Laser Surface Modification of Ti-6Al-4V for Biomedical Applications

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INTRODUCTION

❖Ti-6Al-4V is used in biomedical engineering due to its excellent properties: high strength to weight ratio, low density, high corrosion resistance and good biocompatibility.

❖However, the alloy's use under severe friction conditions is restricted due to poor tribological properties such as high friction coefficient, low hardness and wear resistance[1, 2].

❖Lattice parameters of titanium's crystallography allow for several systems to operate. Such systems induce ion release within biomedical implants thus limiting the alloys use.

❖For titanium alloys to be used in transmission components where there is some metal on metal contact, the problems of surface wear via adhesive and abrasive mechanisms and subsurface damage via plastic deformation from contact loading need to be overcome [3, 4].

❖Ti-6Al-4V is the most popular α + β alloy, accounting for more than half of all titanium sales. The alloy is of interest in this study due to its workability and the ability to produce refined microstructures which are otherwise unachievable in other titanium alloys [5, 6].

❖The present study evaluates the effects of high speed, laser melting parameters on surface roughness, hardness, chemical composition and phase variation.

❖Emphasis is placed on chemical composition and microstructure effect of laser energy beam treatments and production of ideal surface roughening suitable for biomedical alloys, compared to conventional methods.

❖Study of biocompatibility, corrosion and wear resistance of the laser treated Ti-6Al-4V is ongoing.

EXPERIMENTAL

❖Flat Ti-6Al-4V sample ~10 mm * 10 mm * 4 mm deep.

❖Argon gas shielded the melt pool thus avoiding oxidation.

❖The laser beam was kept perpendicular to the workpiece to maximise the absorbance and ensure uniform conditions for processing [7].

❖Microstructure analysis was carried out using SEM .

❖ Surface mean roughness measurements were obtained with a stylus profilometer according to ISO 4287/4288.

❖Energy Dispersive Spectroscopy (EDS) analysis was used to determine the chemical composition of the treated areas.

❖Phase, residual stress and crystallinity characterisation was carried out using X-ray diffraction.

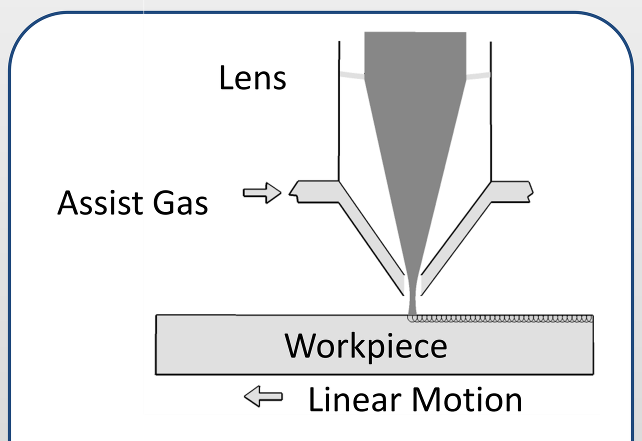

Figure 1: Schematic of the laser processing set-up.

CO_2 Laser Specifications		Fixed Parameters		Varied parameters	
Max Peak Power	1.5 kW	Assist gas/ Pressure	Argon/ 2bar	Residence Time	1.1 – 2.2 ms
Wavelength	10.6 µm	Spotsize	90 µm	Irradiance	15.7 – 26.7 kW/mm^2
Beam Quality	TEM_{00}	Overlap (X)	30%		

RESULTS

Topography and Microstructure

❖ Figure 2 (a) presents the topography of the laser treated region, highlighting the regular processing tracks. No evidence of ablation on the surface is present.

❖Figure 2 (b) shows the effects of laser remelting on the microstructure and depth of processing; depth of processing is crucial to the lifetime of the implant.

❖An increase in irradiance did not always produce an increase in depth of processing; however higher irradiance levels were found to provide for a more uniform depth of processing which reached a maximum of 80 µm.

❖LSM produced a single phase, martensite microstructure. This single phase occurred when various constituents in the alloy have dissolved with rapid solidification thwarting segregation of the various alloying elements into high and low concentration .

❖Minimal roughness was obtained at highest level of irradiance 26.72 kW/mm², roughness increased with decrease in irradiance, see Figure 3.

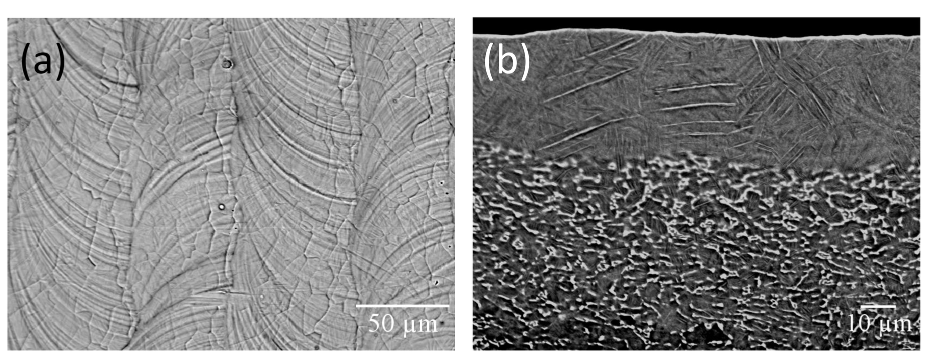

Figure 2: Laser surface modified Ti-6Al-4V sample 1 (a) SE image and (b) BSD

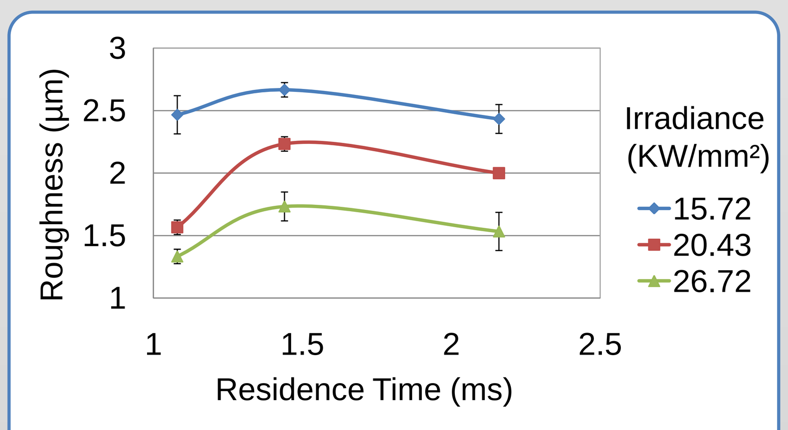

Figure 3: Effects of Irradiance and residence time on roughness

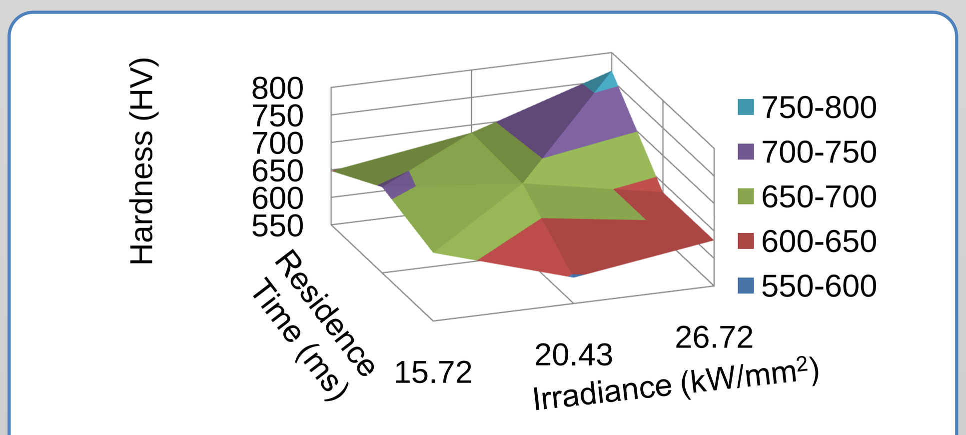

Figure 4: Effects of Irradiance and residence time on microhardness

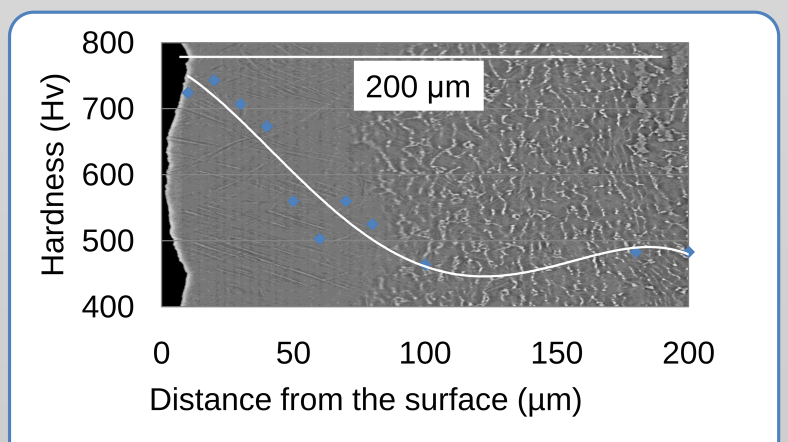

Figure 5: Effects of Irradiance and residence time on roughness

Hardness analysis

❖Figure 4 highlights the effect of laser processing parameters on the resulting microhardness.

❖The 3D surface graph shows the highest microhardness of 760 HV were achieved at the highest level of irradiance (26.72 kW/mm²) and lowest residence time (1.08 ms).

❖Microhardness of the as-received alloy was measured to be 460 ± 13 HV, thus showing a maximum increase of up to 67% in hardness.

❖Figure 5 illustrates the change in hardness with respect to distance from the surface.

❖Hardness values decrease as the distance from the surfaces increases, maximum hardness levels were recorded in the laser treated region .

❖The graph also shows the microstructure variation as the depth increases. Increase of hardness in laser treatment is influenced by the microstructure, martensite structure formation.

XRD and surface composition analysis

❖Figure 6 shows the as receive and laser treated (15.7 kW/mm² by 1.1 ms) XRD profiles

❖Both profiles contain α and β-Ti phase with a lower relative volume fraction of β-Ti

❖Laser treatment of Ti-6Al-4V significantly reduced the volume fraction of the β phase

❖Shift of diffraction peaks to a new 2θ position depicts residual stress within treated samples

❖Figure 7 shows titanium chemical composition distribution with increasing distance from the surface.

❖Laser remelting influenced homogeneity of the chemical composition for all elements

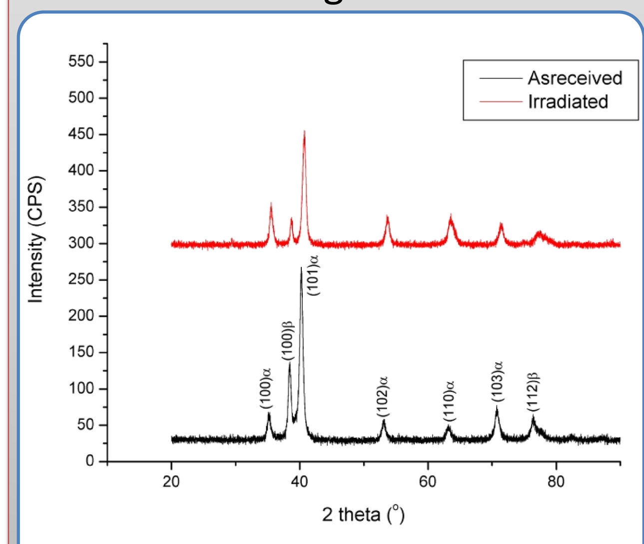

Figure 6: X-ray diffraction profile

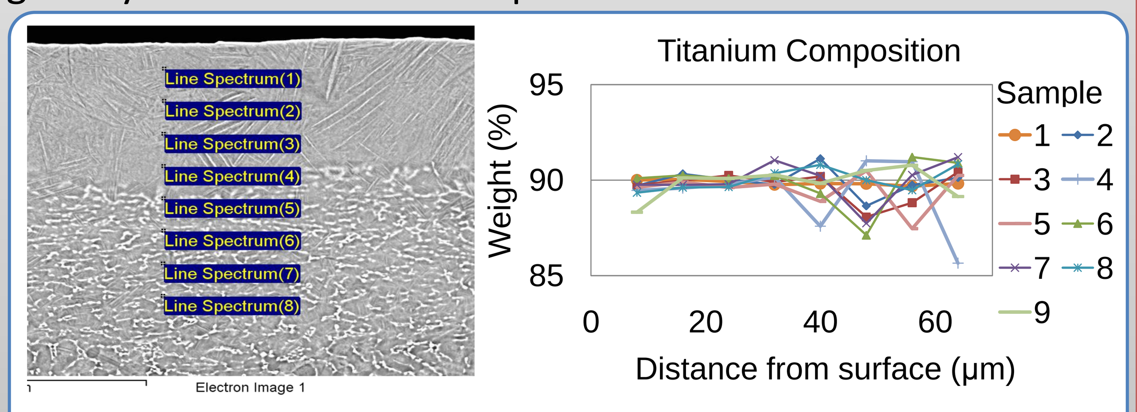

Figure 7: (a) BSD highlighting spectrum points and (b) titanium weight (%) with varying distance from the surface

ON-GOING RESEARCH

Biocompatibility

❖The effect of surface topography on cellular attachment is under investigation *in vitro* using MC3T3-E1 pre-osteoblast cells. Cell attachment is determined using the Hoechst assay.

❖Cell morphology behaviour of the laser treated region is analysed by fixing cells with gluteraldehyde .

❖Analysis of the cell attachment is carried using scanning electron microscopy.

❖LSM has been shown to improve cell attachment and viability in previous literature [4].

Corrosion Testing

❖The effects of LSM on pitting corrosion and metal ion release are under investigation.

❖Pitting corrosion behaviour is calculated from corrosion rate derived from the potentio-dynamic anodic polarization study in Hank's solution.

❖Inductively coupled plasma mass spectrometer (ICP-MS) is also used to determine the concentration of metal ions released.

Wear Testing

❖Tribological evaluation of LSM substrates is carried out using a pin on disc tribometer, see Figure 8.

❖The wear tests are carried out by sliding a pin against the polished samples with a static load at a constant linear speed.

❖Wear resistance is also crucial in minimising metal ion release and improving the implant lifetime.

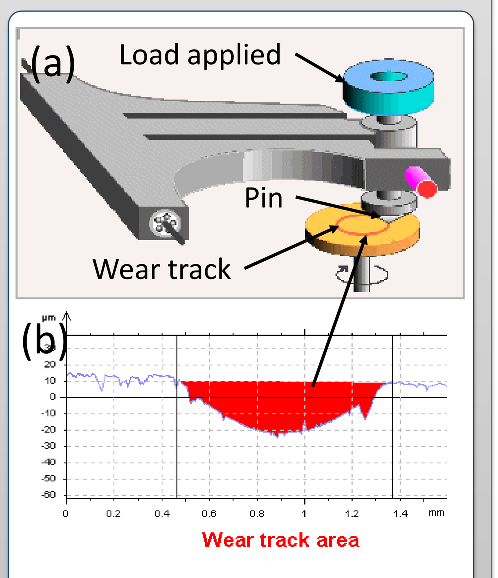

Figure 8: (a) load and pin mechanism and (b) the wear track cross section evaluated

CONCLUSIONS

❖High hardness is achieved at the highest levels of irradiance and residence time.

❖Low residence time indicate minimal contact of laser beam and the workpiece. By increasing the workpiece velocity, lower residence times can be achieved.

❖Extremely high workpiece velocities can be achieved through the use of rotating samples; future work focuses on cylindrical samples for improved residence times.

❖Reduction in surface temperature can also assist in further microstructure effects.

❖Laser surface modification reduces β-phase volume fraction and introduces residual stress within the modified region.

❖Homogenous chemical composition was achieved by laser treatment compared to the substrate.

❖Effects of laser surface modification on biocompatibility, wear and corrosion resistance will be further analysed to distinguish capabilities of the process for biomedical implants.

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