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The effect of laser surface re-melting on the surface roughness and micro-hardness of selective laser melting (SLM) fabricated Ti-6Al-4V samples

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Abstract

Ti-6Al-4V is favourable due to its exquisite properties for example, low modulus, light weight, excellent strength, and corrosion resistance. Despite the excellent properties of the material, the fabrication process of titanium components is challenging due to the poor final surface quality components caused by non-uniform powder distribution during additive manufacturing (AM) using selective laser melting (SLM) process. SLM process produces fully denser parts with better mechanical properties compared to the bulk materials, although the surface quality is poor. This work aims to study the effect of laser surface re-melting (LSM) on the hardness and surface properties of Ti-6Al-4V alloy. The fabricated Ti-6Al-4V sheet was re-melted by a 3 kW IPG Fiber laser. Microstructural evaluations of the Ti-6Al-4V sheet were characterized using an optical microscope. Micro-hardness and surface roughness measurements were determined by means of an HV Vickers tester under an applied load of 300g and load time of 10s and MarSurf PS1 roughness tester machine respectively. Microstructural evolution and hardness properties were all examined before and after the LSM treatment. The experimental results showed the formation of martensitic structure on the areas treated. Micro-hardness depth profiling results showed an average increase of 15–25% which was higher compared to the average hardness of the as-received. The results indicated that the roughness measurements lowered when both the residence time and irradiance increase. Laser surface re-melting treatment showed an improvement of the microstructural modifications and hardness properties therefore, the process can be used to modify the component's surface for reliable and best surface finish.

Keywords: Ti-6Al-4V, SLM, Laser Re-melting, Micro-hardness, Roughness

1. Introduction

Nowadays the demand to manufacture components with good mechanical performance and good surface finish are of great necessity in the aerospace industries (Hassanin et al. (2018); Iwaszko and Strzelecka (2016)). The selective laser melting (SLM) process is one of the well-known, commonly used additive manufacturing (SLM) technologies. The process offers the ability to produce parts with desired geometrical shapes, without tools, reduced costs, material usage and component weight. The process is used to fabricate metal components for various industries such as the medical, aerospace, automotive and chemical industries.

Through the selective laser melting fabrication process, powders are melted with heat from a laser power beam. When heat is applied on the powder material, powders melts and forms a melt pool (Song et al. (2012); Chikarakara et al. (2012); Casalino et al (2015); Gong et al. (2017)). Then the formation of parts occurs when the molten pool solidifies. Partial melting of the powder stair-casing leads to the formation of different microstructures and poor surface quality for aerospace applications respectively. Nicoletto et al. (2018) stated that poor surface quality of parts is one key factor that causes component failures during applications and reduces the component's life span.

In addition, SLM as-built components are exposed to high temperatures which causes powder particles to get attached to molten surface during the process. This will trigger the surface roughness of components. High surface roughness affects components negatively in a way that it lowers mechanical performance in areas that requires high strength, in highly stressed and cyclically loaded areas. According to the study by Vaithilingam et al. (2016), surface roughness (Ra) value of 17.6 µm for Ti-6Al-4V parts was produced via Renishaw's AM 250 SLM machine. According to the study conducted by Yue et al. (2002) and Balla et al. (2014), optimization of SLM parameters such as hatch distance, spacing, particle size and feed powder can also improve surface quality to some degree.

Therefore, to improve surface quality of SLM fabricated parts, numerous post-processing techniques including sandblasting, machining, etching, electro polishing and plasma spraying, are employed Bagehorn et al. (2017) . One limitation of using the above-mentioned techniques is the amount of time needed to treat parts with complex shapes. Bagehorn et al. (2017) stated that any opportunity for improved SLM surface quality is of great importance to enable direct fabrication of various parts without the need for post-treatments. Song et al. (2012); Hassanin et al. (2018); Tian et al.(2005); Lwaszko et al. (2016) further proposed laser surface re-melting technique as one of the outstanding post processing techniques with the potential to improve Titanium and Titanium alloy surface quality of SLM parts. Therefore, to enhance surface quality of SLM Ti-6Al-4V parts, laser re-melting was used

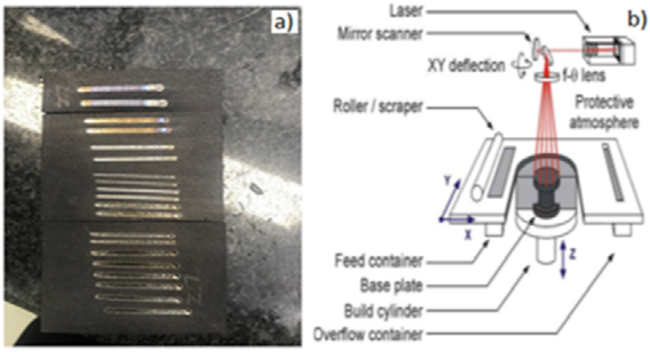

Figure 1: a) Test parts built by SLM and exposed to laser surface re-melting, b) Operating principle of SLM process Kruth et al. (2010)

with the aim to reduce the roughness and improve hardness of the components like laser surface polishing.

The results from the work done by Song et al. (2012); Hassanin et al. (2018); Tian et al.(2005); Lwaszko et al. (2016) proved that the laser treated parts did reduce the surface roughness of the materials and also used enhanced both mechanical performance and micro-hardness of the materials. The current study is mainly focused on the effect of laser re-melting on the surface roughness and micro-hardness of SLM produced Ti-6Al-4V.

2. Material and Methods

The Ti-6Al-4V (120mm by 60mm) sheet alloy for this experiment was manufactured by SLM process. The Ti-6Al-4V sheet was fabricated by IPG fiber laser source characterized by a 3 mm spot diameter and a maximum output power of 1000W. The laser sinters the powder together, layer-by-layer until the model is completed. After the sheets were manufactured the specimens were taken for re-melting as part of the post treatment for reduced surface roughness of the as built and determine the best optimum

Table 1: Laser Re-melting with varied Laser Scanning Speed

Spot Size [mm]	Power [W]	Speed [m/min]
3	750	0.5
3	750	1
3	750	1.5
3	750	2
3	750	2.5

parameters (laser power and scanning speed) to ensure uniform smooth surface finishing. Prior to all analysis the, the samples were taken for metallographic preparation. For the microstructural analysis, the sections were cut, polished, and etched using kroll solution for 15s and were subsequently analysed using Olympus light optical microscope equipped with Analysis ® software. Micro-hardness tests were performed on the cross sections using a Vickers micro-hardness testing system under 300 g load for 10s dwell time and linked to an image processing system for capturing microstructures. Five measurements were averaged for each depth. The objective of the micro-hardness tests was to analyse the hardness variances along the diverse microstructural zones caused by the heat transferred by the laser beam speed. The surface roughness measurements were done using the MarSurf PS1 roughness tester machine. In this paper, the arithmetic mean surface roughness (R_a) is used to represent the roughness.

All the specimens were manufactured on a SLM machine. The following parameters were used for laser treatment:

Table 2: Laser Re-melting with varied Laser Power

Spot Size [mm]	Power [W]	Speed [m/min]
3	750	1
3	500	1
3	450	1
3	350	1
3	250	1

3. Results and discussions

The microstructural characterizations were done after the LSR and the samples were prepared and etched in kroll for 15 s and were later analyzed with Olympus light optical microscope equipped with Analysis ® software. Ti-6Al-4V samples are characterized by the alpha and beta phase structures where the dark sections are known as the beta and the lighter sections, the alpha phase. According to (Kolli and Devaraj (2018)), the alpha grain structure is classified with hard particle properties as compared to the beta grain structure. Fig. 2 Shows the present phases on re-melted Ti-6Al-4V alloy at 109µm magnification.

Figure 2a and 2b shows the image of initial Ti-6Al-4V prior LSR and after. Laser surface re-melting traces cross section in Fig. 2b, divided into three zones: The substrate, re-melted zone, and heat affected zone. The remelted zone shows microstructures

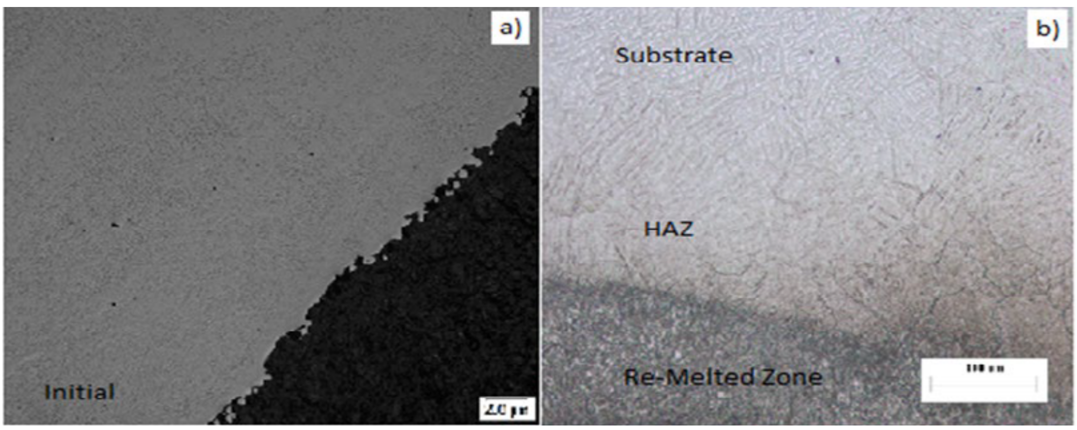

Figure 2: Re-melting trace cross section microstructure after LSR

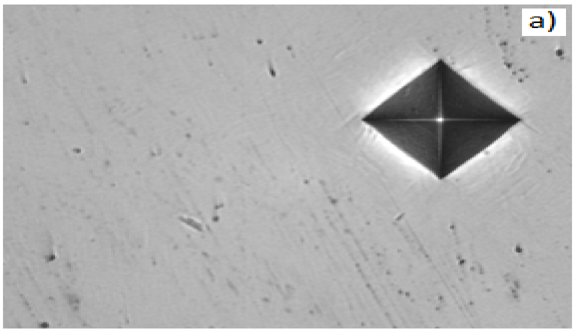

Figure 3: Micro-hardness indentation of the as-built

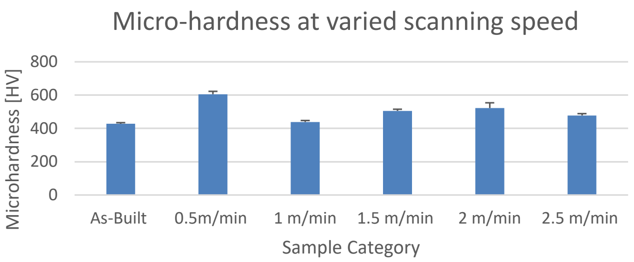

Figure 4: Micro-hardness test measures at different laser scanning speed

with dark spots caused by high energy input during melting, The heat affected zone (HAZ) it is the non-melted part of the material that experienced changes in its material properties as a results of exposure to high heat. The three regions were difficult to appear simultaneously under the same light due to the presence of both the α and β phase. As a results of high temperature gradients during LSR, the articular and fine martensite α phase is observed.

3.2 Micro-hardness profiling

The microhardness profiles were done on the laser re-melted Ti-6Al-4V sheet. The tests were performed on the cross sections using a Vickers micro-hardness testing system under a 300 g load for 10s dwell time and linked to an image processing system for capturing microstructures. Five indentations were done on each sample to allow accurate measurements. Fig 3 below shows the microhardness indentation of the as-built.

An 349_5230.5m/min resulted in the highest hardness value of 600 HV, which means that the longer the residence time resulted in the most improvement.

According to studies by Vamsi et al. (2014) and Yao et al. (2014) the high micro-hardness measurements for re-melted materials are triggered by the development of acicular α and reduction in amount of β phase in these materials. The variation of laser power had enormous influence on the hardness. Based on the results above Figure 5, it is evident that the hardness increases when the laser power increases. Hardness results obtained at laser power of 250W drastically decreased, this is due to the lower melting temperatures applied. The hardness is directly related with heating and cooling of the melt pool, at these low laser powers, it is apparent that the transformation temperatures are not attained.

It is evident that high laser power outputs enhance the micro-hardness properties of the re-melted samples. Nevertheless, the

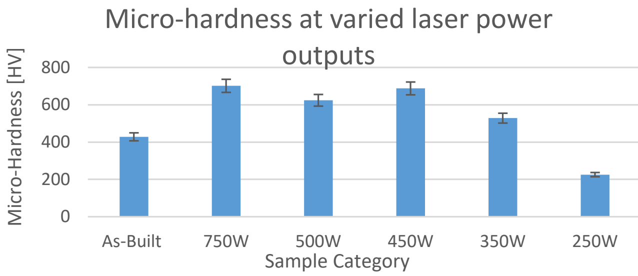

Figure 5: Micro-hardness test measures at different laser power outputs

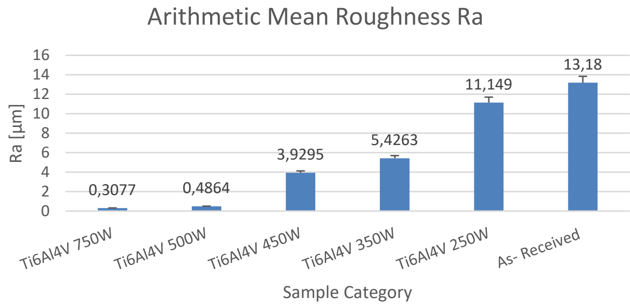

Figure 6: Average R_a and Standard Deviation of Laser Re-melted samples for varied Laser Power Outputs

optimum laser power input ranges between 750W and 450W. It was proven that the hardness of the specimen in the re-melted zone increased significantly as the laser power increased and it slightly increase as the scanning velocity increases. The found regularities should be linked with the cooling rate of the material resulting from the applied treatment parameters, and in consequence, with the extent of the obtained refinement of structure. The samples were left to cool at room temperature.

3.3 Roughness

The LSR samples showed an improvement on the roughness values as compared to the as built. However, the laser surface re-melting depends highly on laser power and scan speed. Based on the results obtained, low power results in high surface roughness values. Roughness average (Ra) obtained for lower power of 250W averaged between 10.81 µm and 11.49 µm showing no improvement on the specimen. The roughness was not reduced because of lower laser power. Further homogenous melting on the specimens attributed to the decrease in the roughness thus producing smoother surfaces. Increased laser power output exhibited improvement on the specimen surface roughness.

The surface roughness of the as-built showed high initial surface roughness after SLM. Roughness of the re-melted specimen reduced when the laser power increased. Visible significant changes revealed that proper melting of the materials allows smooth surface and with no defects. Reduced scanning velocity increases material contact time with the laser, which allows slow cooling rate and decreases roughness. Visible significant changes on sample surfaces treated with lasers at a power of 750W, confirm the occurrence of a large amount of discontinuities.

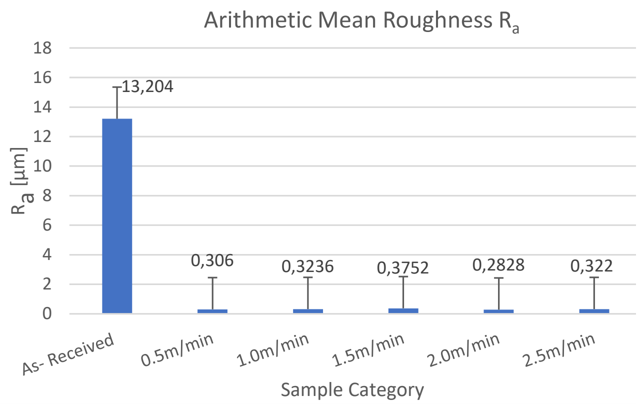

Figure 7: Average Ra and Standard Deviation of Laser Re-melted samples for varied Laser Scanning Speed

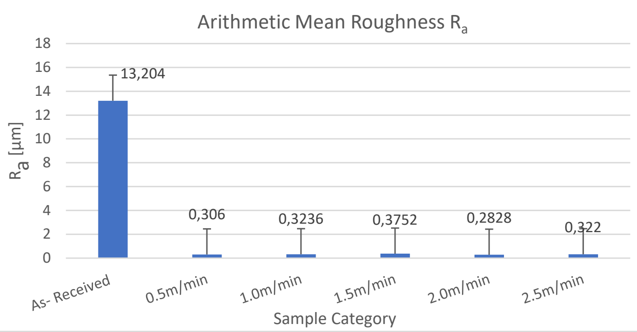

Figure 8: Average R_a and Standard Deviation of Laser Re-melted samples for varied Laser Scanning Speed

In order to get a smother surface, a liquid state (thin layer) must be attained, this means the process parameters must be able to melt the Ti64.

4. Conclusions

Laser surface re-melting attested to be one of the effective surface finishing method for Ti-6Al-4V alloy. With optimized process parameters such as laser power and scanning speed, laser surface re-melting technique will lead to enhanced surface roughness and improvement on the mechanical performances of the alloy. The study revealed that as the laser scanning speed drops, both the hardness and roughness of the samples increases. It can be said that the optimum laser power ranged between 500W and 350W and optimum scanning speed between 0.5m/min and 2m/min respectively for the improved hardness properties. Using the above-mentioned parameters guarantees a crack free surface sample. For improved surface roughness the optimum parameters are concluded as follows: 750W power outputs at laser speed of 2m/min.

Acknowledgements

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