Effect of Hatching Distance on Surface Morphology and Surface Roughness of the Ti6Al4V for Biomedical Implant using SLM Process

Mohd Faizal Sadali[1*], Mohamad Zaki Hassan[1], Nurul Huda Ahmad[1], Hafizal Yahya[2] and Ariff Farhan Mohd Nor[2]

[1] Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur
[2] Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur

Abstract

Sintering Laser Melting is recently used for manufacturing industry to produce biomedical parts. The design properties that affected the topography of porous titanium for a biomedical implant that closely suit to human cortical bone fabricated via additive manufacturing is still limited. The aim of this work was to study the effect of hatching distance on the morphology and surface microscopy of Ti6Al4V using sintering laser melting (SLM). The square cube with the dimension of 10x10x10 mm fabricated at three different levels (0.11, 0.12 and 0.13 mm) of hatching distances. Here, the volumetric energy density parameter, including scanning speed, thickness layer, and laser power were fixed. The result showed that the surface morphology of the parts, consisting of balling effect and microcrack, had the most significant effect on microstructure. In addition, the average roughness on the side surfaces are 4.4 µm and 4.8 µm respectively, which is well suit for the bone-implant application in biomedical product.

Keywords: Sintering Laser Melting, Titanium Alloy, Surface Roughness.

Article Info

Received 15th October 2019
Accepted 29th November 2019
Published 2nd December 2019
*Corresponding author: Mohd Faizal Sadali; e-mail: mohdfaizal.sadali@outlook.com
 ISSN: 1823-7010
eISSN: 2600-7444

Introduction

Sintering Laser Melting (SLM) technology is a layer by layer process by the deposition of material where the laser power melts the powder following the slices generated from a model of three-dimensional (3D) design [1]. SLM is a favorable alternative technic to manufacture components made of highly complex structure and alloy material, especially for biomedical implant.

Titanium alloy especially Ti6Al4V is the largest use of titanium based material in the biomedical industries [2]. It offers a highly corrosion resistance, low specific gravity, fracture toughness and excellent strength to make a bone implant more realistic. Bandyopadhyay et al. [3] suggested the Ti6Al4V alloy structures containing 23-32 vol.% porosity showed suitable modulus property that is equivalent to human cortical bone. Further, Ponader et al. [4] suggested the Ti6Al4V samples with surface roughness less than 24.9 µm suited for cell proliferation, however surface roughness that are higher than 56.9µm reduced the proliferation of human osteoblast cells.

Hatching distance is the distance between the scanning track on the additive manufacturing process. Gong et al. [5] evaluated the laser power and scan rate on fabrication of Ti6Al4AV using SLM and EBM processes. The different process zones corresponding to an incomplete melting, partially dense material, "over-melting" and overheating were identified. The influence of hatch spacing on the microstructure and as-built quality of 316L stainless steel samples fabricated by SLM. It found that the increase of hatch spacing, highly coarsens the surface microstructure due to the reduced cooling rate. The effect of hatching distance determined the higher building rate and density due to the parts are built in a layer by layer process, and each layer is produced in the track-wise fashion [6]. In addition, different hatching distance resulted the different surface qualities and heat transfer behavior [7].

In this study, the influence of hatching distance in the SLM parameter through the surface roughness and surface morphology was evaluated. The SLM process parameters containing volumetric energy density (VED) including laser power, layer thickness, scanning speed and hatching distance were initially fixed during processing processes.

Materials and Methods

Materials

In this study, Ti6Al4V powder supplied by SLM Solution Group AG was used. The material composition for Ti6Al4V is tabulated in Table 1. The particle size of powder is approximately 30µm.

Table 1: Chemical composition of Ti6Al4V

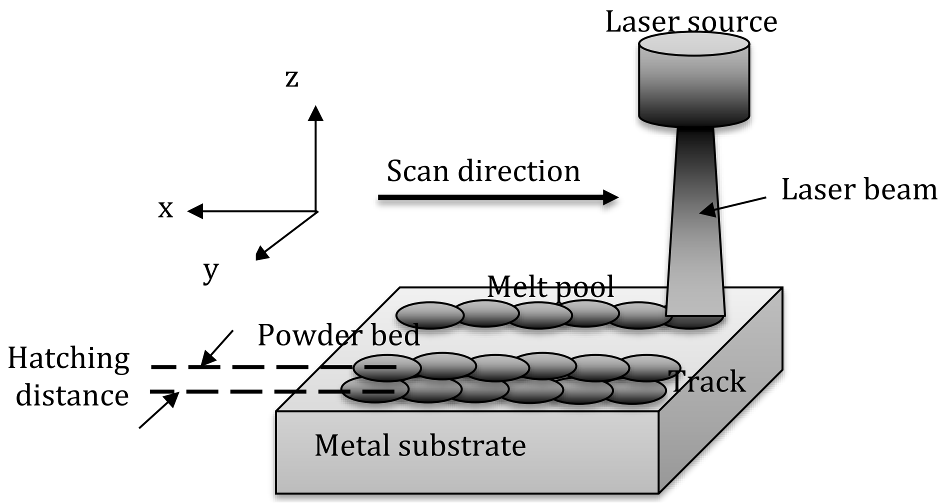
Chemical composition (nominal), %									
Ti	Al	V	Fe	C	N	O	H	Others	Residuals
Bal.	5.5-6.5	3.5-4.5	0.25	0.08	0.03	0.13	0.0125	0.10	0.40

Preparation of samples

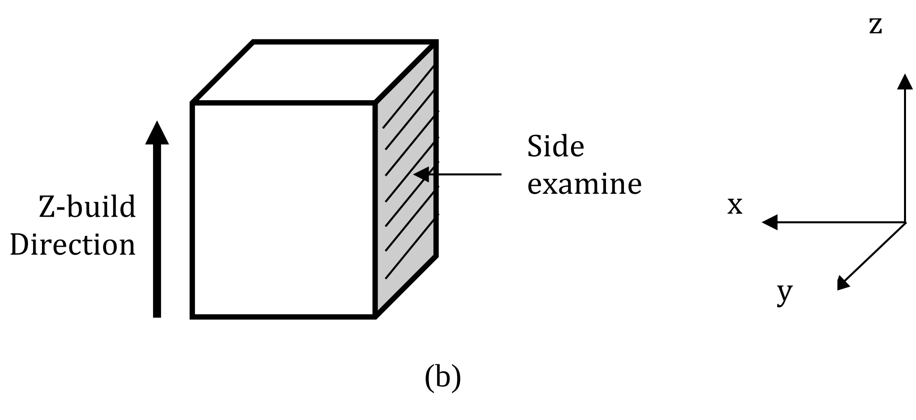
Figure 1(a) depicts a schematic of the SLM process. The specimens are fabricated using SLM125 with a build envelope of 125 x 125 x125 mm at KKTM Kuantan. The samples were manufactured with 10 x 10 x 10 mm cubes. The specimens were directly fabricated on the build plate as shown in Figure 1(b). The volumetric energy density (VED) of the samples was calculated and consisted of laser power (*P*), scanning speed (*v*), hatching distance (*h*) and layer thickness (*t*) as pointed in Equation 1 below:

$$VED = \frac{P}{v.h.t} \qquad (1)$$

Where *VED* is the volumetric energy density in (J/mm^3), *P* is laser power in (*W*), *v* is scanning speed in (mm/s), *h* is hatching distance in (mm), and *t* is layer thickness in (mm).



(a)



(b)

Figure 1 Schematic representative of a typical (a) SLM setup and (b) Ti6Al4V alloy sample building direction

Table 2 illustrates the design parameter used to study the interaction effects of the process parameters and scanning speed of the SLM process [8]. Here, the optimum laser power was fixed at 175W and the scanning speed was 775 mm/s. On other hand, the hatching distance was in the range of 0.11mm, 0.12mm, and 0.13mm respectively. Figure 2 shows a typical flow chart representation of evaluation on effect of hatching distance in SLM process.

Table 2: The SLM processing parametric condition

Parameter	**Unit**	**Value**
Laser Power (P)	Watt, W	175
Scanning Speed (v)	mm/s	775
Thickness (t)	µm	30
Hatching Distance (h)	mm	0.11, 0.12, 0.13

Characterization

In this experiment, the side surface of the sample is studied. The Field Emission Scanning Electron Microscope (FESEM) JEOL JSM-7800F was used to examine the surface morphology on the specimens. The surface roughness features of the sintered samples are examined under the Olympus LEXT 3D Measuring Laser Microscope, model OLS4100.

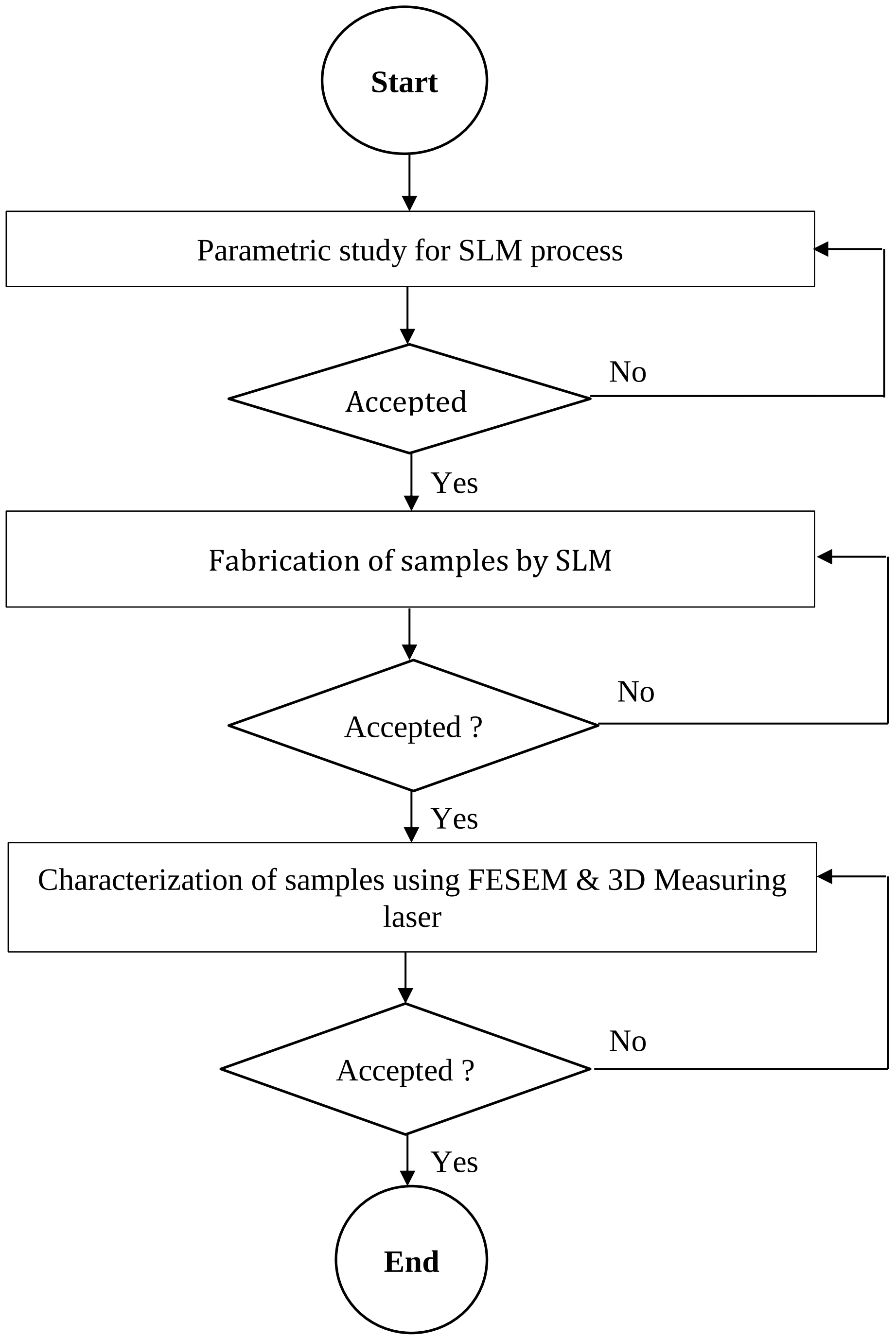


Figure 1: Flow chart for the experiment

Results and Discussions

Impact of Hatching Distances

The typical volumetric energy density (VED) hatching distance traces of the Ti6Al4V alloy is shown in Figure 3. An examination of the figure indicates that this VED increases with increasing of the hatching distance, reaching a peak value at 0.12 mm. This phenomenon shows the influences of hatching distance as a primary parameter in SLM processes suggested by Derahman et al. [9]. They found that the minimum of hatching distance and laser power results produced lower quality of parts. It was directly related to sufficient energy to melt the virgin powder. Shi [10] mentioned that hatching spacing largely influenced the density of the samples. In a proper hatch spacing, near fully dense parts were produced due to proper overlap rate and reduce the entrapped hollow gasses during aggregate process.

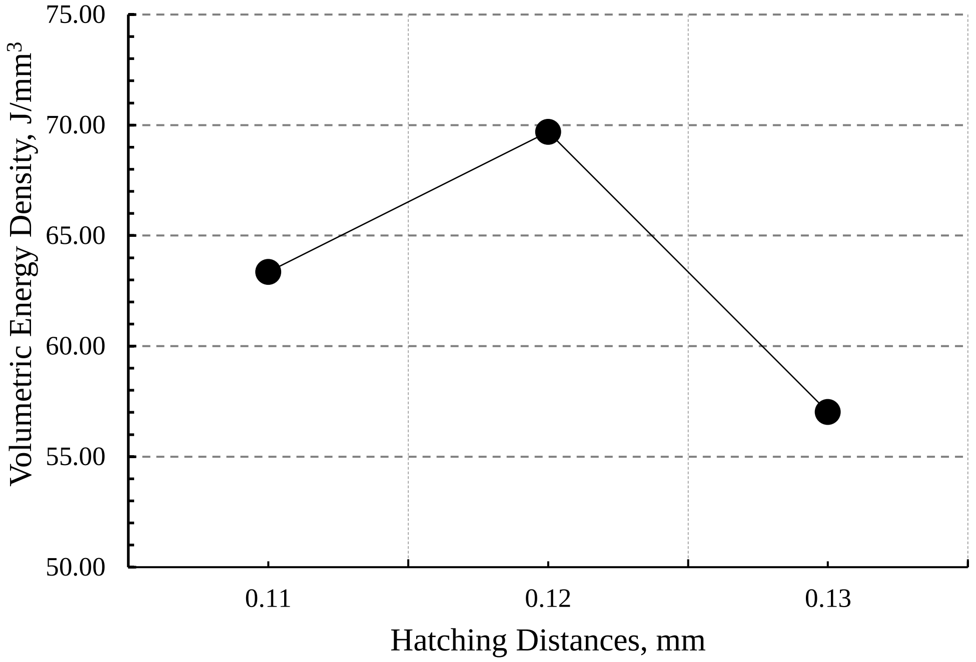


Figure 2 Typical volumetric energy density-hatching distance traces

Balling Effect

Figure 4 shows side surface morphology of the side Ti6Al4V parts fabricated at different hatching distances of SLM specimens with respect to the Z-direction (Figure 1). The balling effect is visually repeated in pattern in all condition of hatching distances. However, the higher balling effect is noted on the Ti-6Al-4V samples at lowest hatching distance (Figure 4(a)). The rough balling effects are possibly due to inhomogeneity and deposition process of the powder between layers in the molten pool. Different states of powder form between dissimilar liquefying and solidification behavior, resulting in the instability of liquid track that breaks up into several spherical agglomerates to obtain the equilibrium phase [11]. Osakada et al. [12] stated that these balls were created due to non-direct solidifying of the powder. Furthermore, during the layer-by-layer of the SLM process, balling effect was a serious interference to create the micro-crack on the surface (Figure 4(b)). This balling effect is not severe as shown in Figure 4(c), however it still tends to produce porosity induced by poor interlayer bonding resulted from inconsistency thickness of the fresh powder deposition on the previous layering process.

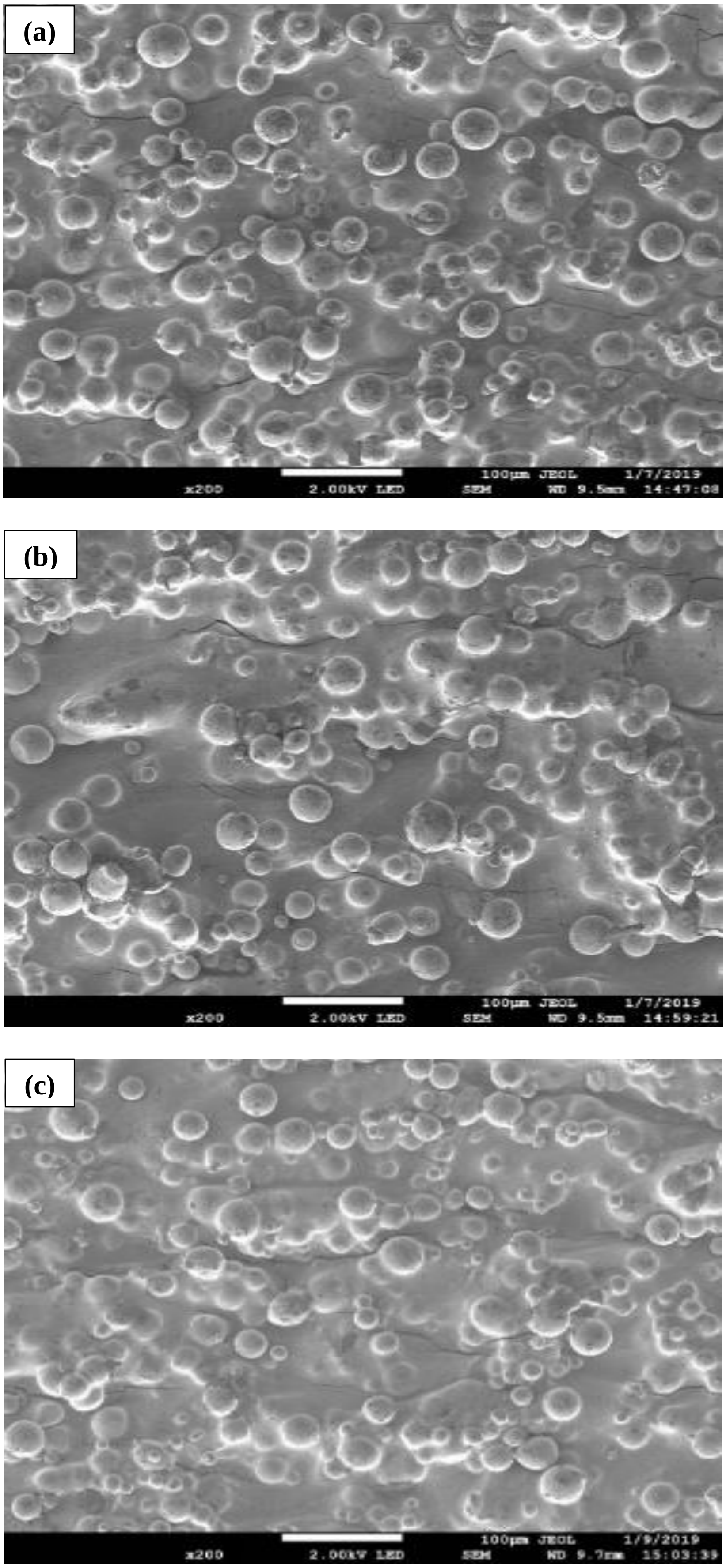
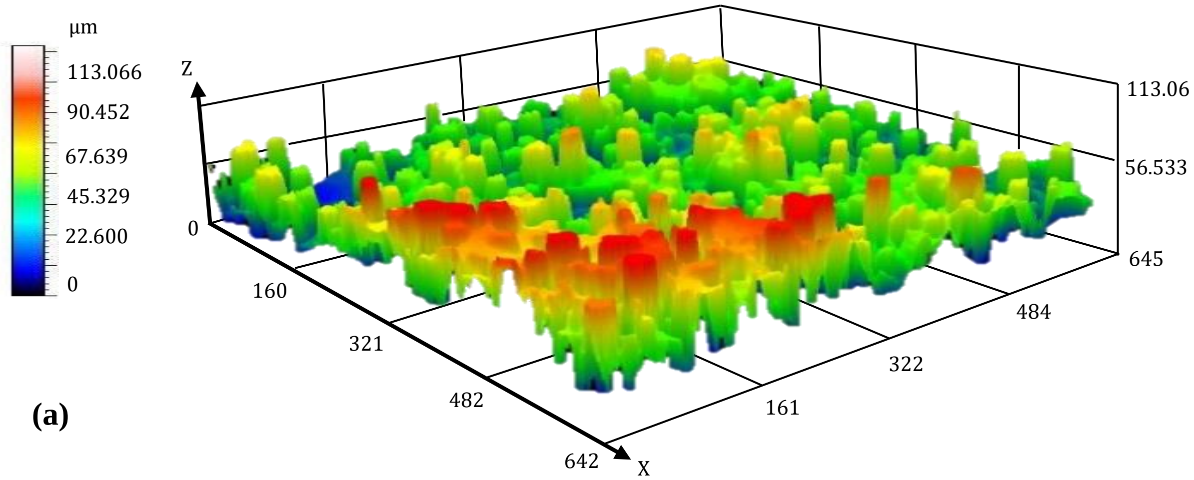


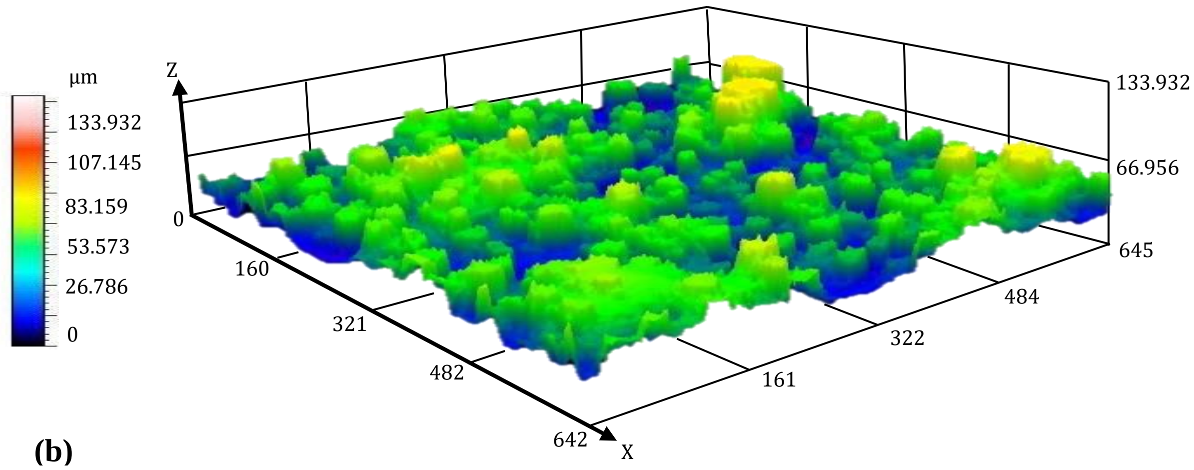
Figure 3: SEM images showing the surface morphology of SLM process on the side of the samples at different hatching distances *(h)*: (a) h: 0.11mm, (b) h: 0.12mm, (c) h: 0.13mm

Surface Roughness

Figure 5 shows the differences of the surface roughness at different hatching distances. As can be seen from the figure, increasing the hatching distance from 0.11mm to 0.13mm, the quality of roughness of the samples is decreased. On the other side, for the hatching distance 0.13mm the roughness is increased. The average value roughness (Ra) of the top surfaces are 4.8µm, 4.4µm and 4.7µm for the hatching distances 0.11mm, 0.12mm and 0.13mm respectively. The increasing of hatching distance resulted in decreasing the roughness quality due to reducing overlap between the melted layer [13]. Foster et al. [14] mentioned that increasing the hatching distance affected the roughness of the parts and created more valley and hill type effect of the surfaces. Here, it can be suggested that an optimum value hatching distance suitable to be suit well with the proliferation of the cell is 0.12mm with the laser power 175W and scanning speed 775mm/s.



(a)



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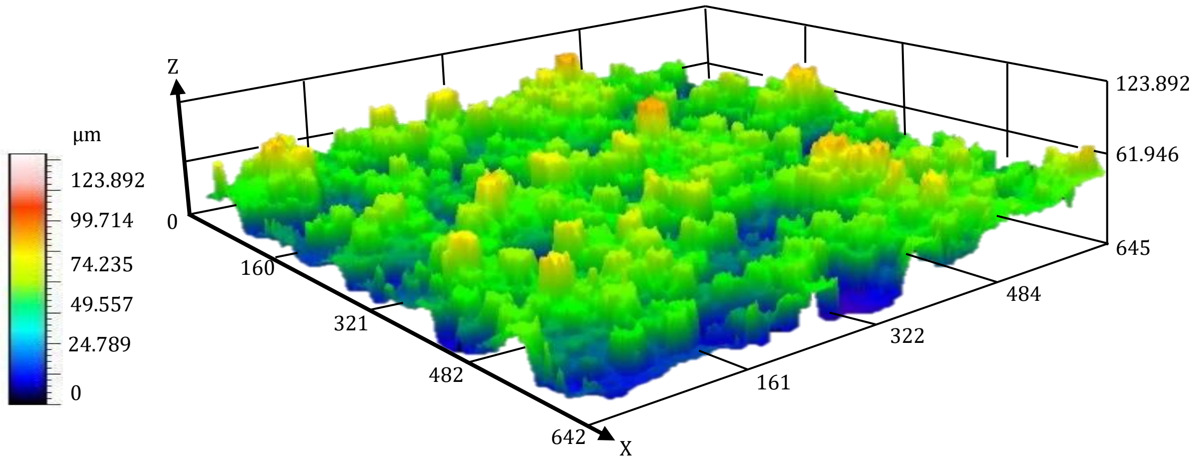

(c)

Figure 4: The surface roughness for the different hatching distance *(h)*: (a) h: 0.11mm, (b) h: 0.12mm, (c) h: 0.13mm

Conclusion

The study of the specimens produced by sintering laser melting (SLM) additive manufacturing technology has guided to the following findings:

- The impact of the different hatching distance on SLM parameter has been revealed.
- The surface morphology with the different hatching distance for the samples has been exposed.
- The hatching distance gives the influence on the quality of the surface roughness to fabricate a part by SLM.
- The optimum hatching distance for this experiment is 0.12mm with the laser power 175W, scanning speed 775mm/s and layer thickness 30µm where resulted in the lowest surface roughness at 4.4µm. The result is acceptable to fabricate bone-implant where minimum requirement of Ra is less than 24.9µm.

In addition, based on this study, it is suggested to study the relationship between all the parameters of SLM to find the most suitable parameter for the surface roughness and bonding between each layer to fabricate bone implant.

Acknowledgements

The appreciation is given to Universiti Teknologi Malaysia and Ministry of Higher Education under “Dana Penyelidikan UTM Razak” (DPUTMRAZAK), R.K130000.7740.4J297 for the financial support provided throughout the course of this research project.

Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Compliance with Ethical Standards

This study was not using any ethical standard.

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