Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-01-0054

Increasing the Productivity in Selective Laser Melting with Large Layer Thickness and Dual Laser for Ti-6Al-4V

Chen-Nan Sun[1,#], Aloysius Tan[1], Duy Nghia Luu[1], Hang Li Seet[1]
Guo Ying Zheng[2], Yongjie Zhang[2], Andy Wei Ming Tan[2]
Zhen Lu[3], Jia Jun Sim[3], Woon Yong Lim[3]

1 Singapore Institute of Manufacturing Technology, Agency for Science, Technology and Research (A*STAR), 73 Nanyang Drive, 637662, Singapore
2 Additive Manufacturing Development Centre, ST Engineering Aerospace Ltd., 540 Airport Road, Paya Lebar, 539938, Singapore
3 SLM Solutions Singapore Pte Ltd., 25 International Business Park, #03-57/58 German Centre, 609916, Singapore
Corresponding Author / Email: cnsun@simtech.a-star.edu.sg, TEL: +65-6793-8568, FAX: +65-6792-2779

KEYWORDS: Additive manufacturing, Selective laser melting, Ti-6Al-4V, Surface roughness, Mechanical properties

In the aerospace industry, there is an increasing demand to explore additive manufacturing (AM) to reduce the lead time and the need for inventory, especially for spare parts and maintenance, repair, and overhaul (MRO) services. However, the AM process is relatively slow due to the inherent layer-by-layer processing nature. To increase the productivity of the AM process, a variety of approaches, such as larger layer thickness and multiple beams/printheads, have been explored by various groups. In this study, we implemented large layer thickness and dual laser system simultaneously in the selective laser melting (SLM) process. Results showed that, with a layer thickness of 130 µm, the build rate of Ti-6Al-4V parts could be up to 28 mm^3/s, which is about 3 to 7 times higher than conventional single beam SLM processing. The specimens were built using part hatching and contour process parameters that were optimized for high density and good surface finish. To assess the impact of large layer thickness on part quality, we also investigated the microstructures and mechanical properties of the as-built Ti-6Al-4V samples. These analyses were additionally conducted on heat-treated specimens as it is generally accepted that the α' martensite formed in SLM is brittle, which can lead to low ductility of the as-built Ti-6Al-4V specimens. Suitable heat treatments can promote the martensite decomposition to α+β lamellae, which increase the ductility and meet the elongation requirement of 10% as specified in ASTM standard F3302-18 for titanium alloys via powder bed fusion. The present study demonstrated the possibility of increasing the productivity of the SLM process without compromising the mechanical performance nor the consistency of the built parts.

NOMENCLATURE

FF = Free Float

1. Introduction

Selective laser melting (SLM), also known as laser powder bed fusion (LPBF), is a widely adopted metal additive manufacturing (AM) process that allows the fabrication of complex structures and is well suited for mass customization. SLM can produce parts with fine features and high accuracy as compared to other metal powder bed processes such as electron beam melting (EBM). This is mainly due to the thin layer thickness, small beam spot size, and fine metal powders that SLM typically uses. As a result, however, SLM suffers from low productivity and the build rate of SLM is normally lower than that of the EBM process [1].

To improve productivity, increasing the layer thickness is a straightforward approach [2] but requires a thorough process parameters optimization to achieve high part density [3-4]. Another approach is to use multiple laser beams in conjunction with the corresponding galvo scanners in one machine so that the build area can be processed by several lasers and scanning-systems concurrently [5].

Ti-6Al-4V is one of the most widely used alloys in the AM industry. The microstructures of as-built Ti-6Al-4V parts typically consist of columnar, prior β grains resulting from rapid solidification and epitaxial growth along the thermal gradient [6]. Within the prior β grains is martensitic structures in the as-built condition. Different processing conditions might result in distinctive microstructures

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

which affect the mechanical properties. To validate the use of large layer thickness in critical industrial applications, it is essential to determine the impacts on the microstructure and mechanical properties of SLM Ti-6Al-4V parts. In addition, we adopted a new laser scanning strategy (Free Float (FF), SLM Solutions) that aimed to print parts with better surface finish, reduction of support structures, and improvements in part quality.

2. Experimental details

2.1 SLM machine, powder material, and process optimization

SLM® 280 (twin lasers) and Ti-6Al-4V Grade 23 ELI powder supplied by SLM Solutions Singapore were used in this study. A comprehensive design of experiment was conducted for process optimization in both part hatching and contour parameters with layer thickness varied from 90 to 140 µm. For part hatching parameters, laser power varied from 500 to 650 W and scan speed varied from 800 to 1200 mm/s. Hatch spacing was kept at 0.15 mm throughout the part hatching study. For part contour parameters, laser power varied from 300 to 600 W and scan speed varied from 700 to 900 mm/s. Free Float was set at medium level when this function was activated.

2.2 Characterization method

Part density was measured by both Archimedes' method (ISO3369) and sample cross-sectional observation using optical microscopy (OM). Theoretical density of 4.415 g/cm^3 was used for Archimedes' density calculation and specimens were ground and polished down to mirror finish before OM analysis. Hardness measurements were conducted via Vickers hardness tester in accordance with ISO6507 standard. The test force was 300 gf with 15 s dwell time; 10 indentations were made on each sample. Surface roughness measurements were conducted using a profilometer. Tensile properties of the as-built and heat-treated Ti6Al4V specimens were tested according to ASTM E8/E8M standard. Tensile test was conducted via a universal test machine equipped with a video extensometer. The load cell was 100 kN and the strain rate was set at 1 mm/min.

3. Results and discussions

3.1 Part density evaluation

A total of 96 density cubes were built with different process parameters. All samples were measured by Archimedes' method and specimens with density ≥ 99.9% were further examined by OM. Results of 130 µm layer thickness and two part-hatching parameters were shown in Fig. 1. Density was high and showed very little porosity.

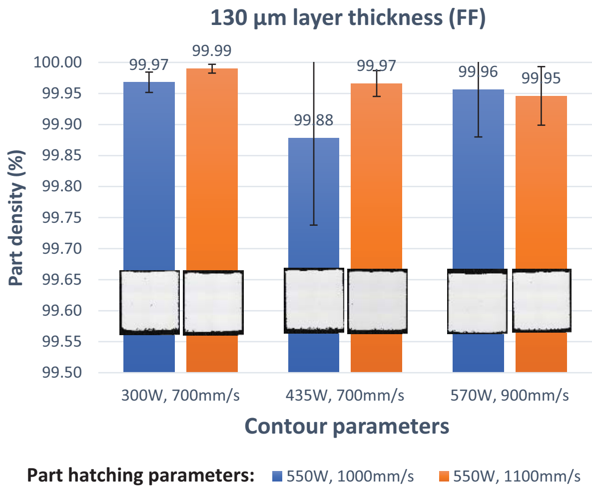


Fig. 1 OM observation (10 mm × 10 mm) showed very dense parts with density ≥ 99.9%. Free Float was activated in this study.

3.2 Surface roughness analysis

Roughness measurement was conducted on samples with different contour parameters. A comparison was also made between samples with and without the Free Float laser scanning strategy. As shown in Fig. 2, the best contour parameters were 300 W of laser power and 700 mm/s of scan speed, with mean roughness values (Ra) of 10.3 ± 1.0 µm when 130 µm layer thickness was used. Based on the evaluation criteria with respect to fast build rate, high density and good surface finish, the optimized process had the following parameters: 130 µm layer thickness, 550 W laser power, and 1100 mm/s scan speed for the part hatching; 300 W laser power and 700 mm/s scan speed for the part contour.

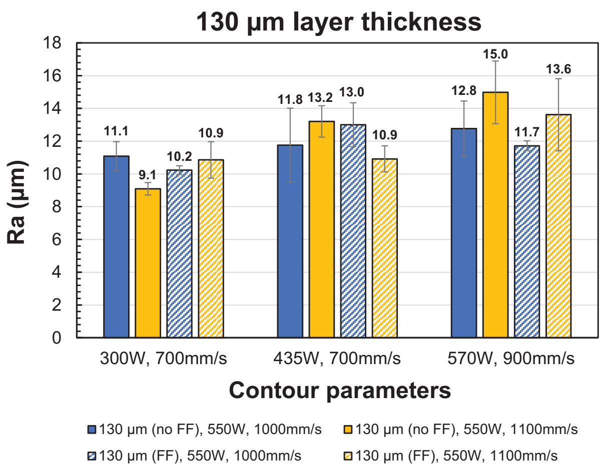


Fig. 2 Surface roughness on vertical walls, showing that the best contour parameters combination was 300 W of laser power and 700 mm/s of scan speed. There was a significant difference with Free Float (FF) or without Free Float (no FF) activation.

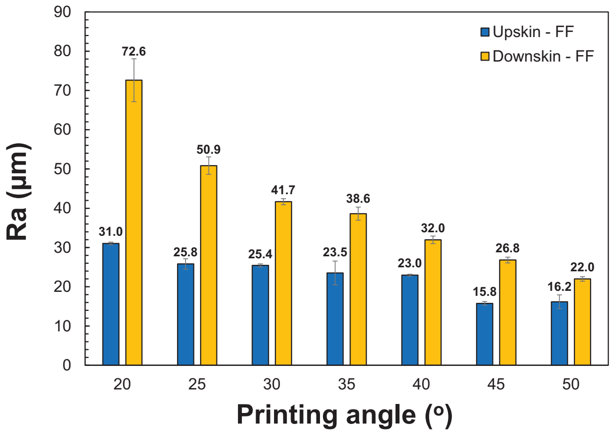
©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

3.3 Surface roughness on angled part

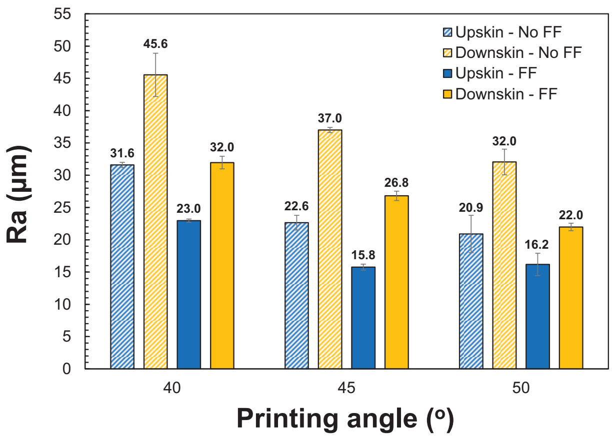
Besides the side surface, roughness measurements were also conducted on samples built with certain tilt angles, with or without the activation of Free Float. With a medium setting in Free Float, the sample tilt angle could be as small as 20° as shown in (b)

Fig. *3* (a). The upskin surfaces were smoother than the downskin surfaces. A comparison of angled samples with or without Free Float activation was shown in (b)

Fig. *3* (b). The surface was rougher without turning on the Free Float function. Typically, it is difficult to fabricate samples with tilt angles below 35° in the SLM process as the printing tends to fail due to overmelting of powders if there is no support structure underneath the part.



(a)



(b)

Fig. 3 Surface roughness of samples (a) with different printing angles when Free Float was activated, and (b) with or without Free Float activation.

3.4 Mechanical properties

3.4.1 Hardness

The hardness value of the as-built specimen was 374.8 ± 6.3 HV0.3, which was in line with the hardness value of 360 ± 5 HV10 found in the data sheet with 90 µm layer thickness [7].

3.4.2 Tensile properties

The tensile properties of the as-built samples are shown in Table 1. The yield strength (YS), ultimate tensile strength (UTS), and elongation were comparable to the values in the data sheet [7].

Table 1 Tensile properties of Ti-6Al-4V in the as-built condition

	Specimen Condition	YS (MPa)	UTS (MPa)	Elongation (%)
This study (130 µm)	As-built (x/y)	1058.4 ± 5.8	1203.2 ± 2.4	5.7 ± 1.7
	As-built (z)	1063.3 ± 7.5	1153.8 ± 12.4	3.4 ± 1.6
Data sheet (90 µm) [7]	Near-Net-Shape (z)	1045	1205	4

4. Conclusions

To meet the increasing demand from the industry, it is imperative to improve the productivity of the AM process. In this study, we implemented large layer thickness and dual laser system simultaneously in the SLM process. We developed a high productivity SLM process with good mechanical performance. The results of this research can be summarized as follows,

- High part density (≥ 99.9%) and good surface finish (Ra = 10.3 ± 1.0 µm) were achieved with the optimized part hatching and contour process parameters.
- Hardness (374.8 ± 6.3 HV0.3) and tensile properties were comparable to those in the literature for the samples in the as-built condition.

ACKNOWLEDGEMENT

This work was financially supported by A*STAR RIE2025 Industry Alignment Fund – Industry Collaboration Projects (IAF-ICP), under Grant No. I2101E0007.

REFERENCES

1. Liu, S., Shin, Y.C., "Additive manufacturing of Ti6Al4V alloy: A review," Materials and Design, Vol. 164, pp. 107552, 2019.
2. Shi, X., Ma, S., Liu, C., Chen, C., Wu, Q., Chen, X., Lu, J., "Performance of High Layer Thickness in Selective Laser Melting of Ti6Al4V," Materials, Vol. 9, No. 12, pp. 975, 2016.
3. Shi, X., Yan, C. Feng, W., Zhang, Y., Leng, Z., "Effect of high layer thickness on surface quality and defect behavior of Ti-6Al-4V fabricated by selective laser melting," Optics and Laser Technology, Vol. 132, pp. 106471, 2020.
4. Jing, Y., Wang, P., Yan, X., "Effect of Process Parameters and Layer Thickness on the Quality and Performance of Ti-6Al-4V Fabricated by Selective Laser Melting," Coatings, Vol. 11, pp. 1323, 2021.

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

5. Yin, J., Wang, D., Wei, H., Yang, L., Ke, L., Hu, M., Xiong, W., Wang, G., Zhu, H., Zeng, X., "Dual-beam laser-matter interaction at overlap region during multi-laser powder bed fusion manufacturing," Additive Manufacturing, Vol. 46, pp. 102178, 2021.

6. Cao, S., Zou, Y., Lim, C.V.S., Wu, X., "Review of laser powder bed fusion (LPBF) fabricated Ti-6Al-4V: process, post-process treatment, microstructure, and property," Light: Advanced Manufacturing, Vol. 2, No. 20, pp. 313-332, 2021.

7. SLM Solutions Material Data Sheet for Ti-Alloy Ti6Al4V ELI (Grade 23) / 3.7165 / B348 / F136.

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.