 3 SEM micrograph of (a) System 2 and (b) System 5

4.0 CONCLUSION

In this study, surface roughness and tensile strength of 3D printed ABS specimens were evaluated at 0.1, 0.2 and 0.3mm layer height setting in combination with two printing orientations. In conclusion, printing orientation and layer height gave significant impact to the surface roughness of the specimens. This result plays an important role to determine the parameter setting for implant fabrication as certain roughness topology will affect cell attachment for further cell adhesion. Nevertheless, only layer height showed significant impact on tensile strength. Thus, with layer height and orientation setting that could be enhanced for a better mechanical and topological properties, Makerbot Replicator 2X is a potential device for patient specific implant fabrication.

Acknowledgement

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